THE UNIVERSITY OF ASTON IN BIRMINGHAM

AN INVESTIGATION OF THE FACTOR-ANALYTIC APPROACH TO THE DETERMINATION OF ABILITIES INVOLVED IN PSYCHOMOTOR LEARNING

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SUMMARY

This research began with an attempt to solve a practical problem, namely, the prediction of the rate at which an operator will learn a task. From a review of the literature, communications with researchers in this area and the study of psychomotor learning in factories it was concluded that a more fundamental approach was required which included the development of a task taxonomy. This latter objective had been researched for over twenty years by E. A. Fleishman and his approach was adopted. Three studies were carried out to develop and extend Fleishman's approach to the industrial area. However, the results of these studies were not in accord with Fleishman's conclusions and suggested that a critical re-assessment was required of the arguments, methods and procedures used by Fleishman and his co-workers. It was concluded that Fleishman's findings were to some extent an artifact of the approximate methods and procedures which he used in the original factor analyses and that using the more modern computerised factor analytic methods a reliable ability taxonomy could be developed to describe the abilities involved in the learning of psychomotor tasks. The implications for a changing-task or changing-subject model were drawn and it was concluded that a changing task and subject model needs to be developed.

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In this section the problem context from which the studies evolved is described. The initial problem was the development of a method for predicting learning rates for particular manual tasks in industry. This required a literature review of the area and especially studies of learning curve prediction. One of the major techniques for predicting learning curves in industry was that of Predetermined Motion Time Systems (P.M.T.S.). Most of this research used Method Time Measurement (M.T.M.) and these studies were reviewed. This led to the realization that a more fundamental approach was required and that it was necessary to understand psychomotor learning through the development of a model which involved task characteristics and which also allowed for the development of a task taxonomy.

Many factories were visited to observe trainee manual workers and to discuss the problem with training officers. A study was also carried out of trainees on the shop floor (Appendix 1). The findings which were obtained from these studies together with the literature review, including an assessment of the clinical and classical testing approach to assessing skills and abilities, suggested that the approach which had been developed over twenty-five years by E. A. Fleishman and his co-workers held the greatest promise.

CHAPTER 1

INTRODUCTION

Research context

This investigation saw its beginnings in talks between a Management Consultancy Company, Associated Industrial Consultants (A.I.C.) Ltd., and the organisers of the Interdisciplinary Higher Degree Scheme of Aston University. This latter scheme required and sought 'real life' problems as the subject for postgraduate research.

The consultants, A.I.C., had been giving advice to companies on how they could predict the rate at which an operator will learn a job. They found that there was no reliable method available by which this could be achieved. This was especially true when predictions of performance were required for individuals or small groups. The performance predictions may be of several kinds. For example:

1. To predict the relative performance of a group of individuals on a task. This information may be used in the planning of production schedules for new tasks.

2. To define the performance level in absolute terms for one or more individuals at a particular time in the future. This would allow us to determine how long it would take an individual to reach experienced worker standard.

Neither of these requirements was adequately covered by either selection tests or by existing 'learning curve techniques'. The consultancy company concluded that there were two approaches to the problem. These were (as defined and labelled by the company):

1. The traditional A.I.C. ad hoc approach. This was to tackle a need as it arose, and to provide working guidance to a client in a specific situation. It was also possible to analyse at a later stage any data obtained and attempt to produce a general rule.

2. The fundamental research approach: the determination of a general method which could then be applied to specific situations as they arose.

A.I.C. decided that the lack of any progress with the first approach over the many years in which work had been carried out suggested that a more fundamental analysis was required. For this reason they joined with the University of Aston in sponsoring the project.

Although the research envisaged was of a fundamental nature it was also a requirement that it should be carried out with the application to 'real life' problems as a central theme. To further the applied aspects of the research, A.I.C. was to provide facilities within companies and obtain access to the data already collected by many companies. However, they fulfilled neither of these commitments. This was because of an economic recession within a few months after the start of the project which led to a reorganisation of the company. Initially the project came within the control of their Industrial Engineering Development Unit which was a small subsidiary unit of A.I.C. This unit was disbanded within a year of the start of the project and then after much indecision the project was transferred to another new subsidiary, Inbucon Productivity Services Ltd. The support from the company was terminated at the end of the second year of the project. The research was then carried on within the Applied Psychology Department and then within the Management Centre, both of the University of Aston.

The Structure of the Research Process

The initial aim of the research was to develop a way of predicting individual operators learning rates and terminal performance of manual tasks. This required a review of studies into learning curves and Predetermined Motion Time Systems. Both of these approaches claimed varying degrees of success with predicting learning rates and terminal performance. As well as a review of the literature, many visits to factories were made and studies of individuals learning real tasks, on the shop floor, were carried out (Appendix 1). These gave great insight into the process of learning and its complexity in the organisational setting and into the large individual differences in the learning process and the subject's response to complex changing tasks and environments. To enable an assessment to be made of the current developments, a number of meetings took place with people carrying out research in areas most relevant to the project. There are relatively few such workers but those met with included Dr. Gustavsson of the Chalmers Tekniska Institute for Industrial Organisation in Gothenburg, Sweden, who was part of the team which produced MTM3 (the third level of the Method Time Measurement predetermined motion time system); Professor N. Corlett of the Production Engineering Department, University of Birmingham; Dr. R. Cooper of Liverpool University and Professor H. Murrell of UWIST.

Work was being carried out in America which was considered to be relevant and accordingly letters were written to Dr. E. Fleishman, American Institute for Research in Washington; Dr. R. Hackman, Yale University; Dr. T. Dickenson, Iowa University and Professor E. R. F. Crossman, University of California at Berkley. The information from the review of the literature, the studies in the factories (Appendix 1) and the personal contacts were valuable in pin-pointing the main areas of weakness in our knowledge, namely, the effect of the interaction between the task and the learner. It was realised that little further progress would be made without the development of an overall framework and model for understanding the learning of psychomotor tasks.

Consequently, the aim was redefined as an attempt to understand more about the interaction between the learner and the tasks which would also lead to "improved generalisations and predictions of human performance" and "a learning and performance theory which ascribes task dimensions a central role" (Fleishman 1978, p. 1007). From the various approaches which had been taken to understand the role of tasks in mediating performance, that of Fleishman appeared to be systematic and to have provided, at least partially, "an integrative framework and common language applicable to a variety of basic and applied areas" (Fleishman 1975, p. 1127). It was decided to extend his approach into area of the learning of industrial and other real life tasks.

However, questions were raised by these studies which necessitated a re-examination of Fleishman's approach and a re-analysis of the studies which he and his colleagues had carried out over 25 years. Factor analytic methods and procedures, which were not available to Fleishman and his co-workers, were used in this re-analysis of the data.

This re-appraisal of the evidence has shown that fewer abilities have been reliably identified than claimed by Fleishman and his colleagues and that there is little or no evidence for the progressive and systematic changes in the contribution of abilities during learning. A further study was carried out to assess the validity of the changing task model of Fleishman et al as opposed to the changing subject model developed by other researchers. It was concluded that both subject and task change and that there are individual differences both in the abilities which have been overlearned and those which have not been overlearned.

The outcome of this research has been to further our understanding of the following:

1. The limitations of the applied studies, such as learning curve techniques and P.M.T.S. methods, in the prediction of operator learning rates and terminal performance.

2. The inadequacies of older factor analytic methods and procedures.

3. The important differences between the results obtained from the Principal Factor and Varimax methods and the approximate Centroid and Zimmerman methods and procedures when both are applied to the data of the studies of Fleishman et al.

4. The generalisability of Fleishman's approach to different populations and real life tasks.

5. The provision of more conclusive evidence for some psychomotor abilities.

6. The contribution of abilities to performance during skill acquisition.

7. A re-assessment of the changing task and changing subject model of skill acquisition.

CHAPTER 2

LITERATURE REVIEW

The first part of the literature review is concerned with studies of learning curves both in industry and in experimental situations. The aim is to assess the extent to which individual learning and group performance may be predicted and what factors have been found to affect the rate and terminal performance in real life tasks. One approach which has been used often during the past forty years in industry for a number of functions, including prediction of operator learning rates and terminal performance, is that of Predetermined Motion Time Systems. The micro motion system know as M.T.M. (Methods Time Measurement) was chosen to investigate as it was not only the most used system, but also because considerable research had been carried out which investigated the prediction of learning rates using the M.T.M. elements as a behaviours taxonomy. This kind of approach is mainly concerned with manual repetitive tasks and is reviewed in the second part of this chapter.

Application of the learning curve technique in industry

The first application of the learning curve technique is popularly ascribed to Wright T.P. (1936). However, he did not refer specifically to learning curves but to cost reduction curves. In the article he utilised labour production ratios and showed graphically the effect of quantity production of aircraft on their cost.

Many years before this article, in the latter half of the 19th century, psychologists had been carrying out experiments in the laboratory to elucidate the conditions which affected learning and memory. Some studied 'real life' situations. Bryan W.L. and Harter N. (1897, 1899) studied telegraph operators, showing the existence of plateaux in the learning curve. A great deal of work was done on trainee typists (Swift, 1904; Swift and Schuyler, 1907; Kjerstad, 1916; Thurstone, 1919; Chapman, 1919; Towne, 1922; Brook, 1928) and on difference of training methods (Poffenberger, 1915; Bruce, 1933; Elwell and Grindley, 1938; Judd, 1908; Woodrow, 1927). It was not until the Second World War when planning production became important that the learning curve was seen to have important practical implications. Concurrently there was a sudden growth in the study of skill acquisition and this was carried out on practical problems by experimental psychologists whose 'concepts and experimental approaches owed a great deal to engineering' (Reed, 1967). However, the approaches to learning taken by the industrial planners and the experimental psychologists working mainly with military problems, were developed separately. Probably this is because although they were working in the same area their objectives were different. Consequently, there followed studies in which the meaning of learning was misunderstood and the learning curve technique was misused. This stemmed mainly from its misapplication in the aircraft industry, where workers learning to work more efficiently is a factor which has minimal effect relative to other factors which create and support high manpower levels at the start of production. Young (1966) says that these other factors are a result of management policy which maintains high manpower levels at the start of production to meet the engineering and customer demands for modifications. He says "as management action gradually reduces this surplus manpower there is a reduction in labour hours per unit that appears to be a function of the number of units produced . . . labour reduction trends in the aircraft/aerospace industry are basically caused by budgetary and other management directed influences as opposed to learning." The resultant curves were called learning curves even when it was realised that workers were replaced in large numbers during a production run of an aircraft and, because learning is a process relating to individuals and not to groups, this was a misuse of the notion of learning.

A number of studies were made to determine the so-called learning curves for different production runs and the mathematical analysis of these curves was soon attempted. Rutan (1948) in an article entitled 'Theory of Learning Curves' said that the derivation of mathematical relationships concerning learning curves begins with the consideration of a table of original data. Then an attempt can be made to discover what fundamental mathematical properties, if any, are exhibited. However, attempts to produce mathematical descriptions of learning curves by Rutan and others did not use data which was sufficiently original to allow the results to be interpreted in terms of learning. Rutan, for example, says that cumulative hours and cumulative average hours are the most important (later taken up by Glover, 1966) because 'learning' applies to the process of manhour cost reduction with continuing production and this information is used in the plotting of learning curves. It would be justifiable for Rutan to call these cost reduction curves but not learning curves. They are not the same; there can be cost reduction without learning. Young (1966) concluded that there are four main factors which affect the measured 'performance' far more than any learning which may have taken place. These are (in the aircraft industry):

1. By establishing the hours for the first unit at a sufficiently high point it is relatively easy to budget any planned reduction curve.

2. Fluctuating labour classification systems - i.e. shift of designation of workers between 'direct' and 'support/indirect' where the latter are not included in computations.

3. Manufacturing methods and tooling changes also distort actual performance trends. Their effect is not evaluated separately and so 'contribute' to reduction in actual times.

4. Manufacturing lot size and material availability. Lot size is related to set-up time which can be a considerable proportion of total time for unit production. The non-availability of materials increases the lot time.

Many people have written on the application of the learning curve techniques in industry. Generally these can be put in two categories, those based on experimental work in the laboratory and in the field and those based on mainly personal case studies.

Of the experimentally based work one of the most famous investigators is De Jong. He says (1961, 1964) that though it is recognised that if an operation is repeatedly carried out the time required per work cycle shows a gradual decline, the extent of this decline and its duration is often underestimated. He found that in all cases which he and his colleagues investigated it proved possible to approximate satisfactorily the gradual decrease in cycle times with the aid of the formula (De Jong 1964, p. 20):

$$T_s = T_1 \left(M + \frac{1 - M}{s^m} \right)$$

where T_s = time for sth cycle

T_1 = time for first cycle

m = exponent of reduction

M = factor of incompressibility

There are differences between individuals learning the same task and De Jong found that there was a fairly wide spread of curves for each worker (more than 20% relative to their average). They found that experience and age is a significant factor in cycle time reduction. He follows Beck and Heyner (1932) in showing that cycle times are greater for short production runs than for long ones. Generally he found that the average unit time necessary for the manufacture of N items coincides with the time necessary for the production of the items with the sequence number 0.3N. This is a function of the averaging curve which he computes with his previously mentioned formula.

From his studies of individuals learning a task he suggests that three noticeable events occur with the decrease in cycle time. These are:

1. Motions become simpler and often shorter
2. Eyes need to be focused less and eye travel is less
3. Left and right hand motions become more simultaneous

Because of changes such as these De Jong supports the use of M.T.M. as a technique for investigating what happens during the learning period. He cites two jobs in which M.T.M. was used to analyse the motions of three subjects in each. In the first, sugar coating cherries, which was a one-handed operation, they found:

1. No alterations, i.e. change of elements
2. Only slight simplification
3. Main factor was the combination and elimination of motions

In the other two-handed task, the wrapping of tins, it was found that:

1. Alterations were of minor importance
2. Simplifications were important
3. Combinations and eliminations were the most important

In both studies they found that the number of M.T.M. elements markedly decreased with the number of cycles. His conclusions drawn from his work are mainly orientated towards work measurement rather than illuminating the problem of the learning process and its measurement. However, they are worth noting in relation to the application of learning curves in work measurement. The conclusions are:

1. In making time studies the number of trials sequentially observed and the experience and qualifications of the operators are important factors. The human capacity to rate the effect of gradually increasing skill on cycle time is poor. No attempt should be made to evaluate the effect of increasing skill when rating the effectiveness of work during time studies (see Gershoni, 1969).

2. In determining time standards notice should be taken of the effect of length of production runs.

3. One can often satisfactorily represent the reduction in cycle time during the first part of a production run by a straight line on log-log paper.

There are many points which would require further explanation before De Jong's method could be applied. For example, how do we recognise in advance the situations where his formula will satisfactorily represent the reduction in cycle time and what does he mean by 'satisfactorily', that is, what magnitude of error might be expected? Also, how do we predict the length of the first part of the production run where the formula is useful and may this not be small and of less importance than the rest of the learning curve? However, there is a more fundamental difficulty with De Jong's writings. It is his inconsistency in his view of what the learning of a skill consists in. It would appear that he makes contradictory statements about what happens to cycle times when only learning is being considered. He says:

> "We have discussed above several cases in which . . . the unit time became smaller and smaller under the influence of gradually increasing skill. In the cases considered the surrounding conditions, that is to say, organisation, tools, materials and such like, remained practically unchanged.
>
> "These cases, like several others, show that the reduction curves almost always coincide in a satisfactory manner with . . . the general formula of the curves."

However, in conclusion he says:

> "Reduction in time arising exclusively from increasing skill cannot be represented satisfactorily by a straight line on log-log paper."

As his formula is represented by a straight line on log-log paper are these two statements not contradictory? Apart from these points it is obvious that De Jong and his colleagues have added considerably to our knowledge of the learning situation by carrying out well designed experiments in the laboratory and especially in industrial settings. However, it would appear that his treatment of the learning situation is too simple. As Corlett and Morcombe (1970) suggest, the rate of learning is affected by:

1. The complexity of the task
2. Motivation of the operator
3. Operator's ability
4. Training methods
5. The ultimate cycle time

They also show that 'plateaux' may occur because the operator is consolidating what has already been learnt or an alteration to the method is made or the operator forgets some part of the task. Plateaux are not always found, for example, Tullos (quoted by Taylor, 1943) did not find a single plateau among 25 subjects learning a telegraphic code. Supporting De Jong, Corlett and Morcombe say that it should not be expected that a linear relationship on log-log paper will be obtained from the beginning of a learning curve, partly because log-log paper tends to emphasise deviations at the beginning. This non-linear relation can be seen in the data collected by Cochran (1969) of 18 girls learning to type over a year - three terms. A linear relationship was not evident until after about 200,000 words or about 14 weeks of practice. This is an example of a typical motor skill acquisition curve.

It would appear that as Corlett and Morcombe say:

> ". . . the process of learning a task does not invariably show steady improvement since the learner, in moving toward skilled performance, is affected by the complexity of the task, his own characteristics and the environment . . . (and) there is a complex interaction between these factors."

However, despite their warnings of the complexities of the learning situation Corlett and Morcombe make some statements which imply a simple treatment. For example:

> ". . . generally the learning curve gives a straight line on log-log paper and the reduction factor can vary from 0.7 - 0.9 depending on the proportion of labour in the task which is man controlled."

The study by Blankenship and Taylor (1938) of three groups of mill workers over a period of 50 weeks illustrates the effect of task complexity and may also involve differences between operator group characteristics. They looked at three tasks; covering, hemming and trimming, of which covering was recognised to be the most complex, hemming the next and trimming the least complex task. They found that on three output parameter measures the complexity order was the same as the output measure order. The output parameters were:

1. Initial output, i.e. after 2.5 weeks.
2. Initial slope

This finding would suggest that task complexity is a factor which does affect the shape of the learning curve. However, one cannot be sure of this from the Blankenship and Taylor study or any other study of this kind. The reason for this is that we do not know what was meant by task complexity. The workers who ranked them in order of complexity may have been basing the ranking on their own knowledge of rate of learning found with trainees. If this was the case then we would draw no conclusions about task complexity. We could say that the workers knew what kind of learning curve each of the tasks produced relative to each other.

Many other articles have been written on the application of learning curves in industry where the advice is based on personal experience of applying the technique to help sort out certain problems arising in a company. This is in contrast to such investigators as have been mentioned above - De Jong, Blankenship and Taylor, etc. - (whose approach was more experimental). Of those who base their advice on personal experience, most, if not all, are consultants. The approaches differ markedly in that an experimenter usually sets up an hypothesis and endeavours to test this hypothesis and, one would hope, he has no vested interests in the results. On the other hand, the consultant collects his information and works hard to make his solution work and, therefore, his interpretation of the data may be slanted towards his solution.

Nevertheless, the articles by consultants based on personal experience of applying the technique are a valuable source from which one may assess the usefulness and efficiency of the learning curve technique when it is actually applied. Glover (1966) reports his conclusions based on over 100 case studies. He says that plateaux will occur and their existence depends on the complexity of the task and the degree of supervision, and that they signify either that the training method or the supervision is inefficient or that there is something in the learning processes of the trainee which causes them to happen. He notes that he thinks we can do nothing about the latter.

The main theme of his paper is what he calls the Culog method of plotting the learning curve. This is merely a cumulative logarithmic measure of cycle times. He favours this method because it eliminates scatter and results in a straight line "well suited for monitoring purposes and being easily constructed by ordinary clerical labour and readily understandable by operators and other staff at shop floor level." He says that such a measure remains unaffected by random daily changes in performance and yields a straight line which he claims is the only line which can be conveniently extrapolated to yield a forecast of future performance. He shows how to determine approximate target times when a new product is being produced and the ultimate production rate is unknown and also when an existing product is being produced and the standard production rate is known. He supplies formulae and 'easy' graphical methods for making the necessary calculations.

Despite the formulae, the effort which he has made to make the calculations easy and the guidelines he supplies for the application of the learning curve technique, it is evident that Glover has either no real understanding of the problems of studying human learning or is prepared to gloss over them in order to sound more convincing. He makes little of the possibility of different 'shapes' of learning curves. For example, he says:

> ". . . a few (studies) have even reported cases of positive acceleration, but while not entirely discounting these, it is felt that for the normal industrial task this form of curve is unlikely to be encountered, at least in its entirety."

He discounts them and discusses only those tasks which he designates 'normal'. Perhaps his definition of normal task is one where the associated learning curve fits his formula. It would seem that he has fallen into the trap of trying to make the difficult subject of learning easy for no other reason than that clerical staff may use the technique. This would not be such a bad aim if his method was a simplistic version of a more complex one. But it is not and because he starts with many assumptions he has no idea what kind and of what magnitude the "error term" might be when his method is applied to different tasks, different kinds of operators, and in different industrial settings.

Nearly all the articles and books written from the basis of personal experience with case studies re-iterate the same simplistic approach, contradictions and misunderstandings. Most of them equate cost reduction curves with learning curves. This initiated the misinterpretations of Wright's 1936 article. Holdham (1970) has written an article which is typical of this type. He shows how to generate an 80% and 90% learning curve and states that they have two characteristics, namely:

1. Incremental improvement in productivity decreases as the quality increases.

2. Learning curves, when plotted on log-log paper, lie on a straight line.

The most obvious point here is that these two characteristics are results of his artificially generated data and not of an analysis of real life data. Holdham says that "in the industrial environment learning is associated with increased productivity" but does not say how they are associated.

Nevertheless, he goes from saying that they are associated to equating them, for he says, "factors that bear on the rate of learning or rate of improvement in productivity are" and then lists nine 'factors':

1. Man-machine ratio
2. Degree of skill or mental effort implied in the task
3. Extent of tooling
4. Quality of organisation and supervision
5. Methods improvement activity
6. Incentives
7. Extent of pre-production planning
8. Sensitivity of work to error
9. Morale

These factors may affect learning and productivity but will affect each differently and each effect may or may not have an effect on the other. There are obviously more factors and they will all be of varying importance depending on the situation.

As is so often the case with articles such as these, they give a vague outline of how to apply a rather vague technique and put in a disguised 'get out' clause. Holdham says:

> "A selection of learning curves experienced in industry is given; however, the reader is cautioned against uninformed application of the data to a specific company. See 'Factors affecting the rate of learning'."

Supposedly, if you try to apply these techniques and fail, then it is because of your lack of awareness of the complexity of the situation.

The use of Predetermined Motion Time Systems in research into the prediction of operator learning rates

Production efficiency became vitally important during the First and Second World Wars. Consequently there was a search for techniques which would enable the investigation and control of factors which affected this efficiency.

Shortly after the appearance of the first articles and reports on the use of learning curves as a technique for assisting the prediction of output in factories, the M.T.M. Predetermined Motion Time System was initiated and developed. This work was carried out in the 1940's by H.B. Maynard, G.J. Stegmerten and J.L. Schwab. The system was developed from the initial idea that manual operations are made up of several basic motions which have little variance no matter what the task. This assumed that these basic motion, or element, times can be summed to give a cycle time for the task. There are various Predetermined Motion Time Systems but they all share these basic assumptions.

Most of the original data was obtained using film analysis of various industrial operations. In the M.T.M. Report 107 (1954) on research methods, it is indicated that film analysis is the most useful method for collecting M.T.M. research data. This method is very time consuming and the development of electronic event recorders which enable the timing of individual motions using microswitches, photo-electric cells and other devices and using a computer either placed on-line or to process the acquired data, has made it possible to do far larger studies in a much shorter time than was previously possible.

Most studies of learning in the industrial situation had been concerned with the whole task which made generalisation from task to task rather difficult. The P.M.T.S. offered a standardised taxonomy for looking at manual tasks. However, there were considerable problems with the application of these systems and the M.T.M. system was no exception. To investigate these problems a series of investigations was carried out. In M.T.M. Report 112 Hancock and Foulke state that the series of investigations is divided into three areas:

1. Experimental work on one-handed operations

2. Simultaneous motions, increased run length and longer cycle time operations.

3. Industrial studies

Report 112 dealt with the first of these three areas. Hancock and Foulke were interested in the additivity assumption of the M.T.M. technique and selected the most frequent motions (see Aberg) to study the effect of context on any one element.

The authors, in common with most other investigators in this area, state that they were concerned with the reinforcement or conditioned learning and not threshold learning. They defined reinforcement learning as starting when the operator can perform the task without help or trial and error attempts. They designed a laboratory task consisting of the four motions

Reach, Grasp, Move and Position with different types of each motion being combined. Sixteen male students were used as subjects. Neither knowledge of results nor a target time were given but the subject was told of the purpose of the experiment. Each subject was given the Purdue Peg Board Dexterity Test and then did ten sessions of 100 cycles per session with a three minute break between sessions.

From this rather limited experiment where the motion sequence was: Reach, Grasp, Move, then Position for six experiments, with only a change in type of motion, they concluded that for Reach:

1. The reach motions exhibited the commonly assumed pattern for learning, that is the negative exponential curve.

2. There was a low variance of the time value, and this decreased with the number of cycles.

3. Most learning occurred in the first few hundred cycles.

They suggest that "low variance can probably be attributed to the relative independence of this motion from the interactions with the motions preceding and following." However, they later say that the degree of learning depends on the context of the reach element. This can be seen by comparing what they call the two levels of difficulty, namely, the first group of experiments of three motions and the second group of four motions. There was no evidence to suggest that learning took place in the first group for the Reach motion but it did show a significant learning effect in the second group. If there was such an interaction then it is doubtful whether the authors can conclude from the low variance of the Reach motion that it shows relative independence of this motion from the interactions with the motions preceding and following. This is made even more doubtful when the comment is made that the Reach motion interacts with more difficult motions and with the degree of interaction varying with the number of cycles performed. In addition there seems to be a direct interaction between the overall attainment of the operation and the Reach motion. They suggest that this may be attributable to the relatively simple operations used.

For Grasp

The variance was small and although the absolute amount of improvement was small there was a high relative learning effect of some 32% improvement. The conclusions for Grasp motions were:

1. Little interaction with other motions.

2. The initial values of the equations appear related to the presence and degree of difficulty of the position motion.

3. Some Grasps take greater than 1,000 cycles to reach standard though one Grasp required 0 cycles (surely 1 cycle) to standard.

For Move

There was a high degree of interaction with a following Position but moves with no following Position showed no learning effect.

For Position

There was a large variance and though the percentage improvement was relatively small it had not finished by 1,000 cycles. They suggest that these results appear because Position is a synthesis of several motion patterns. They agree with Crossman's (1956) suggestion, that the operator chooses the method that produces the fastest time, when they say that the "data gathered on the Position motion lends support to the theory that learning is a process of selecting and developing the best method from several alternate choices." They conclude that interactions between motions occur in the actual stages of learning and that there are great individual differences in the learning of such a task.

Though this was a small laboratory experiment it is an example of how laboratory investigations can help to clarify an industrial problem. Such investigations, as Hancock and Foulke point out, are but a part of a wider approach in the study of operator learning. Hancock (1967) says that previous research in this field can be divided into two classes:

1. Empirical learning curves on simulated industrial operations.
2. The effect of age and experience on learning.

This is a rather narrow view of the work that has been done which has included studies of a large range of operator characteristics, task characteristics and social and environmental factors. He goes on to summarise the findings of M.T.M. Report 112 though some of his statements do not agree completely with the original report. For example, he says that the variance was unchanged over the learning whereas it was reported that, though the Reach variance was small, it decreased with the number of cycles performed. He also summarises the findings from further experiments which compared motions performed with both hands simultaneously with the learning rates of those performed single-handedly. It was found that a different number of cycles was required to reach standard for double compared with single-handed work. He comments that motions requiring higher skills seemingly control the learning rate during early phases. However, this is not very helpful as he gives no idea of what or how he defines motions requiring higher skills and it may well be that this statement is based on a circular definition of motions requiring higher skills. In a laboratory study carried out in Britain, Salvendy (1969) reports similar findings. He used therbligs to analyse four simple laboratory tasks, namely the 'O'Connor Finger Dexterity Test', the 'Purdue Peg Board Test', and a modified 'Purdue Peg Board Test' and the 'One Hole Test'. The analysis was concerned with the Reach, Grasp, Position and Move elements of the task and cycle times.

It is rather difficult to understand the data as presented in the article since there is a large discrepancy between the number of people involved in each of the four experiments, as stated in the description of the experimental design and as it is stated in the data presentation. Because of the experimental design, there were also problems with transfer effects and male and female differences which were not controlled for and not even discussed. Nevertheless, by normalising the distribution performance times of each trial and using the changes occurring in the histogram performance times from trial to trial as the measure of the rate of acquisition of the speed skills, Salvendy drew five main conclusions:

1. Not all elements improved equally.

2. Those elements which show the least variability and which have the highest perceptual load, improve the most.

3. Initial performance was not related to later performance or rate of learning for most people.

4. Those operators who show low rate of learning should be used on steady and continuous jobs. Those of high rate of learning should be put on versatile jobs, i.e. where speed/skill content changes frequently.

5. Decrease in cycle time can be attributed to:

   (a) Decrease in the K of R sought by the operator (similar to Crossman's idea that the skilled operator need no longer check his work).

   (b) Increase in smoothness of operation especially between transport and stationary elements.

   (c) Simplification of motion pattern especially with respect to fingers and thumb.

   (d) Kinaesthetic sense takes over from vision.

(e) Increased ability to cope with the unexpected owing to previous trial and error learning.

(f) Presumably a decrease in the frequency and length of mental blocking.

Some of these conclusions are derived from the investigator's theoretical ideas about the learning process than from the experiment conducted. The second conclusion makes a statement about characteristics of the elements which were not measured or even really identified. A similar criticism can be levelled at 5(a), (d), (e) and especially (f) which makes little sense in this context.

These laboratory studies corroborated what psychologists had found in almost all learning situations, that is, that learning depended not only on the complexity of the material but also on the context. More recently psychologists have realised that it is not enough to claim that individual differences are a major factor in the learning situation but also that the dimensions on which we measure the individual differences interact with task characteristics which differ in effect, depending on the stage of learning being studied.

Laboratory studies when well designed and properly conducted are a valuable means of investigating what are thought to be the controlling factors in a given situation. However, many industrial researchers think that these kind of studies can only be part of the investigation and that it is necessary to actually go on "the shop floor" and test your laboratory derived conclusions and methods in the real life situation. This may be a necessary part of the study of an industrial problem but what may be termed an industrial study may really be a badly controlled pseudo-laboratory study whose only claim to being an industrial study is that it was run in a room which was part of a factory. Such a study is that of Paine (1964) which is usually referred to as the 'TRW Study'. It is cited by Hancock et al (M.T.M. 113A) as one of the "Industrial studies which were conducted to confirm the laboratory findings . . . ." Paine states in the article that the industrial data (of this and other associated studies) "will be used to validate or to disprove the learning equations developed in the laboratory and to identify those factors which require further study." However, the task used was an inspection operation which was used in the factory but which was modified for the experiment. The trials were run in a room in the factory and not actually in the normal work area. The experimental design allowed for a male/female difference factor to exist without the possibility of identifying any kind of effect. That is there were two female unskilled, two male semi-skilled, and two female skilled subjects used in the study. Age is known to be a major factor in any learning situation and here the design was again lacking because the two experienced workers were considerably older (46 and 62) than the other four (35, 22, 25 and 29 years old). Despite these shortcomings Paine considers that it is valid to draw the following conclusions:

1. The learning equations developed in the laboratory were generally inadequate predictors.

2. Laboratory equations for the first 500 cycles were a poor fit. The reasons suggested to explain this lack of precision were:
   (a) Linear equations are poor for the first 100 cycles.

(b) Threshold learning may not have finished.

(c) Eye focuses are an important factor early on.

(d) The varied nature complexity of the industrial situation compared with the laboratory.

3. Linear equations from 501 - 1,000 were a reasonably good fit.

4. Learning was not complete at 1,000th trial.

5. Separate equations are desirable for experienced and for inexperienced operators especially for the first 500 cycles.

6. Age may need special attention.

7. There was no difference between industrial and student subjects.

8. No male/female difference.

From the comments made previously about this study it can be seen that conclusions 5, 7 and 8 do not follow from the data collected.

Hancock (1957) comments on this study by Paine and the other two so-called industrial studies, MACE and GEICO Studies. He summarised results of these attempts to apply the learning curve predictors set out in M.T.M. Report 112.

1. The prediction of the number of cycles to reach standard was adequate but the prediction curves for cycles previous to this were not a good fit.

2. The number of eye fixations at the beginning was 2 - 3 times that of the number when the standard was reached. When the prediction curves were modified by a factor of 2.5 this gave a good fit between the actual curves and the prediction curves.

3. Very short breaks (5 - 10 minutes) had negligible effect. Longer breaks of a night or more did have a significant effect but this diminished with the number of cycles.

4. Age was not found to be an important factor, until above the age of forty.

Another attempt to use the prediction equations set out in M.T.M. Report 113 was carried out by Mayne (1969) at Pirelli Ltd. in England. In the first part of the study they looked at one person assembling and dismantling the main parts of a tape recorder. The average time for each successive five cycles was recorded. The experiment had to be restarted, with the same subject, after 20 cycles because the subject changed the motion pattern. With the modified motion pattern the prediction curve appeared similar to the actual times recorded for the first 380 cycles. However, if they had included the first 20 cycles, which were of a very similar motion pattern, in the analysis the fit is not so good. They then applied this method to an actual shop floor operation, that of building a car type. The predicted number of cycle times to standard was 1,900 and they found a variation in element times to standard to be between 200 - 2,900. This was followed by a study of three workers being trained by taped instruction whose time basis was devised from the other study. The correlation between predicted and actual was found to be very good. However, this is most probably an artificial correlation because the learning is being paced by the prediction curve data.

In another article Mayne (1970) describes how drift of cycle times will take place because of practice. He says that this drift is minimised if the operators are trained on optimum motion patterns. He demonstrates the approach which is similar to that described in his other article (Mayne, 1969) to the prediction of drift with an example of a peg board task. This is not well demonstrated and one wonders why the details of how it was accomplished for an actual job were not given instead. However, he does give data on three actual operations which show a very good prediction of the amount of drift actually found.

Discussion

There have been but a few reported investigations into the use of P.M.T.S. during the learning stage. These investigations have been mainly laboratory studies of simple tasks. The so-called industrial studies have been either poorly designed and carried out or poorly reported. We have vague comments about the latter in M.T.M. 113A. For example, it was stated in M.T.M. 113A of the MACE Study that "the fit of the prediction equation with the learning appears to be very good" and of the GEICO Study that the prediction curve "appears to be a good fit". The conclusion stated regarding the TRW study is more assertive but extremely misleading, that is, that "the predictive curve is an excellent fit". This is not what was concluded in the original article by Paine and is only true for one operator when the rather dubious 'eye movement factor' is applied to the original equations. This last point refers to Hancock (1967) showing that if the TRW equations are modified by a factor of 2.5 then they are better predictors. This may be the case but to relate this to the fact that the number of eye movements at the beginning of the learning period is 2 - 3 times the number when the learning trials are finished is unjustified.

Eye movements are often brought into studies such as these and are said to be related to the 'mental component' of the task. Work Factor System (Van Santen, 1970) cites eleven elements which make up the 'Mental Processes'. They are a curious mixture of physiological and psychological terms which causes the inevitable overlapping of many of their definitions. They have been "put together in the form of combinations" which most often occur. These are known as Mento Intervals and are:

* The React Interval
* The Inspect Interval
* The Compute Interval
* The Read Interval

The Work Factor System claims to give time values to each of the elements which constitute these 'elements'. Certainly psychologists would be very interested in how they derived these times such as:

Conduct	-	1 time unit
Identify	-	6 time units
Decide	-	6 time units

However, these times are not worthy of further study because of the conceptual confusion and unreliability of the basis from which they are derived.

The studies discussed here show that the P.M.T.S. assumptions of additivity of elements and the assigning of single times for all types of people do not hold, at least in the learning situation. Laboratory studies are shown to be useful especially when well designed and properly carried out. Two such studies are those of Sanfleber (1957) and Gershoni (1971). Sanfleber found that the motion pattern affected the elemental times, but this varied from person to person in absolute amount and trend. He also says that when several people are averaged, which is a typical procedure for learning curve studies, the "Gestalt influence" is eliminated. That is, the effect of the motion pattern for analysis is lost.

The experiment reported by Gershoni is part of a series of well designed laboratory investigations in the area of learning. He found that workers who are allowed to select their own micro-method will produce wide variations in cycle time and change their motion pattern during the learning process. The methods they develop will not be comparable to those of trained work study practitioners.

Where the workers were paid a monetary incentive and taught a specific method they improved as per the conventional learning curve. The standard deviation of cycle times also appears to decrease with the number of cycles performed. However, the standard deviation of non-incentive workers appears much higher than those on incentive. In some cases learning continued after 7,000 cycles but with some non-incentive workers there was negligible learning.

In a later study Gershoni (1979) concludes that learning a task is not

> "like learning to run races. The problem is not one of learning to move ever faster until the standard is achieved . . . . The main issue would seem to be one of using the most efficient motion patterns" (p. 1205).

This follows Crossman's (1969) suggestion that the trainee has a repertoire of motion patterns from which he gradually selects the most appropriate one. These suggestions which are prevalent in the literature still do not progress our understanding of learning process. Gershoni (1979, p. 1195) says that the main question is "how does the worker's behaviour change during the learning process?" But descriptions of behaviours do not give an understanding of the learning process or the reasons for inter and intra individual differences in performance. The further question must be asked "why does the worker's behaviour change during the learning process?"

The next section of the literature review outlines the search for a framework within which an answer to this question might be developed.

Task characteristics

Although tasks are ubiquitous in the study of human performance there has been relatively little research into task taxonomies, task characteristics, their effects on performance and their conceptual nature. Attempts have been made in the last twenty years to produce task taxonomies. These efforts have mainly arisen from the practical needs of national Departments of Employment who require a classification system in order to produce and monitor labour policies. These classification systems are inadequate for most needs of psychological research because of their generality and often practical rather than conceptual basis for classification.

As well as providing a basis for understanding the interaction between the task and the learner, a task taxonomy provides a means of assessing the commonality of task behaviours which "determines in part the extent to which data can be generalized from one task to another" (Meister 1976, p. 101). One of the most influential classification systems was that devised by Berliner et al (1964) and shown in Exhibit 2.1. This is not a taxonomy because there are no rules which govern either the levels or the categories. Nevertheless it is fairly "comprehensive and easy to use" (Meister 1976, p. 105), but the terms are not exclusive and allocation to a category is carried out by inspection of a task. Many similar kinds of task classification system have been proposed, for example Steiner 1966, Chambers 1969 and Miller 1971. All used fairly gross descriptions of processes such as observe, detect, code, search and many others. However, little progress has been made with task taxonomies and this may be because the search has been for a universal task taxonomy. As Meister (1976, p. 102) says

> "the popular belief that only one taxonomy is possible . . . is quite untrue. Alternative taxonomies are possible, based on the purpose for which they were assigned: training (Cotterman 1959; Gagne 1965), selection (Fleishman 1967), and human engineering of equipment (Colson et al 1974) are examples."

Studies concerned with the psychology of groups have been one of the

main sources of evidence suggesting that task differences do affect the performance of a group. Hackman (1968) found that the differences between three types of tasks accounted for 50% of the variance of certain aspects of group output. The tasks were differentiated on two dimensions - task type and task difficulty. Morris (1966) similarly found that tasks with different characteristics affected group interaction.

The work of Hill (1969) is interesting because of his attempt to relate a subjective variable to a physical correlate. He saw work variety as a subjective variable and he tried to relate this variable to some 'objective' measure of variety. Although the 'variety' was not within a task, but defined by the changing from task to task, it may well be valid to draw the analogy with elements within a task.

He obtained four 'objective' measures:

1. Number of different tasks executed within the period.

2. Total number of changes of task executed within the period.

3. The entropy of the set of different tasks occurring within a defined period of time.

4. Entropy of the total number of tasks occurring within the period.

He used a rating technique to obtain rankings of perceived variety. He found as Wyatt and Fraser (1928) suggested that perceived variety was a non-linear relation with workers' preference. That is, that too few changes were seen as boring and too many changes were seen as annoying. He found that the only physical correlate which followed this non-linear relationship was that of the entropy of the total set of tasks. It may be the case that these kinds of measures of physical variety, when applied to the element pattern within a task, could provide a basis for looking at task characteristics and their effects on the operator's learning curve.

Cooper (1970) suggests the following structure to enable one to assess the effect of the intrinsic characteristics of the task on motivation and satisfaction. The structure has been developed from Turner and Lawrence's (1965) study of the intrinsic characteristics of a wide sample of jobs.

Motor variety	)	Physical		
Optional interaction on the job	)	variety		
Required interaction	)	Task	)	
Object variety	)	uncertainty	)	
Responsibility	)		)	Skill
			)	variety
Knowledge and skill	)	Response	)	
Autonomy	)	uncertainty	)	
Optional interaction off the job	)		)	

However elegant this structure is, it still does not allow one to do more than inspect a task and decide on how it compares on each of the factors with another job.

Hackman (1969) presents an analysis of "the role of tasks in behavioural research". He says that "tasks do make important differences in behavioural research data, differences which for the most part are not presently understood." He sees two criteria for distinguishing between the many definitions of 'task':

1. The degree to which 'task' is conceptually distinguished from the general situation which confronts an individual.

2. Whether tasks are viewed as external to the performer or are seen as being internal to the performer and defined by him.

In any situation there are two aspects of the task. Firstly, the task as defined by the experimenter, management, or whoever institutes the task and secondly, the task as redefined by the performer or operator. The situation is objectively, from the standpoint of the observer, the same but the views of what constitutes the task are different.

Realising that there always exist two views of the task content for any one task, except where the task is set by the performer, Hackman suggests four approaches to task description:

1. **Task qua task**

   The task is characterised by the "objective" qualities of the task. For example, object variety. This is the type of approach which was included by Turner and Lawrence (1965) in their study of the intrinsic characteristics of a wide sample of industrial jobs.

2. **Task as behaviour requirement**

   The task is defined in terms of the processes required in order to carry out the task successfully (for example Miller 1971).

3. **Task as behaviour description**

The task is defined in terms of responses actually made. This has been a popular approach with the industrial psychologist. It is the kind of approach used in the M.T.M. Research Study 114 where one factor of manual skill learning which is considered is that of the job characteristics in terms of complexity, redundancy and organisation and these are assessed in terms of 'cue-motions'.

4. **Task as ability requirements**

The task is defined in terms of the personal abilities which are required of the performer for successful task completion. One of the main exponents of this is Fleishman (1967, 1978) who, using well designed experiments and involving factor analyses of the data, has given evidence to support his view that most "psychomotor tasks can be categorised in terms of eleven basic skill factors."

Hackman believes that "it is essential that we develop some means of describing and classifying our independent variable (tasks) other than in terms of the dependent variables which we ultimately wish to predict." He says that on this criterion only the first two approaches can be considered, though describing tasks in terms of ability requirements is a more acceptable approach than in terms of behaviour description because it uses more enduring aspects of the performer. He thinks that though the task qua task's approach is the most desirable it is not feasible. It is the description of tasks in terms of behaviour requirements which, he suggests, holds the most promise. Because the required behaviours are different from task to task, and depend only on task demands, he concludes that they can legitimately be viewed as characteristics of tasks rather than of the performer. He suggests a tentative framework within which it may be possible to:

1. Trace out some of the effects attributable to the task.

2. Identify some points in the task performance process at which 'personal' factors have important interactions with task-based factors.

His framework suggests three ways in which task effects can take place:

1. Tasks affect the kinds of hypotheses one can generate about behavioural strategy.

2. Tasks can affect the performer characteristics, e.g.
   (a) Motivation changes
   (b) Cognitive and physiological arousal changes

3. The task influences the output possibilities and the performer can adjust his behaviour to optimise on some outcome, i.e. learn to do the task in some way.

Hackman concludes that "a high priority research need is the development of understanding about what 'types' of task dimensions have substantial behavioural impact, what the nature of this impact is, and how it interacts with various experimental treatments."

Hackman's analyses of "the role of tasks in behavioural research" is useful, but his recommendations with regard to the type of task description which we need to develop in order to assess the effect of task characteristics on performance are not argued convincingly. The second of Hackman's four approaches, that of behaviour requirements, is implied from the behaviour of subjects carrying out the task or from envisaging this behaviour. It is no more or less independent of the performance than the ability requirements' approach which is also partly derived from performance scores.

Ferguson (1956) says that "no satisfactory methodology has emerged for describing particular learning tasks, or indicating how one task differs from another other than by a process of simple inspection." Attempts have been made to differentiate tasks by inspecting and rating them in terms of their relative 'complexity'. For example, in the previous section of this review the Blankenship and Taylor (1938) study was discussed, where part of the experiment required experienced workers to rate three tasks in terms of complexity. This ranking was then compared with performance measures and significant relationships were found. However, one is never sure what the rater's concept of complexity is and it may well be synonymous with the performance measures taken.

Where there are no unequivocal quantifiable dimensions available, then there is a case for what Ferguson calls "simple inspection". However, it is necessary to state as precisely as possible what is meant by the factors being rated and of course the more obvious the difference between tasks on the factors the more acceptable is the data.

Naylor (1962) suggested that learning rate is associated with two factors and that the relative efficiency of part and whole task training is a function of these two factors or variables. These are:

1. Complexity
2. Organisation

Complexity was defined as a function of the information processing demands imposed on the subject by each component of the task separately. Organisation was specified by the demands placed on S by the interactions or interrelations between task components.

Following the work of Birmingham and Taylor (1954), Briggs and Naylor (1962) proposed that the dynamics of each task dimension determine the complexity level. Thus, positional control is viewed as less complex than rate control, which is less complex than acceleration control. Using this idea of complexity Briggs and Naylor looked at Naylor's original hypothesis (1962) that training method effectiveness is related to both task complexity and task organisation and that there is a possible interaction between these two variables. Their first study (Briggs and Naylor, 1962) was an evaluation of the effect of task complexity on method efficiency, but they failed to obtain data which accepted or rejected Naylor's hypothesis. They concluded that: at all levels of task complexity in a relatively highly organised task, the 'whole' method would be superior to a part schedule; that when all task dimensions are independent, that is relatively unorganised, then an increase in task complexity will result in a part-task training schedule becoming superior.

In the studies of Naylor and Briggs we found a more exacting definition of task complexity and organisation, but the experiments are constructed around these definitions. It would be very difficult, if not impossible, to apply these definitions to other experimental situations in the laboratory, far less in the industrial setting.

While Naylor's definition of task complexity and organisation falls into the "task qua task" category, in Hackman's analyses there are many researchers who contend that we should accept that the task is defined by the performer and not the person who sets the task. Weitz (1966) reasons that task difficulty can be equated with aptitude to perform the task. He says that for high aptitude subjects the task is easy and for low aptitude subjects the task is difficult. He has hypothesised, and there is growing evidence in support, that personality variables should predict task performance early in time for high aptitude subjects and late in time for low aptitude subjects. This suggests that learning takes place at differential rates for different people and that the task descriptors that we use probably change in importance through time with regard to their effect of the learning process.

The evidence of an interaction between individual characteristics and task characteristics makes it even more imperative for a task taxonomy to be developed for use in the learning situation. However, the question arises as to which type of approach is most appropriate and which taxonomy is most relevant. Companion and Corso (1977) suggest a set of nine criteria for the evaluation of task taxonomies. They are:

"1. The taxonomy must simplify the description of tasks in the system. This is necessary because the goal of any taxonomic scheme is to make the subject matter of the taxonomy more manageable.

2. The taxonomy should be generalizable. If the taxonomy is system specific, the effort necessary to develop it might outweigh the benefit derived. Also, generalizability is congruent with the necessary assumption that activities have some common basis.

3. The taxonomy must be compatible with the terms used by others. Unless the taxonomy is in a form that is meaningful to those who will use it, its application will be inefficient and often ignored.

4. The taxonomy must be complete and internally consistent, i.e., it must deal with all aspects of human performance in the system without a logical error.

5. The taxonomy must be compatible with the theory or system to which it will be applied.

6. The taxonomy should help to predict operator performance. This is necessary to evaluate and compare performance between operators on different as well as identical tasks.

7. The taxonomy must have some utility, either practical or theoretical.

8. The taxonomy must be cost effective. It is possible that in many situations the time and money required to develop and implement a task taxonomy may add to the overall cost of the system and provide litle increase in operating efficiency.

9. The taxomony must provide a framework around which all relevant data can be integrated. Without this the taxonomy is merely a verbal device with no ties to reality and, therefore, no applicability."

They also stress the need for the taxonomy to integrate existing data. However, these criteria may not be relevant to all purposes and to differing states of development of a taxonomy. Indeed these criteria may only be appropriate to a finished taxonomic system and none such system is claimed to exist.

There have been an enormous number of attempts to identify and assess abilities. The vast majority fall into three kinds of approaches, namely, clinical, classical testing and factor analytic. The first two are attempts to identify what Cattell (1971, p. 12) describes as "surface traits". In clinical judgement an expert is required to make an assessment based on his experience. Consequently, it is extremely subjective. Of course, there are many problems with this approach and even if there is high inter rater reliability, this may be the result of common training. This approach is exemplified in skills analysis as described in Chapter 2 and it is well documented in the book edited by Singleton (1978) entitled "The Analysis of Practical Skills" which is Volume I of a series entitled "The Study of Real Skills". This approach lacks a uniform methodology and the notion of a skill is different for different analysts. Some use it to describe the total task which could range from "a concert pianist" to a "motor mechanic tightening a bolt" (Singleton, 1978, p. 2), whilst others have made subjective judgements about the cognitive skills involved (see Whitfield D. and Stammers R.B. in Singleton, 1978). Consequently, this more clinical approach to skill acquisition leads, as Singleton (1978, p. 314) admits, to "a bewildering variety of taxonomies of skill . . . . Some authors have attempted to relate skills closely to the task required in the particular industry, some have tried to use the academic terminology of experimental psychologists and almost every author eventually reaches a rather uneasy compromise between these two extremes."

The above approach has serious limitations in that it requires an expert to make the assessment. We know little of the validity of these judgements and little of the inter expert reliability. Further, the results of such judgements are difficult to generalise from. As Singleton says, "Studies of other jobs by other research workers may well require a considerable extension or even complete revision of these ideas." (Singleton 1978, p. 318.)

The second approach to the analysis of skills and abilities, the development of tests which predict job performance as used in classical testing, attempts to construct carefully paper and pencil tests and apparatus tests which are successively refined to identify a particular attribute which a person would need to possess in order to be successful at a particular task or job. However, unlike the previous approach, the aim is to produce a test which assesses an aptitude which is required by a number of tasks and jobs, and which allows for a quantitative estimate to be made of the degree to which a person already has or could acquire that aptitude, and also its relative importance in the successful operations of a task or job. The methodology involved is based heavily on correlational analysis and is generally directed towards the maximisation of the correlation between test score and task or job performance. The problems related to such an exercise are extensive and include questions of validity, reliability, test fairness, and other aspects which have been extensively covered by such authors as Weiss and Davison (1981), Lumsden (1976) and Anastasi (1976). The search for predictive power in tests has not been very successful and this may be because inappropriate models are being utilised. This aspect will be discussed more in the next section. This approach is also characterised by a lack of a unifying model or theory which would allow for a finite number of aptitudes, abilities or skills to be identified. This may be seen in the number of new tests which are developed every year claiming to assess a particular characteristic of humans. Over 3,000 measures were described by Chun, Cobb and French in 1975 and Buros lists 2,467 tests in his 1974 edition. The development of such a mass of tests means that there is much overlapping, though this in itself is not easy to assess nor rectify, if that is required. However, the tests may still be unidimensional in that a unidimensional tests does measure a single attribute, but the attribute is complex. As Lumsden (1976, p. 267) says, a test "maps the ability of the subject to do items" in the test. He argues that the ability is complex and may involve a number of abilities and does not reflect a single theoretical attribute or construct. The use of the term ability with different meanings is rather confusing and he concludes, though gives no argument in justification, that "the construction of theoretically singular tests is probably impossible." (Lumsden, 1976, p. 267.)

It is with the development of Spearman's work on the application of factor analysis to the problem of identifying the underlying source traits, which shape and constrain human performance, that a more general model and approach is possible. This would also allow us to understand the process of skill acquisition and relate our findings to different tasks and jobs, and also to different people. This necessitates the establishment of an ability taxonomy and, consequently, a classification of abilities in such a way that we are able to identify and quantitatively assess them.

There has been an enormous amount of work carried out using factor analysis as a means of identifying abilities, especially in the study of intelligence. Within the factor analytic approach there are two main groups of research. There are those who use factorial methods that allow a large general factor to emerge as the first factor, and those who prefer methods that yield a number of independent or primary factors and no large general factor. Some researchers such as Bernyer (1958) and Cattell (1963) argue that both methods are fundamentally reducible to each other (McReynolds, 1968). The major proponents of a large general factor such as that identified by Spearman are Burt (1949) and Vernon (1956, 1961, 1965). The latter suggests a hierarchical group factor theory where one factor g covers more than twice the amount of variance as all group factors combined. After this main factor there are two main group factors, namely verbal-numerical-educational on the one hand and practical-mechanical-spatial-physical on the other hand. These also break down into verbal, number, mechanical information, spatial and manual minor group factors. There would also be specific factors associated with the minor group factors.

However, this is a particular model and, as yet, has not been shown to be more worthy than the multiple factor model proposed by Thurstone and developed by researchers such as Guilford (1967), Fleishman (1978) and Cattell (1978). As Vernon (1961, p. 25) says, "The strict hierarchical picture of mental structure is an over-simplification. For the results of any factor analysis depend largely on the composition of the population tested . . . and on the number and kind of tests studied." Nevertheless Vernon would probably not agree with Coan (1964) who suggested that these different theoretical orientations may be simply preferences for different modes of verbal description.

Cattell (1978) has taken a different approach by starting with a multiple factor approach but carrying out oblique rotations which allow for second order and third order factor analysis. This then groups the initial factors into supra factors which in itself is the formation of a hierarchy.

It is the combination of the objectivity of testing the powerful statistics which allows for the extraction of relationships which are not evident from mere correlations, the utilisation of a general model which involves source traits, and the possibility of relating one study directly with another study, which makes Factor Analysis potentially so valuable and, as Kerlinger (1980. p. 659) says, "the queen of analytical methods".

Factor analysis has dominated the studies of individual differences in abilities and indeed, as Carroll and Maxwell (1979, p. 608) state, "The bulk of recent research is predicated on a multifactorial view." Perhaps the best example of a factorially derived taxonomy of cognitive abilities is the publication of the revision of the well-known E.T.S. kit of factor reference tests (Harman, Ekstrom and French, 1976). Many of the tests listed by Buros (1974) are developed by factor analysis. However, relatively little has been carried out in the area of psychomotor abilities. The main researcher in this area is E. A. Fleishman who, with a number of colleagues, has contributed enormously not only to the development of a taxonomy of psychomotor abilities, but has greatly furthered our ideas and understanding of skill acquisition. As Singer (1980, p. 194) says, "Perhaps the most extensive work in the area of motor abilities completed thus far by any one scholar (and his colleagues) is attributed to E. A. Fleishman." The approach and the taxonomy developed by Fleishman and his colleagues has been the subject of studies to assess their applicability to particular areas of research.

There are few studies which assess the validity or usefulness of proposed task taxonomies. One study by Levine et al (1973) evaluated the task taxonomy developed by Fleishman (1978) and his colleagues over twenty years, based on an ability requirements' approach. Levine et al examined the tasks used in vigilance studies and rated them in terms of the abilities required by the tasks. They then examined the data within and between these categories of tasks to try to improve the generalisations which could be made about factors affecting vigilance performance. They claimed that despite the differences among specific tasks in terms of equipment, displays, response requirements and other aspects, the classification system enabled an integration of the results from the 53 studies of vigilance performance and the identification of functional relationships which were not identifiable from the original analyses. This study was extended by Parasuraman (1976) who was able to confirm the usefulness of this classification system for improving generalisations about performance on vigilance tasks. Similar results were claimed by Levine et al (1975) in their study which categorised the tasks used in research on the effect of alcohol on task performance. If we use abilities as our task descriptors we must be aware that, if the ability or skill factors change with time during the learning period in their relative importance, then our description of the task will change. Further evidence of this is given by Fleishman and his colleagues (1954, 1967). They say that with large numbers of practice tasks their studies show that:

1. As practice continues, changes occur in the particular combinations of abilities contributing to performance.

2. These changes are progressive and systematic and eventually become stabilised.

3. The contribution of 'non-motor' abilities (e.g. verbal, spatial) which may play a role early in learning, decreases systematically with practice, relative to 'motor' abilities.

4. There is also an increase in a factor specific to the task itself.

These findings may also be very relevant for the selection and training of personnel in a manned system. The identification of the abilities required by a task would have important practical consequences, and the application of these findings to the prediction of job performance in a selection procedure will be discussed in the following section.

Application of Fleishman's findings to the design of the selection procedure (Atkinson 1973)

The two World Wars gave rise to an emphasis on production efficiency which is still with us. However, as the demand for more output per man rose, a number of problems were manifested. One of these problems was that the tasks became more complex (King 1964), tended towards the decision-making type of task, and training time had to be less. Previously most jobs could be done by a wide range of people, but now far fewer jobs are unskilled and, consequently, there is a very limited opportunity for transferring personnel from one job to another without retraining.

As a result of most jobs being semi-skilled or skilled, recruitment and selection has become a very important function within the industrial system: the better one can determine the outcome of taking a person on, the more predictable will be the system behaviour.

Selection procedures use some kind of assessment of the candidate and this normally involves measures or tests. These test scores serve as predictors of some index of job success, the performance measure (criterion). Many approaches (Gagne, 1964, Fleishman, 1967) require an analysis of the abilities required to do the job successfully and then the construction of tests which will test each of these main abilities. An index of job success is still required, because this approach relies on the relationship holding that someone who is highly successful at the job also tends to have high levels of the identified abilities. Those who are poorer on the index of job success will not have high levels of the abilities identified.

It has been argued that one can use a single measure of overall job performance. However, Seashore, Indik, Georgopoulos (1960) concluded from a large scale field study that "the validity of overall job performance as a unidimensional construct and as a basis for combining job performance variables into a single measure having general validity" was contradicted by the data which they obtained.

Because of such misgivings over the use of a unitary concept of job performance, there have developed approaches which try to assess, by skills' analysis, what skills are required of the job and then find tests which are reliable, predictive measures of these skills and which also discriminate those successful at the job. But, even after many years of developing tests such as the O'Connor Finger Dexterity and the Purdue Peg Board Test, we have not developed adequately reliable tests. Corlett, Salvendy and Seymour (1971) concluded that the two above mentioned tests are inherently too unreliable to constitute adequate tests of speed-skill acquisition.

There are two main types of predictor measures (Cronbach, 1970) used. These are:

1. Measures of maximum performance, e.g. general mental ability, proficiency at a task, etc.

2. Measures of typical performance, e.g. interests, attitudes, general personal information, personality, etc.

Both, however, use the same analytic model. This model is that there is some behaviour of a person doing a job which leads to some degree of success or failure in doing that job. This behaviour is shown by what is termed "experienced worker" or such phrases as "the competent manager". If we look at their behaviour we should be able to analyse it into a set of skills which are necessary to carry out the task. Therefore we should then be able to test candidates for the job by finding out if they have these skills or abilities, or at least have the potential to acquire them. On the basis of this model, tests may be correlated with a measure of job success.

However, we have still not found tests with high predictive powers, and those which have significant correlations are few. Lent, Aurback and Levin (1971) analysed all the data of the 405 studies published as validity information in the journal 'Personnel Psychology' over the twelve year period ending January 1966. This amounted to a total of 1,506 joint predictor-criterion uses occurring. Their principal analytic technique was the determination of Significant Batting Averages (S.B.A.) which were established by obtaining the ratio of significance frequency (hits) to usage frequency (turns to bat). They arbitrarily selected .05 level of significance, as this was the level used in most of the studies. They found that 'Aptitudes' was the most frequently used predictor class and 'Supervisor's Evaluation' the most frequently used criterion class. The Aptitudes had the highest of the predictors' S.B.A and, of the criterion measures, Achievement yielded the highest stable S.B.A at .98. Apart from these a very high proportion was found to have no significant predictive power at least 50% of the time that they were used in research.

Is our inability to produce high powered predictive tests a result of our failure to ask the right question, and is it therefore a matter of sifting the questions until we obtain the most appropriate test or tests? This does not seem to be the case. It is the model we use which is inadequate, even though few have made the model explicit. As Wallace (1965) said about the possibility of progress in this field: "We are sterile because our empiricism has prevented us from developing even the rudiments of new insights or generalisable concepts."

The assumption that the behaviour we are trying to predict is shown by what is often called "The Experienced Worker" or the "Competent Manager" or whatever, may not be appropriate. This assumption implies that this is the most appropriate behaviour to be found and therefore implies that learning which has any effect on performance has stopped. However, we know that this does not happen (Murrell, 1971). So what part of the learning curve do we call "Experienced Worker Behaviour"?

It may be that a more useful approach would be to accept that learning carries on and that the label "Experienced Worker Behaviour" is placed on the curve by local factory concensus and therefore fairly arbitrary. However, it would appear that during the learning period of even fairly simple psychomotor tasks, various abilities are required. This would intuitively seem reasonable. Fleishman et al (1954, 1960), using a factor analytic approach, showed that there was a change in the nature of the factors contributing variance at early and later stages of practice. Therefore, Fleishman says "Performance at any stage of practice is regarded as determined by a set of co-operating but independently variable abilities" and "the important point is that earlier in the learning period the use of certain skills is a minimal but necessary requirement for achieving a certain amount of progress in performing the task." These findings suggest that it is not sufficient to use tests to predict the potential of candidates acquiring the abilities found on one specific part of the learning curve, no matter how "flat" it appears, as we do when analysing the behaviour of the "Experienced Worker". We must determine the other abilities which are required during the learning period and whether the candidate has the potential to acquire these abilities. The change of abilities required during the learning period is shown in the study by Fleishman and Fruchter (1960) on the learning of morse code (Exhibit 2.2). From this we can see how the contribution of each of the factors changes with the progress of learning. The change in factor pattern may have been even more apparent if other tests, more suitable to the abilities required in the later stages of learning, had been included.

The approach suggested by this model can be illustrated by Exhibit 2.3. If Stage 5 is accepted as the experienced worker stage, then an analysis of his behaviour would show three abilities, namely F, A and E. However, for

EXHIBIT 2.2 Change in contribution to performance by different factors during the training of subjectsto receive Morse code. From Fleishman E. and Fruchter B. (1960).

EXHIBIT 2.3 Illustration of change in ability pattern during the learning stages for an imaginery task.

		Learning Stages				
		1	2	3	4	5
	high	C	B	A	E	F
Ability		D	D	E	G	A
Involvement		E	E	F	F	E
	low			G	A	

the candidate to become an experienced worker he must be able to acquire abilities A, B, C, D, E, F and G or have already acquired them. Therefore, we should not administer only those tests which assess his potential for acquiring the abilities F, A and E, but also those abilities B, C, D and G which are required for learning F, A and E.

We could assess a candidate on his potential to acquire the skills and predict how far he could progress. For example, from Exhibit 2.3 we can see that if a person had the potential to acquire skills B, C, D and E and not A, F and G we could predict that he would complete only Stages 1 and 2 successfully. (It may be the case that Stage 2 is a job itself and this would indicate that he could be taken on to do the job at Stage 2.)

Using this model we should be able to identify more accurately those applicants who will be successful at the job as defined by the last stage in the learning process.

Conclusions

The use of learning curves to predict the rate of learning and the terminal performance of trainees is very limited. These limitations require the subjects to be identical or at least extremely similar to the subjects on whom the curves were based. As no individual differences are taken into consideration it is not possible to assess the effect of using subjects with different characteristics. Similarly, as no task characteristics are identified, it is not possible to generalise to other tasks and so predictions are limited to exactly the same task from which the curve was derived. Even within these limitations the learning curve technique has not met with great success.

The use of micro motions, as in P.M.T.S., has given insights into the organisation of motor behaviour and has been of practical importance, especially for predicting terminal performance for tasks which have not yet been carried out. However, it suffers from the same criticisms as the learning curve technique with the added limitation that the task must be manual and repetitive. The repetitiveness is not in terms of objectives but requires the exact movements to be carried out in the same order every time. These types of tasks are becoming fewer and fewer.

The need for a more complex model of learning meant that task characteristics must play a central role and, to allow for generalisations from task to task, it is necessary to develop a task taxonomy. The most promising taxonomy is that using the abilities' approach and in particular that of Fleishman and his colleagues.

It is this approach in general and Fleishman's in particular which will be investigated and used to develop an understanding and thereby a model of the learning of psychomotor tasks. One of the objects will be to assess the generalisability of his findings to real life tasks, for as Singer (1980, p. 194) says in reference to Fleishman's ability taxonomy,

> "It should be emphasized that most of the task from which these abilities have been derived have not been athletic or real life in nature, a restriction in the interpretation and application of Fleishman's findings."

SECTION 2

SECTION 2

The original studies reported in this section were carried out to assess the generalisability of the Fleishman approach and the applicability of his findings to real life tasks. Two of the studies were field studies and one was a laboratory simulation of an assembly task.

The study of the trainee typist was also designed to test the changing task model which Alvares and Hulin (1972) had ascribed to Fleishman's interpretation of his studies. Two of the Atkinson studies involved small samples and the validity of carrying out a factor analysis on small samples was discussed. It was realized that the study of sewing machinists could only be indicative but also that it played an important part in giving direction to the subsequent research. Two factors accounted for the vast majority of the performance variance during the eleven weeks of training the sewing machinists received; whilst one factor declined, the other increased in contribution. This change in factor pattern was systematic and progressive but neither loaded prominently on any of the reference tests. This meant they could not be identified and, consequently, it was not possible to assess all of Fleishman's findings as described in the previous chapter.

To achieve more control over the learning situation a simulation of a typical industrial assembly task was designed utilizing 'Lego' blocks. The results showed changes in the contributions from the factors as practice continued but the changes were neither systematic nor progressive. Further, both factors were identified as non-motor abilities and there was no task specific factor. The former may have been the result of too short a practice time which did not allow for motor abilities to appear.

Nevertheless these studies suggested that verification of Fleishman's findings and a more fundamental test of the model of the learning process, upon which his studies are based, was necessary. To this end the study of 74 students, including 39 trainee typists, over 10 months was carried out. The data were analysed, in the first instance, to assess whether there were any changes in the factor pattern during the 10 months' practice. It was found that one factor accounted for the vast majority of the variance on the practice task and this was tentatively identified later in Chapter 6 as Response Orientation ability. There was no pattern of change in factor contribution during learning and no evidence of a task specific factor.

All three of these studies led to the conclusion that either Fleishman's findings did not generalize to other types of tasks and populations or that the more modern procedures and methods which had been used to analyse these three studies had produced the different findings.

The design of the study of trainee typists allowed for test scores from the beginning, middle and end of the 10 month training to be analysed. This enabled an assessment of the changing task model of learning and the assumption made by Fleishman and others that abilities are overlearned and consequently, apart from minor practice effects, will be seen as constant ability test scores over months and years.

The analysis was carried out by examining changes in the means of test scores ("students t" test) and correlations between the three stages of test scores. Each stage was also subjected to a factor analysis both including and excluding the test scores.

It was found that the ability which accounted for the majority of the variance on the criterion task was different for each of the three stages, but the "t" test and the correlations suggest that some of the abilities were also changing as indicated by changes in test performance. This meant that a more complex model of learning is required which includes a changing task and changing subject together with the possibility of individual differences in those abilities which are overlearned and those which are not.

The final part of the analysis was a factor analysis of the test scores for the first test administration for all 74 students without including the scores on the practice task. Three factors were identified but only one could be linked to the studies reported in Chapter 6.

CHAPTER 3

THREE NEW STUDIES OF ABILITY CONTRIBUTIONS TO LEARNING

The question arises whether Fleishman's conclusions from his programme of research studies may be generalised to other populations and types of task. Almost all of the subjects used in the programme of research carried out by Fleishman and his co-workers were Air Force personnel and all of these were trainees. None of the subjects was an industrial worker and none of the tasks was an industrial task. Indeed the majority of the criterion tasks were laboratory tasks and only three studies out of sixteen involved real criterion tasks and these were: learning morse code, pilot performance, and graduation of Navy midshipmen from flying training.

To answer this question it was decided to apply Fleishman's methods to an industrial situation. There is a number of problems with replicating Fleishman's method in an industrial situation. Firstly, access has to be negotiated for a study which will probably be of little use to the host organisation; secondly, it is rare that a large number of personnel will be taken on and given exactly the same training for the same job; thirdly, it is necessary to be given enough time to administer tests which are not used by the organisation and testing is usually restricted to pencil and paper tests; fourthly, it is difficult to insist on systematic and standardised training procedures for all subjects; and fifthly, it is not always possible to obtain an objective performance measure.

One company was found which appeared to meet most of these requirements and the task was one which was expected to require similar psychomotor abilities as defined by Fleishman et al. The job was that of a sewing machine operator in a factory in Scotland.

When this study was started it was anticipated by the company that well over thirty sewing machinists were to be taken on within 12 months. However, within a few weeks of the start of the study the company found itself unable to take on any more than twelve. Of those, two dropped out within a few weeks and data on only ten subjects were available.

The justification for including this study rests on a number of considerations. The study is the first part of a series of studies carried out, all of which led to a questioning of the original studies carried out by Fleishman et al. The technique is that of 'exploratory' rather than 'confirmatory' factor analysis, and consequently the aim is to suggest direction to a series of studies. Nevertheless, there are statistical considerations which may dictate that factor analysis is not appropriate or that there are severe constraints on what may be concluded from the analysis. In the following section on the use of small samples it is hoped to show that the factor analysis of the data in the study is justified but only as part of an exploratory series of studies and not on its own.

Small sample considerations

The effect of sample size on a Principal Factor solution is difficult to assess. In none of the major texts on factor analysis is there a full scale statistical treatment of the topic, only in Cattell 1978 and Child 1970 is the topic even briefly discussed. It is assumed in all the texts that the sample size in the study is large, that is, greater than about 50 cases. If this condition is accepted then much valuable information will be lost and many areas of study where sample sizes are necessarily small, such as clinical and industrial studies, will not be accessible to the factor analyst using the R technique (Cattell 1978, p. 324) which has been used in all the studies discussed here.

However, because there has been little research on this topic it is not the case that factor analysis of small samples should not be carried out, albeit with great caution. Correlation coefficients may be calculated for any size sample, but the magnitude of the correlation coefficient which is accepted as 'significant' depends on the probability of obtaining that value by chance, rather than as the result of there being a relationship. The 'popular' levels of probability are $p \leq 0.05$ and $p \leq 0.01$ and these denote our confidence in the correlation coefficient being not due to chance.

Therefore, when some sources state a particular number below which they say the sample size should not fall, it is an arbitrary value which should be accompanied by details of the significance levels which have been accepted and how the relationship between the two has been calculated. For example, Child (1970, p. 40) says "with small samples (30 or less) the correlation coefficients are quite unstable. The addition or omission of two or three individuals' scores can make a noticeable difference to the correlation value." But this problem is just the kind of effect which significance levels cope with. The question remains of what level of confidence may be associated with the factor pattern obtained.

Cattell (1978) discusses in some detail the problems of small samples. He says (1978, p. 488):

> "If one then asks why is it not as good in general practice to do a factor analysis on a small sample as on a large one . . .

> the answer is (a) as we have seen that the sizes of factors and correlations among factors will 'wobble' to the determinable extent of correlations on a small sample and make inferences to the population on these matters uncertain to the extent; and (b) the hyperplane is also likely to get more blurred . . . and make simple structure more difficult to find."

Earlier Cattell (1978, p. 487) explains that "the real danger" with small samples is that "a common error factor with small N may come to assume a magnitude that places it in the ranks, as regards size, of substantive factors . . . . Nevertheless . . . the true influence factors will keep their number and their loadings down to quite small samples."

A more serious problem arises if a higher-order factor structure is required but that is not the case in the studies reported in this research. This research involves only an initial factor structure which is then rotated. The latter is not affected seriously by small samples, as Cattell (1978, p. 492) says, "Granted that skilled rotation has been able to set aside common error factors, small samples should yield true factor patterns as reliably as in large samples."

Cattell discusses other considerations of sample size, its relationship with the number of factors to be extracted, that is, number of subjects should be greater than 2^k where k is the number of factors extracted, and problems of generalising to the parent population.

However, there is very little hard evidence on the various aspects of small sample factor analysis and one of the few studies reported is an empirical analysis of the effect of sample size on eigenvalues, observed communalities, and factor loadings by Aleamoni (1973). From a sample of 2,322 subjects each with scores on 15 variables, 36 samples were randomly selected over 5 different levels of N. Three sets consisting of 10 samples each with N's equaling 17, 25 and 100; one set consisting of 5 samples of N = 400 and one sample with N = 1,600 were drawn from the sample population. The correlation matrices, principal-component factors, and quartimax and varimax rotated factors were obtained for each sample and for the original population. The results are shown in Exhibits 3.1 and 3.2 . If one is carrying out a confirmatory factor analysis then from the results of Aleamoni's study, samples of N = 400 are adequate to generalise to populations of N = 2,322 and indeed as Aleamoni concludes, "it may well be that N smaller than 400 (but certainly larger than 100) will be adequate." However, for exploratory factor analysis it may be seen that the final factor solution is very robust, even down to 17 subjects. The coefficients of congruence for the sample size of 17 are all on average significantly (at $p \leqslant .05$ level) congruent with the 2,322 population factor analysis and rotation.

In Exhibit 3.2 it can be seen that the Varimax solution consistently produced the highest coefficient of congruence and the coefficient of congruence for the 17 samples is .804 . This is very high and suggests that factor analysis in conjunction with the Varimax rotation is very 'robust', even for very small samples. For N = 400 samples Aleamoni concludes "the varimax rotation yielded identical factors . . . with an average of only one or two factors showing dissimilarity for the N of 100 and increasing to an average of three dissimilar factors for the N of 17." It should be noted that 6 factors were extracted and that the average number which were dissimilar was 2.6 for N = 17 as given in the table in Exhibit 3.2. Very probably those factors which showed some dissimilarity were the last factors to be extracted (factors 5 and 6 and sometimes 4) in the Principal

EXHIBIT 3.1

MEANS AND STANDARD DEVIATIONS OF EIGENVALUES FOR THE FIVE SETS OF SAMPLES

Aston University

Illustration removed for copyright restrictions

a Solution based on a single group   b Mean of solutions for 5 samples   c Mean of solutions for 10 samples

From Aleamoni 1973

Aston University

Illustration removed for copyright restrictions

Exhibit 3.2

From Aleamaris, 1973

Components analysis. What is important is the high similarity (congruence coefficients) of the final factor pattern between the N = 17 sample and the N = 2,322 population and this is probably especially true of the first three factors extracted. Therefore, from this study it can be seen that, for exploratory factor analysis, even a sample size of 17 produced valid factors for at least the first three or four factors.

One of the main relationships is that of sample size and the size of factor loadings which may be considered significant, but there has been little work in this area. As Harman (1976, p. 441) says, "The sampling distribution of statistics arising in factor analysis has been largely neglected during the rapid development of descriptive procedures . . . . Because of the lack of precise sampling error formulas for factor coefficients and residuals, approximation procedures were developed by Holzinger and Harman (1941, pp. 122-36)." The formula developed by the latter is:

$$\sigma = 1/2 \sqrt{(3/r - 2 - 5r + 4r^2)/N}$$

Tables which give these values for N = 20 to N = 500 and for r = 0.1 to r = 0.75 where r is the average value in the correlation matrix were calculated by Holzinger and Harman and are reproduced in Appendix 3 from Harman 1976 (p. 443). These values may be used for Principal Factor analysis and for rotated factor patterns, whereas the Burt-Banks formula (Child 1970, p. 99) is not suitable for finished rotated factors (Cattell 1976, p. 480).

Lastly, the relationship of sample size to the number of variables is important. Humphreys, Ilgen, McGrath and Montanelli (1969) say that as yet no minimum N can be specified but recommend that N should be as large as feasible and include the smallest number of variables which will still serve the purposes of the investigation. Cattell (1976, p. 508) states that the situation to be avoided is the square matrix, where the number of subjects is the same as the number of variables which he says results in specific and common factor space becoming confused. However, we have to turn to the few studies which have investigated this area empirically. A short review of these studies is given by Aleamoni (1976) who concludes that "Even though previous investigators have stated that no minumum N can be specified, if one is interested in maximising the number of possible dimensions underlying V (the number of variables), then N must be at least greater than V."

From the foregoing it would appear that there is little statistical basis to produce guidelines for the effect of sample size on the factor analysis and subsequent rotations and that the few empirical studies carried out suggest that, at least for the first two or three factors extracted, sample sizes as low as 17 can be used. This is especially appropriate when the factor analysis is exploratory rather than confirmatory. There are few statistically based methods of determining the significance levels for particular factor loadings (coefficients) but for unrotated factor loadings the Burt-Banks formula may be used, and for rotated factor loadings the Holzinger-Harman formula may be used.

The following factor analysis of 10 subjects is accepted as being extremely marginal even for exploratory factor analysis but nevertheless is included because of the above findings in empirical studies, and because of the part it played mainly by raising a number of questions in the series of studies carried out.

Study of trainee sewing machinists

As previously described, the job chosen for investigation to assess the validity and usefulness of Fleishman's conclusions from his programme of studies for different types of tasks and for a different population was that of the sewing machinist.

The task and situation is representative of many found in industry. It also required a length of training which was not so short that training was of little importance and yet not so lengthy that the subjects would never get near to experienced worker standard in the time available.

Procedure

The first step was to visit the factory and study the selection and training procedures and shop floor work.

Every applicant for the job of sewing machinist was given a number of tests and an interview. The tests were basic tests from the N.I.I.P and some others which had been produced by a consultancy company. There was a new policy on training which meant that the subject spent only three to four days in basic training and then went straight on to the shop floor. Every day their performance was rated by the supervisor on the basis of the quantity and quality of their work and they were paid according to the average of the five ratings each week.

It was decided that the existing tests were inappropriate for the technique which was to be applied because they were not derived from factor analytic studies and were therefore likely to be multi-factorial.

From the work by Fleishman (1967) and from studying the task and talking with the training officer and supervisors, five tests were selected from those developed in Theologus, Romashko and Fleishman (1970) and Theologus, Fleishman (1971), and used with a sixth test similar to the Gibson spiral maze - the self-paced Spiral Maze test. The tests were:

1. The Self-paced Spiral Maze test
2. Perceptual speed
3. Pursuit aiming
4. Steadiness
5. Discrimination Reaction Time-printed
6. Minnesota Rate of Manipulation

Details of the tests with their reliabilities are given in Appendix 2.

It is necessary to ensure, when carrying out a factor analysis, that there is no serious non-linearity between the variables from which the correlation matrix is derived. This condition is required because as Gorsuch (1974, p. 12) says "factor analysis can be approached as one method of analysing data within the broader multivariate linear model" and later Gorsuch (1974, p. 15) says "If non-linear relationships are involved, no statistical analysis within the linear model is truly adequate."

Scattergrams were plotted for the variables in all the three studies and, although with the small samples it was not easy to discriminate, there appeared to be no serious non-linearity which would have meant that the data was inappropriate for factor analysis. (Examples are shown in Appendix 6.) This finding is not surprising as the same tests were also used by Fleishman and none of his data is reported as showing serious non-linearity.

Method

The six tests were given to the applicant along with the other tests which were normally used by the personnel officer. Twelve subjects were given the tests; however, two dropped out within two weeks. The daily ratings and the average of those for each week, as computed by the Work Study Department, were obtained for the remaining ten subjects over an eleven week period. These ratings were exclusive of the four days of basic training (Exhibit 3.3).

Analysis

The six tests gave nine measures (Exhibit 3.3) and these together with the eleven performance measures were intercorrelated. The significance level for a Pearson product-moment correlation coefficient with sample size of 10 and $p \leqslant 0.05$ is 0.576. The intercorrelation matrix (Exhibit 3.4) was inspected for correlations greater than 0.576 and those test variables which showed either no significant intercorrelations or only one with any other variables were excluded. This left only five test variables. In order to avoid a square matrix as discussed earlier, the eleven performance variables were reduced to four by selecting weeks 1, 5, 8 and 11.

The reduced intercorrelation matrix of 9 variables and 10 factors was then

Exhibit 3.3 — The performance ratings over the 11 weeks following basic training and raw scores on the test battery for the 10 subjects

SUBJECT	WEEK 1	2	3	4	5	6	7	8	9	10	11
A	22	36	37	42	51	63	67	87	95	100	100
B	33	40	44	49	52	58	66	75	74	68	72
C	33	52	50	52	51	65	64	81	98	93	78
D	52	66	71	70	84	80	76	81	90	86	73
E	24	40	52	81	76	81	85	80	101	108	73
F	36	54	48	58	57	69	82	85	87	76	91
G	26	24	25	41	36	48	50	33	56	38	23
H	19	31	35	49	39	14	30	35	53	75	69
I	17	23	25	16	18	23	25	18	28	22	28
J	18	26	47	32	37	52	65	72	68	76	84

Reference test scores prior to training as sewing machine operators

SUBJECT	Spiral Maze Time	Spiral Maze Errors	Perceptual Speed – Time	Perceptual Speed – Errors	(Pursuit) Aiming	Steadiness	Discrimination React. Time – Time	Discrimination React. Time – No. Correct	Minnesota Rate of Manipulation – Turning
A	57.5	9	182	7	86	30	56	25	32
B	63	7	75	10	74	29	44	10	33
C	67	6	126	9	86	53	44	26	31
D	41	6	129	10	77	37	45	27	36
E	63	3	202	11	84	31	35	12	27
F	90	6	144	4	71	27	105	28	36
G	105	5	384	4	66	23	99	26	26
H	31.5	7	245	8	86	39	107	25	30
I	106	3	174	6	67	26	78	24	30
J	57	7	149	7	49	31	40	21	33

Table 3.4 Correlation coefficients for the eleven performance variables and the nine reference test measures for the trainee sensory panel data

CORRELATION COEFFICIENTS..

	VAR001	VAR002	VAR003	VAR004	VAR005	VAR006	VAR007	VAR008	9	VAR010
VAR001	1.00000	.90549	.76214	.58992	.73458	.64495	.55461	.50783	21	.26753
VAR002	.90540	1.00000	.85560	.74101	.81422	.70010	.65234	.69062	[illegible]	.55001
VAR003	.76214	.85560	1.00000	.72634	.86611	.74478	.73294	.74585	84	.66934
VAR004	.58992	.70101	.72634	1.00000	.93078	.71307	.72831	.68842	32	.72649
VAR005	.73455	.81422	.86611	.93078	1.00000	.84010	.81593	.74221	01	.74524
VAR006	.64495	.70010	.74478	.71307	.84010	1.00000	.95588	.85519	15	.65066
VAR007	.55461	.65234	.73294	.72831	.81593	.95588	1.00000	.99915	18	.71271
VAR008	.50783	.69062	.74585	.68802	.74221	.85519	.99915	1.00000	85	.83729
VAR009	.58541	.70298	.71084	.76432	.82201	.87815	.88518	.93085	08	.90345
VAR010	.26758	.55001	.66934	.72649	.74524	.65066	.71271	.83729	45	1.00000
VAR011	.21610	.50497	.57175	.40863	.54512	.49180	.63457	.85739	08	.83823
VAR012	-.19825	-.34976	-.56724	-.44213	-.48410	-.11422	-.18757	-.40367	72	-.68044
VAR013	.08335	.13058	.12638	-.08801	.04043	.02243	.12707	.42313	74	.37202
VAR014	-.36596	-.52781	-.58281	-.12593	-.31277	-.34467	-.37551	-.58573	95	-.35854
VAR015	.27223	.38103	.68331	.55765	.59413	.35884	.30512	.39673	83	.55690
VAR016	.19910	.40624	.16406	.51973	.42771	.15516	.09075	.23455	67	.53190
VAR017	.25928	.46955	.44023	.27473	.24913	.10644	.04829	.29292	21	.49426
VAR018	-.18987	-.25836	-.56447	-.20978	-.44970	-.58104	-.49936	-.57532	66	-.51711
VAR019	.16806	.17475	-.07630	-.24023	-.18616	-.10741	-.24469	-.17725	94	-.19102
VAR020	.58574	.64361	.59841	.09765	.32980	.30851	.37706	.53807	7[illegible]	.22762

	VAR011	VAR012	VAR013	VAR014	VAR015	VAR016	VAR017	VAR018	9	VAR020
VAR001	.21610	-.19825	.08335	-.36596	.27223	.19910	.25928	-.18987	06	.58574
VAR002	.50407	-.34976	.13058	-.52781	.38103	.40624	.46955	-.25836	75	.64361
VAR003	.57175	-.56784	.10638	-.58281	.68331	.16406	.44023	-.56447	3[illegible]	.59841
VAR004	.40863	-.44213	-.08801	-.12593	.55765	.51973	.27473	-.26978	23	.09765
VAR005	.54512	-.48410	.04043	-.31277	.59413	.42771	.24913	-.44970	16	.32980
VAR006	.49180	-.11420	.02243	-.34467	.35884	.15516	.10644	-.58104	41	.30851
VAR007	.63457	-.18757	.12707	-.37551	.30512	.09075	.04829	-.49936	69	.37706
VAR008	.85739	-.40367	.42313	-.58573	.39673	.23455	.29292	-.57532	25	.53807
VAR009	.74108	-.39572	.28274	-.35895	.45283	.46087	.40221	-.52366	91	.27873
VAR010	.83823	-.68044	.37202	-.35854	.55690	.53198	.49426	-.51711	02	.22762
VAR011	1.00000	-.60867	.04514	-.58960	.38359	.27821	.34582	-.35784	98	.60287
VAR012	-.60857	1.00000	-.52388	.33278	-.67111	-.37144	-.53227	.35337	09	-.31332
VAR013	.04514	-.52338	1.00000	-.22271	-.03415	.11344	.19205	-.02832	35	.47308
VAR014	-.58960	.33278	-.22271	1.00000	-.49239	-.05356	-.33944	.56717	61	-.73140
VAR015	.38359	-.67111	-.03415	-.49239	1.00000	.45927	.58038	-.74737	45	.23518
VAR016	.27821	-.39144	.11344	-.05356	.45927	1.00000	.50445	-.02430	13	-.12643
VAR017	.34582	-.53227	.19205	-.33944	.58038	.50445	1.00000	-.30965	11	.13742
VAR018	-.35784	.35337	-.02832	.56717	-.74737	-.02430	-.30965	1.00000	11	-.12202
VAR019	[illegible]	.14[illegible]	.18[illegible]	[illegible]	[illegible]	[illegible]	.18511	.54181	[illegible]	[illegible]
VAR020	[illegible]	-.31[illegible]	[illegible]	[illegible]	[illegible]	-.126[illegible]	.13742	-.12202	[illegible]	1.[illegible]

subjected to a principal components' analysis and the eigenvalues plotted on a graph. Both the K-G criteria and the 'Scree test' determined the number of factors as five (Exhibit 3.5). However, from the principal factor analysis the fifth factor extracted contained no significant loadings and so the factor analysis and rotation were run with four factors extracted using the principal factor method and then a 'Varimax' rotation. The computations were carried out using 'S.P.S.S.'. The Principal Factor pattern and the 'Varimax' rotation solution are given in Exhibit 3.6 for both four factors extracted and five factors. Cattell (1978, p. 55, p. 69) holds the view that it is better to overfactor by one than underfactor by one. In this case the five factor pattern will be used (Exhibit 3.6B).

The size of factor loadings which may be considered to be statistically significant has been discussed earlier and it was noted that there is no conclusive method for determining such a value. However, Harman (1976, p. 154) does suggest that, as a rough estimate, the standard error of a factor coefficient (loading) may be determined by the method described in Appendix 3. Therefore for this analysis where $r = 0.463$ and $N = 10$, $\sigma = 0.2749$. However, because so little is known of small sample factor analysis it would be safer to accept only a loading of twice this value or more. Therefore to achieve greater confidence, only values of about 0.6 or greater will be accepted as significant.

The effect of extracting five factors rather than four was for the extra factor to split two factors and create a new factor with significant loadings on variables 8 and 11. These loadings are higher on the extra factor than when they were loading on two separate factors, which suggests that five factors better describe the underlying 'structure' than four factors (Exhibit 3.7A).

Exhibit 3.5 Scree test applied to Latent Root values for factors in Principal Components analysis of trainee sewing machinists study.

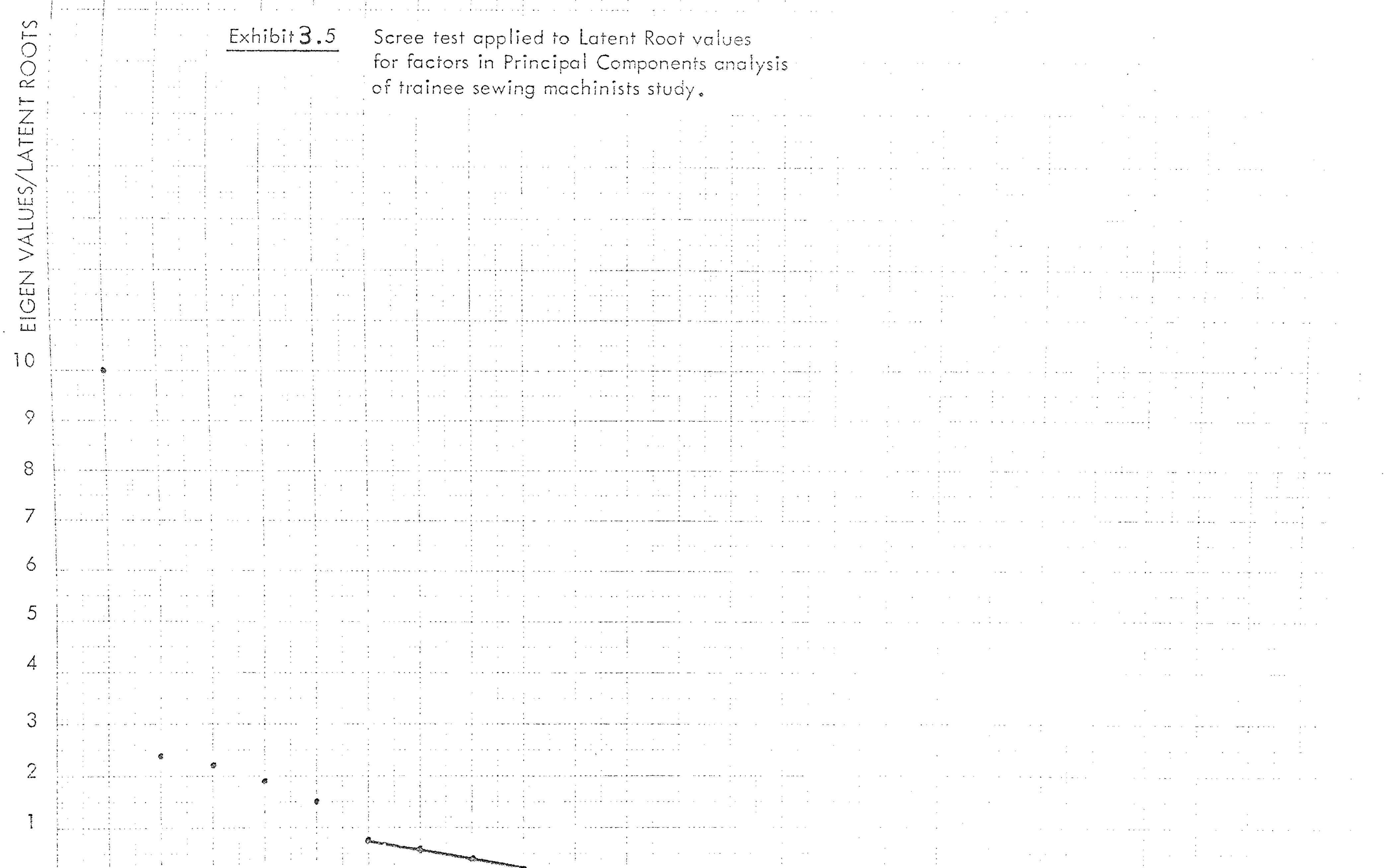


Exhibit 3.6A Analysis of trainee sewing machinist study with four factors extracted

FACTOR MATRIX USING PRINCIPAL FACTOR WITH ITERATIONS

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
VAR001	.61544	.32115	.64524	-.18351
VAR005	.79552	-.11207	.50408	.22066
VAR008	.84607	.10997	-.01824	.18951
VAR011	.80189	.20630	-.39026	.44679
VAR012	-.61032	.24024	.11012	-.22010
VAR014	-.76730	-.16082	.36100	.45675
VAR015	.67918	-.67882	.03421	-.15408
VAR018	-.63955	.45867	.12256	.22358
VAR023	.64441	.63724	-.10922	-.17035

VARIMAX ROTATED FACTOR MATRIX
AFTER ROTATION WITH KAISER NORMALIZATION

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
VAR001	.07238	.90848	.03229	.31669
VAR005	.40139	.77321	.43172	-.02258
VAR008	.29929	.39525	.63363	.34191
VAR011	.15074	.07525	.93476	.36792
VAR012	-.45249	-.13112	-.51519	-.05845
VAR014	-.43904	-.07630	-.21045	-.84848
VAR015	.93806	.19117	.17433	.00992
VAR018	-.77471	-.08654	-.17544	-.21439
VAR020	-.11133	.34126	.33847	.78668

Exhibit 3.6B Analysis of trainee sewi machinist study with fiv factors extracted

FACTOR MATRIX USING PRINCIPAL FACTOR WITH ITERATIONS

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
VAR001	.60845	.34198	.65172	-.09075	-.15755
VAR005	.78596	-.08661	.50214	.19782	.11703
VAR008	.88132	.14445	-.00929	.10171	.43946
VAR011	.79635	.19031	-.40672	.34860	.19719
VAR012	-.66216	.33153	.18524	-.44940	.42069
VAR014	-.75748	-.16618	.32532	.47187	.12772
VAR015	.68124	-.67537	.07340	-.14557	-.18434
VAR018	-.64758	.45759	.07554	.36749	-.21403
VAR020	.65006	.66331	-.14018	-.10845	-.27408

VARIMAX ROTATED FACTOR MATRIX
AFTER ROTATION WITH KAISER NORMALIZATION

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
VAR001	-.05963	.91110	.05105	.32896	.02208
VAR005	-.32337	.76982	.40382	-.02320	.26346
VAR008	-.33187	.39053	.82030	.25085	.05196
VAR011	-.10117	.04652	.84246	.37174	.35862
VAR012	.23103	-.11532	-.23957	-.13135	-.90571
VAR014	.49230	-.06915	-.23922	-.79797	-.07130
VAR015	-.82489	.22849	.01725	.01334	.49764
VAR018	.85028	-.09206	-.25732	-.11816	-.06082
VAR020	.12073	.31524	.28068	.57227	.12454

Exhibit 3.7A

	FACTORS			
	1	2	3	4
Week 1		.9085		
Week 5		.7732		
Week 8			.6336	
Week 11			.9348	
Spiral Maze				
Perc. Sp/Time				-.8485
Perc. Sp/Errors	.9381			
D. R. T.	-.7747			
M. R. M.				.7867

Exhibit 3.7B

	FACTORS				
	1	2	3	4	5
Week 1		.9111			
Week 5		.7698			
Week 8			.8203		
Week 11			.8425		
Spiral Maze					-.9057
Perc. Sp/Time			-.7980		
Perc. Sp/Errors	.8249				
D. R. T.	-.8503				
M. R. M.				.8723	

A is the factor analysis with four factors extracted; B is the factor analysis with five factors extracted. Only loadings greater than 0.6 are shown.

Interpretation and discussion

From Exhibit 3.7B the performance variables of weeks 1 and 5 are loaded on one factor and weeks 8 and 11 are loaded on another factor, and neither are loaded significantly on any of the test variables. The percentage of variance accounted for by each factor during the 11 weeks is:

Factor 2	Factor 3	Total
83%	0%	83%
59%	16%	75%
15%	67%	82%
0%	71%	71%

This indicates that there are two factors which account for most of the performance variance during the training of sewing machinists and that one factor is dominant during the initial stages, but is replaced by the other factor between the fifth and eighth week. However, none of the tests used identified either of these two factors.

This finding does support Fleishman's claim, as stated earlier, that the particular combinations of factors contributing to performance on a task change as practice on the task continues and also that the changes are progressive and systematic. However, the results did not allow for corroboration or otherwise of the further claims that eventually the ability pattern became stabilised, or that non-motor abilities are dominant early in learning and are supplanted by motor abilities, or that a factor specific to the task itself increases in contribution as learning continues.

The lack of any test variables being significantly loaded on factors 2 and 3 did not allow the latter claims to be tested. Neither could these two factors be identified as psychomotor abilities. The interpretation and identification of the other factors will be left to the re-analysis of Fleishman's studies in Chapter 7.

Conclusions

This study has suggested that Fleishman's findings of changes in factor contribution to performance during learning may generalise to "real life" training situations and to a wider population than trainees in the Air Force. However, the lack of any test variables significantly loading on the two factors which had performance variable loadings, and the small number of subjects involved means that this finding can be no more than a suggestion which requires further studies to corroborate the findings.

The Lego assembly study

The results from the study of the trainee sewing machinists in a factory, which did not completely corroborate Fleishman's findings, may well have been because of certain aspects of the experimental design. The number of subjects is one aspect and also the lack of control over some of the conditions which exist on the shop floor in a factory. Another possible source of error is the measure of performance for, although the ratings depended on quantity of material sewn, it also took into account the quality of the work and, though the ratings were carried out by a very experienced trainer, there may well have been systematic bias or some other error involved. For these reasons it was decided to carry out a study of learning a task in the laboratory. The task was designed to simulate a typical assembly task found in the electrical and light engineering industry. The aim was to carry out the study under controlled conditions.

Task

The task which was settled upon utilised the children's game of LEGO building blocks. These were chosen because of their availability and size. They require skill to position, a reasonable amount of pressure to assemble and finger dexterity rather than hand movement to manipulate.

All but one of the battery of tests used in the study reported in the study of sewing machinists were used to determine the change in skill pattern during the learning period.

Apparatus

Three hundred LEGO blocks were used. They consisted of 75 red, 75 blue, 75 white and 75 yellow blocks each measuring 3/8" x 5/8" x 1/2". The apparatus was fixed to a flat horizontal wood board measuring 80 cm wide by 45 cm deep and 2 cm thick. This was placed at 84 cm from the floor and the subject sat on a stool which was 65 cm from the floor.

A plastic base as supplied with LEGO blocks was cut into a 2 cm x 5 cm rectangle. This was to act as the 'Fixture Plate' onto which four blocks, one of each colour, were to be assembled. Four LEGO dispensers were constructed. These allowed only one block to be extracted at a time and automatically another dropped into the vacant place. Each of these dispensers could accommodate 25 blocks on their sides. To keep these 'topped up', four fillers were made which were similar to the dispensers but had no cutaway lower portion. All were made in aluminium box sections (Exhibit 3.8). A chute was constructed which allowed the subject to drop the completed four blocks into the slotted section where they slide down into a receptacle (Exhibit 3.9).

The four dispensers were fixed vertically onto a backboard 6.5" apart and the fixture plate was located centrally, about 8.5" from the backboard (Exhibit 3.10).

Transducer

A photoelectric cell was located at the top of the chute (Exhibit 3.9) which relayed to the computer the end of one assembly cycle and the beginning of the next.

Hardware

The computer used was a Digital Equipment Company 4K PDP8E with built-in real-time clock. The computer outputted onto a Model 33 ASR teletype and to a FACIT High Speed Punch which could punch up to 75 characters per second. Exhibit 3.11 is a schematic drawing of the logging system.

Exhibit 3.8

Part of the equipment used in the 'Lego' experiment.

The filler was used to 'top up' the dispenser.

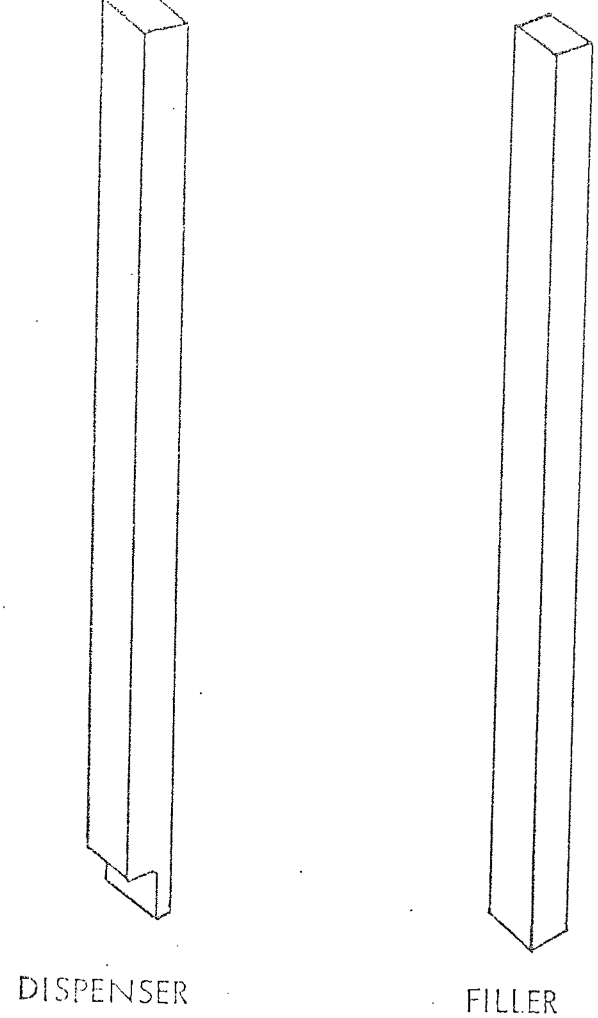
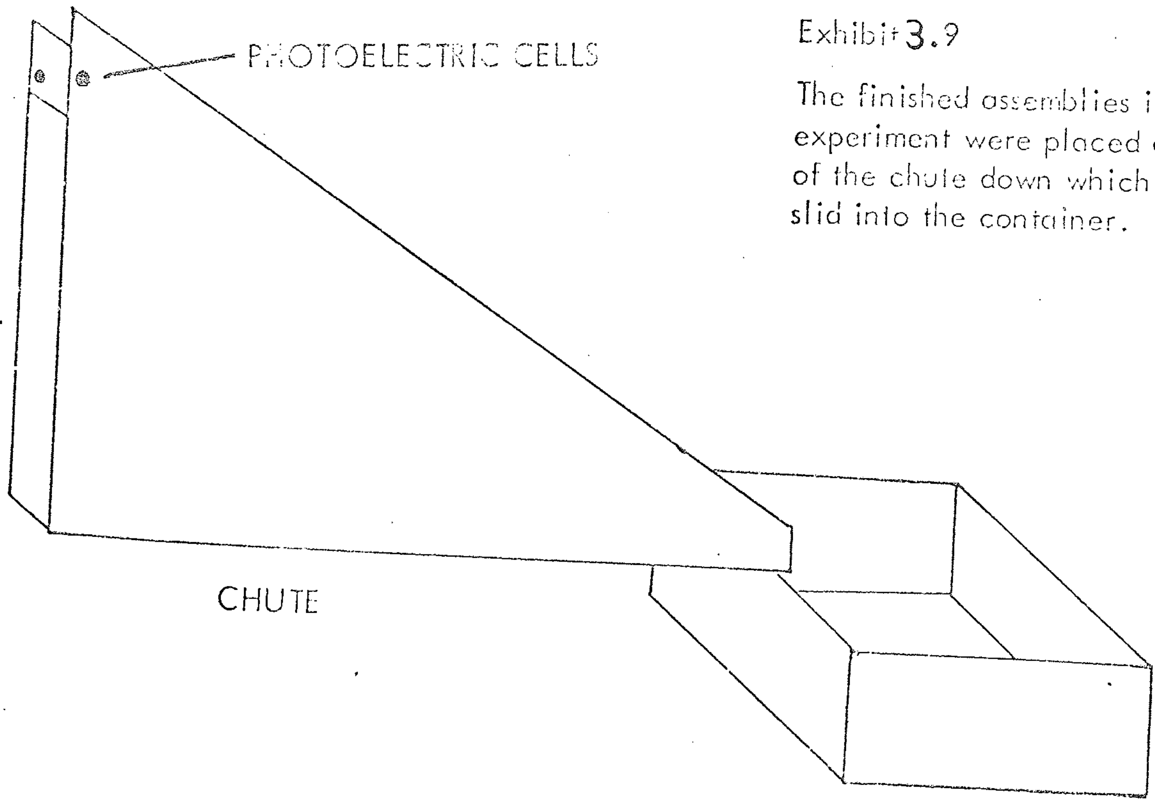


Exhibit 3.9

The finished assemblies in the 'Lego' experiment were placed at the top of the chute down which they then slid into the container.



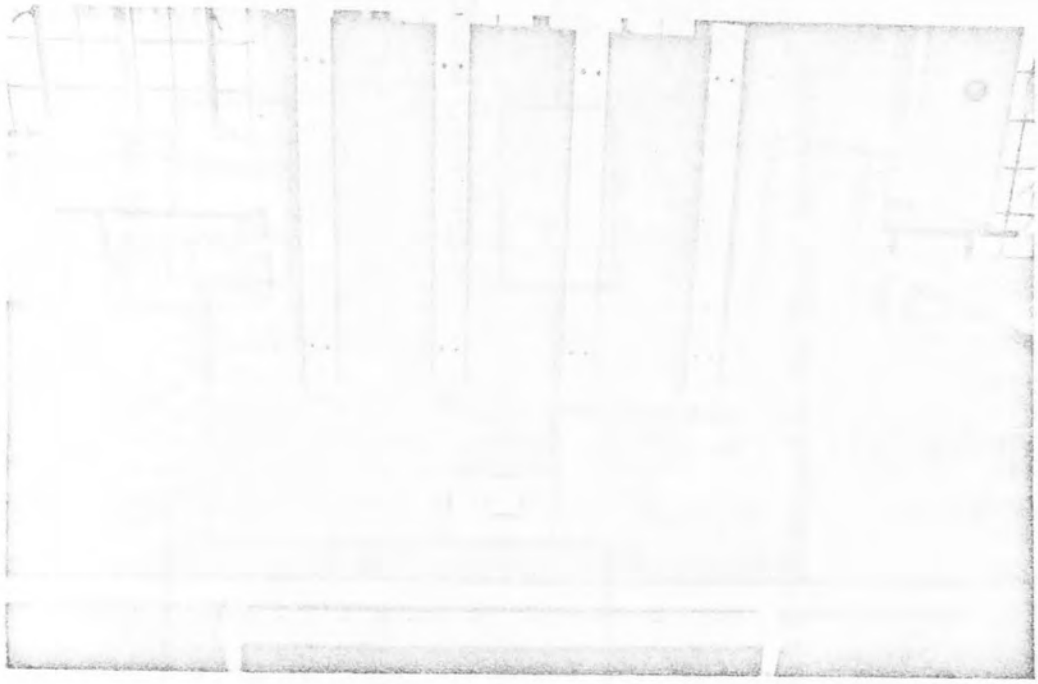


EXHIBIT 3.10

The apparatus for the 'Lego' experiment as seen by the subject. The four 'dispensers' at the back were covered by a large black board which has been removed to show the 'dispensers'. The plastic base on which the assemblies were constructed is seen in the centre foreground.

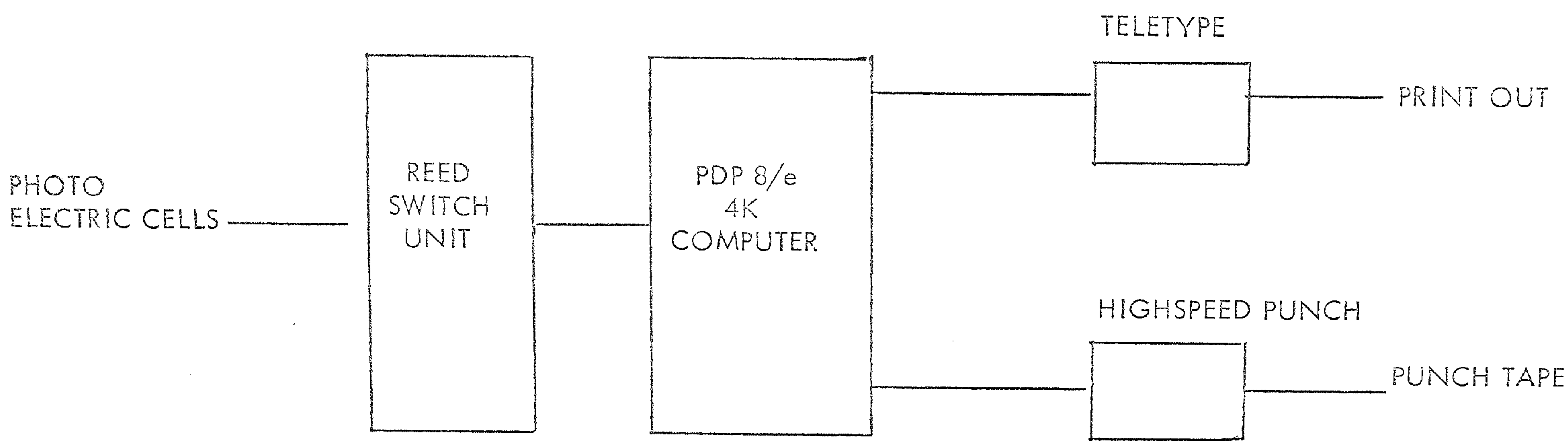


Exhibit 3.11 Schematic diagram of the DATA LOGGING SYSTEM used in the 'Lego' experiment

Tests

Five of the six tests which were used in the previous study were also used in this study. They were all paper and pencil tests. The one left out was the Minnesota Rate of Manipulation test, which is not a paper and pencil test, and was so similar to the task itself that it was felt that it might be misleading, or at least give no help in understanding the underlying processes of learning this task. The tests were (see Appendix 2):

1. Discrimination Reaction Time
2. Steadiness
3. Perceptual Speed
4. Rotary Pursuit
5. Aiming

Trial Group

Seven subjects were run prior to the running of the experimental group. These trial runs gave much information which allowed for modification of the procedures and the data recording. The first three subjects were asked to assemble the blocks and carry on for as long as they could. It was noticed that reports of fatigue started after about six to seven minutes, accompanied by complaints of the blocks having 'sharp' edges. The other four subjects were run in five minute sessions with about a minute's rest in between. This was found to be satisfactory. The time intervals of the cycles recorded by the computer were checked by a separate timing system using a digital timer.

Programming

The PDP8E has an interrupt system and a built-in real-time clock which greatly facilitated the writing of a data logging programme. When an event occurs an interrupt is activated, the channel number on which the event occurred is stored and the time at which it occurred is also stored.

Subjects

The subjects were ten men and eleven women, all between the ages of 18 and 30 except for one who was 45. None had any previous experience of assembly work in a factory. Their occupations were:

Postgraduate students (7)

Technicians (4)

University staff (3)

Doctor (1)

Secretaries (4)

Teachers (2)

Method

Testing:

The five tests were administered in the same manner as detailed in the previous study. The testing was carried out in a different room to the one in which the experiment was run.

Experiment

The room was blacked out and the lighting was controlled to give good illumination and yet at a low enough level for the photoelectric cell to work efficiently. The subject was seated at the table on which the apparatus was placed, as shown in Exhibit 3.12. The subject could not see the experimenter who worked behind the backboard refilling the dispensers and controlling the computer. The following instructions were given to each subject:

> "I want you to assemble four LEGO blocks, one on top of the other, and place the assembly into this chute. I want you to start with your left hand and take a red block from the far left dispenser and press it onto this base. Meanwhile your right hand should pick up a yellow block from the far right dispenser and press it onto the top of the red block. Meanwhile your left hand should go to the second dispenser from the left and get a blue block and press this onto the white block. This is the completed assemblage. This is then broken off from the base and placed in the chute with your right hand. Whilst your right hand does this your left hand should go to the far left dispenser to get a red block and so start assembling another four blocks.
>
> You must press the blocks together firmly and I want you to make as many assemblies as possible in the time available.
>
> There will be four sessions run of about five minutes each, with a one and a half minute rest in between each session.

EXHIBIT 3.12

A subject seated at the apparatus as used in the 'Lego' experiment. The backboard has been removed to show the 'dispensers'. The chute down which the completed assemblies were placed is to the right of the subject. The collection bin for the completed assemblies and the data logging apparatus is not shown.

Any questions?"

The subjects were also shown two lots of four blocks being assembled by the experimenter. A small payment was made to each subject.

The data and data analysis

The raw data event times were punched out by the High Speed Punch which was on line with the PDP8E Computer. The cycle times were computed from the time intervals between the events on the channel which was linked to the photoelectric cell on the chute. In the sense of output times per unit this was the proper measure of cycle time.

The data logging programme had been written in assembler language but the programmes for analysis were written in the much higher level language FOCAL. This is far more suitable for data manipulation. The programme which was written is shown in Appendix 5. This programme converted the raw data into cycle times.

Results and analysis

The five tests administered yielded 29 measures of performance (Exhibit 3.13) which reduced to 8 variables. The error scores on the Discrimination Reaction Time test were either 0 or 1 and consequently excluded. Trial 1 on the Steadiness test and trials 1 and 2 on the Pursuit Aiming test were excluded to allow for warm up effect. Where error scores are included, that is with the Perceptual Speed test and the Spiral

Exhibit 3.13 Raw scores for the battery of tests administered to the subjects and the average values of their cycle times on the assembly task (60 cycles per session)

Subject		Discrimination Reaction Time 1	2	Steadiness 1	2	3	Perceptual Speed 1	2	Spiral Maze 1	2	3	4	5	6	(Pursuit) Aiming 1	2	3	4	5	6	Lego assembly task average cycle time per session 1	2	3	4
A	Times	34	27	59	59	56	36	49	46	39	36	35	38	37	70	70	69	72	74	72	6.195	5.88	7.289	6.115
	Errors	1	0				3	2	3	1	3	4	9	1										
B	Times	43	33	30	29	37	47	43	71	60	63	47	50	51	67	69	69	70	69	72	6.424	5.218	4.92	4.64
	Errors	0	0				2	4	0	0	0	0	1	0										
C	Times	32	24	101	97	95	43	44	46	36	35	32	30	28	80	85	89	89	94	92	6.486	6.26	5.63	4.75
	Errors	0	0				0	0	1	3	6	1	7	6										
D	Times	28	24	98	107	75	38	39	42	35	30	28	27	28	74	73	77	85	82	81	7.2	6.11	5.677	5.233
	Errors	0	0				4	3	1	7	10	5	10	7										
E	Times	43	34	62	55	60	80	105	49	45	42	40	40	38	71	70	72	70	70	71	8.211	6.98	9.21	7.723
	Errors	0	0				3	1	0	0	0	1	3	1										
F	Times	52	44	50	42	45	85	80	75	60	63	63	60	54	47	44	33	43	36	49	8.954	8.669	9.315	8.487
	Errors	4	1				3	4	1	3	2	1	8	3										
G	Times	37	27	79	79	70	62	75	51	42	36	36	35	33	72	81	78	83	81	83	7.576	5.865	5.625	5.779
	Errors	0	0				0	1	6	1	2	2	4	4										
H	Times	46	35	52	60	72	43	49	40	35	33	28	30	30	70	72	70	71	67	75	8.64	5.986	6.083	5.85
	Errors	0	0				3	4	1	0	0	0	0	0										
I	Times	30	22	114	106	95	48	49	45	35	26	27	25	23	84	81	79	82	85	95	6.04	5.81	6.42	6.56
	Errors	0	0				1	3	3	7	4	8	4	8										
J	Times	36	25	58	44	43	72	52	58	56	53	52	55	55	75	74	75	79	75	73	6.385	7.327	6.95	6.62
	Errors	0	0				1	2	1	0	1	0	1	0										
K	Times	31	30	69	68	59	45	51	35	26	24	23	30	28	89	96	100	102	110	112	7.8	6.057	6.04	5.236
	Errors	7	0				1	2	2	8	10	10	7	0										
L	Times	41	29	32	51	62	62	58	58	50	46	49	44	43	72	67	70	66	65	72	6.152	5.628	6.28	6.7
	Errors	0	0				1	4	0	0	0	1	1	0										
M	Times	33	23	64	65	69	46	54	84	57	46	48	45	51	68	78	83	99	87	94	7.721	6.53	6.355	8.24
	Errors	0	0				2	1	0	0	2	4	1	1										
N	Times	42	35	57	72	113	53	52	73	54.	62	45	47	42	82	85	98	96	87	84	7.28	7.144	7.58	7.58
	Errors	1	1				2	8	0	3	4	2	4	2										
O	Times	32	26	46	56	56	41	37	48	50	49	54	56	50	70	72	68	67	72	75	6.38	7.046	5.612	5.66
	Errors	0	0				0	1	2	4	1	0	0	0										
P	Times	45	40	59	77	90	75	95	78	62	50	45	47	42	69	67	70	78	77	83	8.057	8.112	8.029	7.41
	Errors	0	0				0	0	0	1	1	4	1	6										
Q	Times	35	30	69	70	74	63	87	43	39	34	39	38	34	63	61	69	76	77	80	6.81	6.64	6.03	5.51
	Errors	0	0				3	1	1	0	1	2	2	2										
R	Times	38	30	22	39	37	75	88	66	60	63	66	56	57	67	65	60	71	71	70	5.94	6.23	5.93	5.53
	Errors	0	0				2	5	1	1	0	0	0	0										
S	Times	35	33	71	62	74	78	92	52	48	44	35	34	32	62	72	72	73	82	80	7.236	6.887	6.74	6.078
	Errors	0	1				9	2	1	1	3	3	2	1										
T	Times	25	27	101	114	93	39	51	45	37	32	26	28	22	76	83	82	84	88	91	7.365	6.13	5.859	5.832
	Errors	0	0				1	4	1	2	3	5	4	8										
U	Times	52	38	46	53	60	52	65	68	54	52	45	47	45	62	68	66	71	67	72	7.45	6.79	6.037	5.93
	Errors	0	0				3	1	0	2	1	1	0	0										

Maze test, they were taken from different trials from those which the performance times were taken. This is to ensure experimental independence of error and speed scores. Average scores over two or three trials were used, where appropriate, in order to minimise any short term 'nuisance' variable effects.

A total of eight reference test variables was used in the factor analysis together with the average times for the 80 cycles carried out in each of the four sessions. The final reference test raw data matrix which was used in the factor analysis with the four criterion task performance measures is shown in Exhibit 3.14.

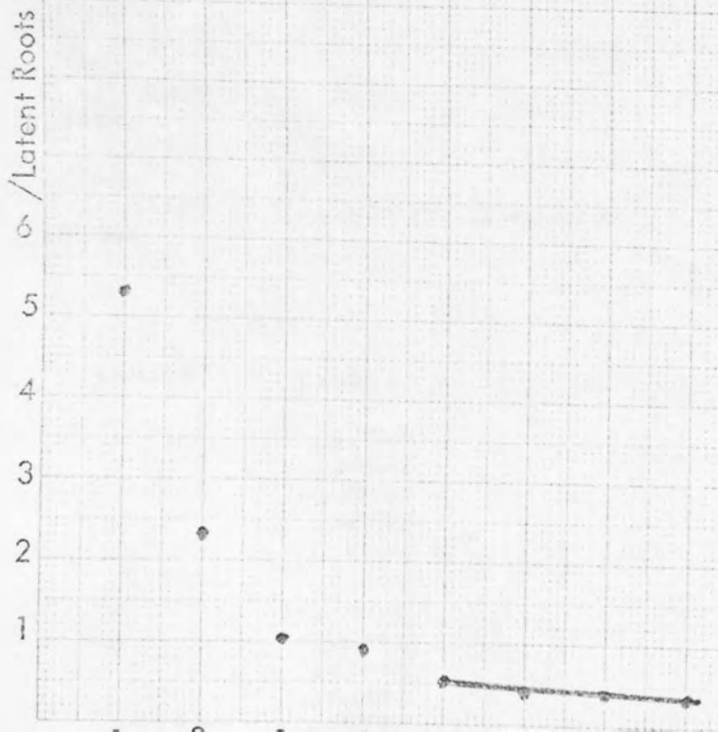
A principal factor analysis was carried out to determine the eigenvalues with communalities of 1.00 for each factor. Exhibit 3.15 shows a plot of the eigenvalues which, when the Scree test is applied, suggests 4 factors whereas the K-G criterion gives a cut off at 3 factors. Four factors were chosen to be extracted and a Principal Factor analysis was carried out followed by a 'Varimax' rotation using the S.P.S.S. computer programmes. Exhibit 3.16 is the intercorrelation matrix and Exhibit 3.17 shows the factor pattern produced by the Principal Factor analysis and the 'Varimax' rotation factor solution.

To identify those loadings which are statistically significant use will be made of Holzinger and Harman's (Appendix 3) equation to determine the standard error of factor coefficients. The average value r of the correlation matrix on which this factor analysis is based is 0.367 and from Appendix 3 with an N of 20 (in this analysis N = 21) the standard error of the factor coefficient = 0.258 . Therefore loadings of 0.3 or more are

Exhibit 3.14 Test data as used in the Factor Analysis

SUBJECT	Discrimination Reaction time		Steadiness	Perceptual Speed		Spiral Maze		(Pursuit) Aiming
	Time 1	Time 2	Average of trial 2 & 3	Speed	Errors Total	Average of trials 2, 4, 6	Average of trials 1, 3, 5	Average of trials 3,4,5,6
A	33	27	58	36	5	37	4	72
B	43	33	33	47	6	53	0	70
C	32	24	96	43	0	31	5	91
D	28	24	91	38	7	28	8	81
E	43	34	58	80	4	40	1	71
F	52	44	44	85	7	63	4	40
G	37	27	75	62	1	35	3	81
H	46	35	66	43	7	30	0	71
I	30	22	101	48	4	28	4	85
J	36	25	44	72	3	54	1	76
K	31	30	64	45	3	26	7	106
L	41	29	57	62	5	47	0	68
M	33	23	67	46	3	48	2	91
N	42	35	93	53	10	49	4	91
O	32	26	56	41	1	52	0	71
P	45	40	84	75	0	46	3	77
Q	35	30	72	63	4	37	1	76
R	38	30	38	75	7	61	0	68
S	35	33	68	78	11	36	2	77
T	25	27	104	39	5	27	5	86
U	52	38	57	52	4	48	1	69

Exhibit 3.15 Latent Roots of factors obtained from a principal components analysis of Lego assembly task data.



CORRELATION COEFFICIENTS..

1	VAR002 / VAR012	VAR003	VAR004	VAR005	VAR007	VAR008	VAR009	VAR010	VAR01
VAR002	1.00000	.85527	-.48457	.51191	.16157	.57313	-.46582	-.63630	.444 -
27	.46674								
VAR003	.85527	1.00000	-.31585	.54000	.29475	.41714	-.20223	-.54929	.608 -
11	.60909								
VAR004	-.48457	-.31585	1.00000	-.38402	-.11161	-.69947	.61374	.58069	.033 -
52	-.00225								
VAR005	.51191	.54000	-.38402	1.00000	.15288	.51533	-.34097	-.50015	.228 -
68	.67337								
VAR007	.16157	.29475	-.11161	.15288	1.00000	.10388	-.01465	-.22430	.033 -
51	.07414								
VAR008	.57313	.41714	-.69947	.51533	.10388	1.00000	-.55366	-.62064	-.034 -
73	.36620								
VAR009	-.46582	-.20223	.61374	-.34097	-.01465	-.55366	1.00000	.47123	.137 -
30	.11373								
VAR010	-.63630	-.54929	.58069	-.50015	-.22430	-.62064	.47123	1.00000	-.173 -
13	-.32469								
VAR011	.44427	.60811	.03352	.22868	.03351	-.03473	.13730	-.17313	1.000 -
00	.53635								
VAR012	.46674	.60909	-.00225	.67337	.07414	.36620	.11373	-.32469	.536 -
35	1.00000								
VAR013	.42249	.52872	-.09483	.59706	.10123	.31496	.02267	-.40805	.489 -
53	.77641								
VAR014	.42609	.39504	-.08097	.48792	.12119	.43882	-.10132	-.29702	.458 -
49	.66461								

	VAR013	VAR014
VAR002	.42249	.42609
VAR003	.52872	.39504
VAR004	-.09483	-.08097
VAR005	.59706	.48792
VAR007	.10123	.12119
VAR008	.31496	.43882
VAR009	.02267	-.10132
VAR010	-.40805	-.29702
VAR011	.48953	.45849
VAR012	.77641	.66461
VAR013	1.00000	.79679

Exhibit 3.16 Intercorrelation matrix of variables in the Lego assembly task-study. They are identified as:

VAR002	Discrimination Reaction Time Trial 1
VAR003	Discrimination Reaction Time Trial 2
VAR004	Steadiness
VAR005	Perceptual Speed
VAR007	Perceptual Speed Errors
VAR008	Spiral Maze
VA[illegible]	Spiral Maze Errors
VAR010	(Pursuit) Aiming
VAR011	Average cycle time Se
VAR012	Average cycle time Se
VAR013	Average cycle time Se
VAR014	Average cycle time Se

FACTOR MATRIX USING PRINCIPAL FACTOR WITH ITERATIONS

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
VAR002	.83184	-.17103	.33678	-.11360
VAR003	.84267	.11133	.51261	.14941
VAR004	-.49727	.65332	.02081	.03007
VAR005	.73794	-.00884	-.20787	.20771
VAR007	.20129	-.02902	.10582	.16594
VAR008	.69093	-.46922	-.26565	.00938
VAR009	-.38527	.66681	.04552	.17637
VAR010	-.69274	.33227	-.03238	-.06564
VAR011	.48532	.51038	.34790	-.25366
VAR012	.73562	.51307	-.17264	.19432
VAR013	.73234	.45206	-.27341	-.03765
VAR014	.67912	.35456	-.34255	-.26418

VARIMAX ROTATED FACTOR MATRIX
AFTER ROTATION WITH KAISER NORMALIZATION

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
VAR002	.25100	-.56377	.56025	.39091
VAR003	.29452	-.26283	.62439	.67963
VAR004	.00760	.80262	-.00392	-.17654
VAR005	.57765	-.38185	.01692	.38886
VAR007	.04728	-.08200	.05138	.26171
VAR008	.34969	-.77899	-.05366	.18721
VAR009	.06715	.78825	-.02001	-.00124
VAR010	-.24870	.61984	-.15319	-.35513
VAR011	.37966	.14367	.70610	.13431
VAR012	.82529	.04325	.19517	.38843
VAR013	.85663	-.06658	.23191	.15755
VAR014	.81909	-.17422	.25875	-.07637

Exhibit 3.17 Principal Factor analysis and Vari
rotation of Lego assembly task dat

significant but as Harman says, "knowing that the sampling errors are probably underestimated, a more stringent level of significance should be required" (Harman 1976, p. 441). Consequently loadings greater than or equal to 0.4 will be accepted as significant loadings and these are shown in Exhibit 3.18.

Discussion

The 'Varimax' rotation produced two factors with statistically significant loadings on the criterion task. The percentage variance accounted for by these two factors is:

		Factor 1	Factor 3
Session	1	14%	50%
	2	68%	4%
	3	73%	5%
	4	67%	7%

Factor 1 also has a significant loading with the times on the Perceptual Speed test, and Factor 3 has large loadings on both trials of the Discrimination Reaction Time test. The abilities which these marker tests involve will be discussed in Chapter 6 when more evidence is available.

From the table above it can be seen that there was a large change in factor contribution between the first and second sessions and that the contribution of both factors remained stable over the last three sessions. This gives support to Fleishman's conclusions that changes occur but factor

Exhibit 3.18

	FACTORS			
	1	2	3	4
DRT 1		-.564	.560	.391
DRT 2			.624	.680
Steadiness		.803		
Perceptual Speed	.578			
Perceptual Speed Errors				
Spiral Maze		-.779		
Spiral Maze Errors		.788		
Aiming		.620		
Session 1			.706	
Session 2	.825			
Session 3	.857			
Session 4	.819			

Loadings greater or equal to 0.4 in the Varimax rotation shown in Exhibit 3.17

contribution becomes stabilised eventually. If the changes were progressive and systematic, as Fleishman also claims, then this was not apparent. This would have taken place within the first session, if it took place at all.

The two other claims Fleishman makes, that there is a change from non-motor to motor ability dominance as practice continues and that there is an increase in a factor specific to the task, were not evident in this study. Although the identification of the factors has been left till later, the dominance of both factors throughout with their high loadings on the two non-motor tests and no evidence for the emergence of a factor specifc to the criterion task, suggests that these two other claims of Fleishman's do not always hold.

Conclusion

This study of an assembly task in controlled conditions gave results which corroborated Fleishman's findings that the factor contributions changed as practice continued and some evidence that these contributions stabilise in the latter part. However, though the assembly task required motor behaviour, the three tests which involved motor behaviour did not significantly load on the assembly task. That at least 67% of the variance was accounted for in the last three stages suggests that as far as the practice continued (320 cycles) there was no significant motor factor contribution, nor a factor specific to the task.

The Study of Trainee Typists

The study of sewing machinists and that of the Lego assembly task produced conflicting results and only partially corroborated the claims made by Fleishman regarding changes in factor contribution during learning. Again this may be the result of small samples or it may be because the length of the learning period was different in the two studies - the sewing machinists study was over a period of 11 weeks and the Lego assembly task took only about 35 to 40 minutes to complete. The latter was comparable with most of Fleishman's studies. To try and overcome these two aspects of the experimental design, a further study was undertaken of forty trainee typists over a period of about 41 weeks or 10 months between September and June (one subject dropped out during the course). This was part of a larger study which will be described in Chapter 4 (Exhibit 3.19).

Method

There were eleven measures of typing performance taken between September and the following June. Also nine measures were taken from the five tests administered making twenty variables in total (Exhibit 3.20) which were intercorrelated (Exhibit 3.21) and subjected to a Principal Components analysis. This produced eigenvalues (Exhibit 3.22) for each of the factors and, following Cattell (1978, p. 76), the eigenvalues were plotted and the 'Scree test' used to determine the number of factors. The data was then re-analysed using the Principal Factor method with six factors set to be extracted and a Varimax rotation carried out (Exhibit 3.23).

Exhibit 3.19 Experimental Design of study of 39 trainee typists and a control group of 35 domestic science students

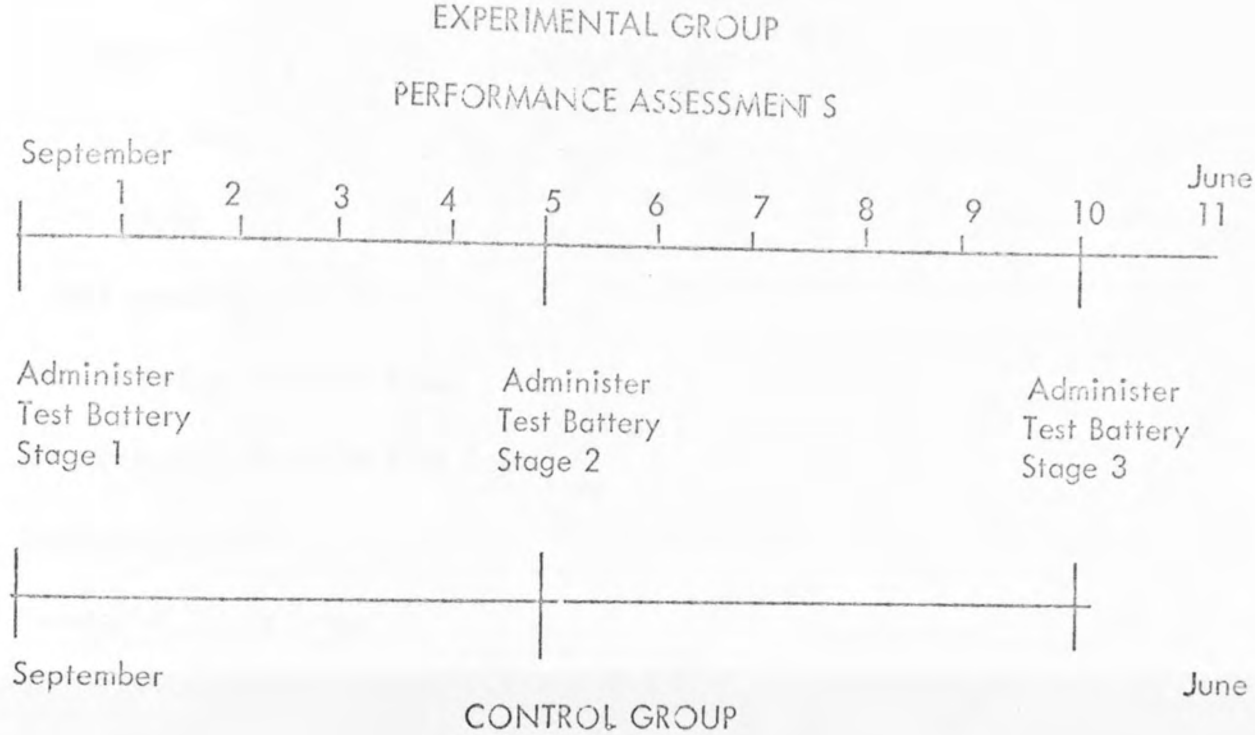


Exhibit 3.20 Reference tests used in study of trainee typists

(Pursuit) aiming

Steadiness

Steadiness Errors

Spiral Maze

Spiral Maze Errors

Discrimination Reaction Time

Discrimination Reaction Time Errors

Perceptual Speed

Perceptual Speed Errors

Ten performance measures were taken during the ten months together with the final Exam score.

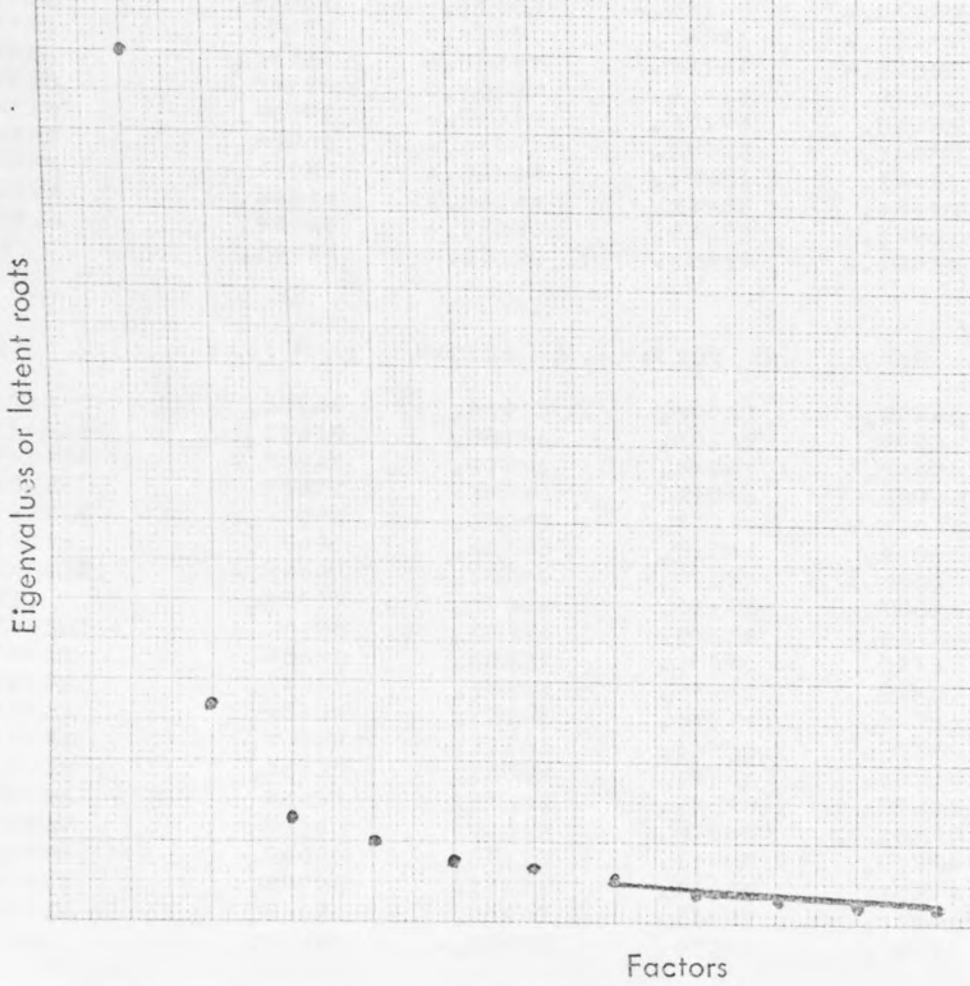
CORRELATION COEFFICIENTS..

Exhibit 3.21 Correlation coefficients of the intercorrelation of the nine reference test measures and the eleven criterion task performance scores for the 32 trainee typists.

	AIM04	STEAD04	ERRST04	SPIR04	ERRSP04	DCR01	ERRDCR01	PS01	ERRPS	01	PERF01
AIM04	1.00000	.61787	.44258	.31259	.08743	.50781	-.31894	.61741	.427	23	.46829
STEAD04	.61787	1.00000	.79346	.55135	.38166	.34868	-.24185	.42318	.158	00	.19018
ERRST04	.44258	.79346	1.00000	.38105	.49635	.15279	-.24198	.18610	.124	50	.00312
SPIR04	.31259	.55135	.38105	1.00000	.26450	.43240	-.30585	.42551	.148	69	.37927
ERRSP04	.08743	.38166	.49635	.26450	1.00000	-.18250	-.05527	.15797	.030	24	-.07083
DCR01	.50781	.34868	.15279	.43240	-.18250	1.00000	-.51166	.40430	.417	03	.70382
ERRDCR01	-.31894	-.24185	-.24198	-.30585	-.05527	-.51166	1.00000	-.25497	-.234	04	-.39280
PS01	.61741	.42318	.18610	.42551	.15797	.40430	-.25497	1.00000	.729	64	.50920
ERRPS01	.42723	.15800	.12450	.14869	.03024	.41703	-.23404	.72964	1.000	00	.50269
PERF01	.46829	.19018	.00312	.37927	-.07083	.70382	-.39280	.50920	.502	69	1.00000
PERF02	.48216	.25386	.07990	.45231	-.09107	.71933	-.39010	.50811	.463	51	.96331
PERF03	.42852	.23172	.06847	.39464	-.11785	.61806	-.32821	.41393	.350	60	.86173
PERF04	.45528	.25877	.07022	.41130	-.01837	.70604	-.44114	.40117	.376	78	.89617
PERF05	.50418	.27974	.04988	.32715	-.02839	.60392	-.36398	.44684	.392	23	.85572
PERF06	.41485	.26269	.06942	.44046	.01404	.70264	-.32884	.45064	.471	33	.90311
PERF07	.37080	.21799	.06091	.29130	.07637	.56246	-.35994	.34617	.327	19	.85771
PERF08	.42433	.22060	.02983	.32433	.03460	.54456	-.30711	.40427	.352	99	.87596
PERF09	.45644	.34342	.11323	.43513	.12442	.55269	-.38156	.40843	.29[illegible]	59	.81186
PERF10	.46916	.20890	.02293	.33444	-.01351	.60642	-.37450	.47916	[illegible]	17	.91491
EXAM	.26085	.13487	-.15392	.32591	-.09477	.54187	-.38982	.32515	.158	53	.69929

	PERF02	PERF03	PERF04	PERF05	PERF06	PERF07	PERF08	PERF09	PERF1	0	EXAM
AIM04	.48216	.42852	.45528	.50418	.41485	.37080	.42433	.45644	.469	16	.26085
STEAD04	.25386	.23172	.25877	.27974	.26269	.21799	.22060	.34342	.208	90	.13487
ERRST04	.07990	.06847	.07022	.04988	.06942	.06091	.02983	.11323	.022	93	-.15392
SPIR04	.45231	.39464	.41130	.32715	.44046	.29130	.32433	.43513	.33[illegible]	44	.32591
ERRSP04	-.09107	-.11785	-.01837	-.02839	.01404	.07637	.03460	.12442	-.01[illegible]	51	-.09477
DCR01	.71933	.61806	.70604	.60392	.70264	.56246	.54456	.55269	.606	42	.54187
ERRDCR01	-.39010	-.32821	-.44114	-.36398	-.32884	-.35994	-.30711	-.38156	-.374	50	-.38982
PS01	.50811	.41393	.40117	.44684	.45064	.34617	.40427	.40843	.479	16	.32515
ERRPS01	.46351	.35060	.37678	.39223	.47133	.32719	.35299	.29159	.465	17	.15853
PERF01	.96331	.86173	.89617	.85572	.90311	.85771	.87596	.81186	.914	91	.69929
PERF02	1.00000	.88985	.84933	.86554	.89440	.83884	.87878	.83340	.906	23	.69817
PERF03	.88985	1.00000	.82917	.81543	.83661	.82699	.83354	.78953	.841	23	.57164
PERF04	.84933	.82917	1.00000	.77805	.82107	.80279	.79861	.78246	.840	79	.58005
PERF05	.86554	.81543	.77805	1.00000	.85709	.79035	.89744	.78619	.837	12	.64375
PERF06	.89440	.83661	.82107	.85709	1.00000	.86105	.86057	.81482	.890	64	.65331
PERF07	.83884	.82699	.80279	.79035	.86105	1.00000	.88685	.89082	.886	58	.62837
PERF08	.87878	.83354	.79861	.89744	.86057	.88685	1.00000	.89702	.939	21	.70520
PERF09	.83340	.78953	.78246	.78619	.81482	.89082	.89702	1.00000	.913	49	.68406
PERF10	.90623	.84123	.84079	.83712	.89064	.88668	.93921	.91349	1.000	00	.71867
EXAM	.69817	.57164	.58005	.64375	.65331	.62837	.70520	.68406	.718	67	1.00000

Exhibit 3.22 Plot of the eigenvalues or latent roots and the application of the Scree test to the data from the trainee typist study



FACTOR MATRIX USING PRINCIPAL FACTOR WITH ITERATIONS

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6
IM04	.57002	.45488	-.21270	-.10354	-.17157	.26887
TEAD04	.37869	.82045	.17279	-.13105	-.01133	.19792
RRST04	.15428	.86121	.22930	-.03941	-.24723	-.12811
PIR04	.47639	.40156	.13414	-.12588	.34158	-.08968
RRSP04	.02305	.53118	.28203	.45556	.14925	-.19195
R01	.74330	.06129	-.14533	-.48483	.02492	-.14996
RDCR01	-.44715	-.14851	-.00749	.22821	-.08983	.15307
01	.57680	.37918	-.57034	.20462	.24376	.14067
RPS01	.49708	.17375	-.66789	.21173	-.10649	-.20441
RF01	.95365	-.17126	-.06832	-.00129	-.02078	-.08184
RF02	.95654	-.11463	-.02145	-.05682	-.00899	-.02545
RF03	.87872	-.13961	.06071	-.03817	-.11605	.01097
RF04	.88224	-.08781	.05107	-.09552	-.05166	-.13031
RF05	.88786	-.10530	.03410	.03522	-.09115	.11411
RF06	.92372	-.10312	.03194	.04005	-.00973	-.11441
RF07	.88352	-.15887	.20203	.16055	-.09850	-.06199
RF08	.91802	-.17894	.15951	.19451	-.06126	.12056
RF09	.89314	-.04144	.23948	.14109	.06480	.08614
RF10	.94501	-.16607	.03073	.14061	-.03577	.03611
XAM	.70484	-.23129	.10684	-.10051	.30689	.11944

Exhibit **3.23** Principal Factor and Varimax Rotation of data from the study of trainee typists

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6
IM04	.33589	.61915	.39663	.07748	-.14997	.08686
TEAD04	.11569	.88196	.09232	.20531	.19620	.14990
RRST04	-.05448	.82811	.02905	.14676	.34872	-.25384
SPIR04	.26027	.34710	.09086	.48474	.25976	.21886
RRSP04	-.03049	.29004	.03461	-.02886	.73607	-.00050
DCR01	.51499	.22743	.21784	.61585	-.29849	-.05279
RRDCR01	-.29523	-.18909	-.09937	-.41533	.00974	.01596
PS01	.26617	.26018	.81165	.14689	.08887	.30902
RRPS01	.26406	.05354	.83876	.10134	.00205	-.18689
ERF01	.88442	.02829	.28976	.27733	-.08083	-.01370
ERF02	.87317	.10993	.24286	.29722	-.09822	.03240
ERF03	.85130	.12846	.14174	.18786	-.11464	-.02497
ERF04	.80968	.11703	.15858	.33769	-.05861	-.07447
ERF05	.85705	.16390	.19131	.10839	-.09533	.06546
ERF06	.86463	.07344	.22380	.27426	.02650	-.02684
ERF07	.92280	.06818	.07805	.10592	.09780	-.05388
ERF08	.96840	.09110	.11958	.01458	.03617	.09929
ERF09	.88766	.17571	.06584	.13774	[illegible]	.16404
ERF10	.93174	.06097	.23[illegible]	.11642	[illegible]	.05964
XAM	.67465	-.05950	.022[illegible]	.30936	-[illegible]	.34658

Varimax rotation

Results

The results from the adminstration of the tests prior to the learning and from the performance measures on the criterion task of typing may be analysed in the same way that Fleishman used and that used in the two previous studies. Exhibit 3.23 shows the factor pattern from the Principal Factor Analysis and the 'Varimax' rotation solution. From the application of the 'Scree test' (Exhibit 3.22) six factors were determined to be common factors. To identify the size of loadings which may be taken as statistically significant, the formula given in Harman (1976, p. 441) can be used as in the previous two studies. The average value of the intercorrelation matrix (Exhibit 3.21) is 0.445 and from Harman's table shown in Appendix 3 with an N = 40 the standard error is 0.142. However, to be even more stringent, only loadings greater than or equal to 0.3 will be considered significant. Exhibit 3.24 shows those loadings which are greater than or equal to 0.3 for the Varimax rotation shown in Exhibit 3.23. The striking feature of the results is the dominance of one factor which accounts for between 66% and 92% of the variance of performance during the 9 months of training. Only 46% of the exam score variance is accounted for by this factor and small contributions of some 10% to 12% by two other factors. This suggests that the exam is not testing exactly the same abilities as the performance measures during the training, however that is not the focus of this study.

Factor 1 is also loaded moderately highly on the Discrimination Reaction Time test and also on Aiming. The interpretation and labelling of factors will be more thoroughly dealt with in Chapter 7, therefore for now it is sufficient to note these loadings. As far as Fleishman's claims regarding

Exhibit 3.24

	1	2	3	4	5	6
Aiming	.336	.619	.397			
Steadiness		.882				
Errors Steadiness		.828			.349	
Spiral Maze		.347		.485		
Errors Spiral Maze					.736	
Disc. React. Time	.515			.616		
Errors Disc. React. T.				.415		
Perceptual Speed			.812			.310
Errors Perc. Speed			.839			
Performance 1	.884					
" 2	.873					
" 3	.851					
" 4	.810			.338		
" 5	.857					
" 6	.865					
" 7	.923					
" 8	.960					
" 9	.888					
" 10	.932					
Exam	.675			.309		.347

Loadings greater or equal to 0.3

the results of his systematic programme of studies, these results do not corroborate them.

There is no change in the factors (abilities) contributing to performance on the task as practice continues and there is no evidence of a factor specific to the task itself. Consequently, there is no evidence of progressive and systematic changes which become stabilised, nor of a change from non-motor to motor abilites as practice continues.

Conclusions from the three studies

Changes in factor contribution during practice were found in two of the studies but not in the larger, longer term study. Even when changes occurred they were not consistent with Fleishman's conclusions. The reasons for the difference in findings between these three studies and those of Fleishman's may be because the type of training tasks used in the three studies were very different from the laboratory type tasks used in the vast majority of cases by Fleishman et al . . . . As well as the difference in type of training task there was a difference in the population used. As noted earlier, Fleishman's studies used mostly trainee Air Force personnel but also some University students, whereas the three studies reported here were mostly shop floor workers, secretaries and technicians, involving 105 subjects in all. There are also methodological differences. These include:

(a) The way that factors are interpreted in a study and shown to be the same as factors in other studies.

(b) The use of the more exact Principal Factor and Varimax methods instead of the approximate methods of factor analysis used by Fleishman and his co-workers in their studies.

To investigate the discrepancies between the findings in the three studies described above and the findings of Fleishman and his co-workers, it is necessary to re-assess the decision process and criteria used for the interpretation and comparison of factors by Fleishman and his co-workers in the light of current research and knowledge. The main sources used are Child (1970), Gorsuch (1974), Harman (1976) and Cattell (1978), though many others will also be used and cited. This re-assessment will be described in Chapter 5.

The study of trainee typists reported in this chapter was part of a larger experiment which was designed to test the changing task model of learning which was described by Alvares and Hulin (1972), who identified Fleishman's studies as examples of this model. The design of the typist study followed the suggestion of Lee Cronbach (1957) and Fleishman (1972) that there is a need for combining the experimental with the correlational study. This study is reported in the next chapter.

CHAPTER 4

AN EXPERIMENT TO ASSESS THE CHANGING TASK MODEL

The study of trainee typists described earlier in Chapter 3 was part of a larger study which was designed to assess the validity of one of the main assumptions made by Fleishman. This is the assumption that the basic abilities are overlearned and except for a small 're-learning' curve when they have not been practised for some time, there will be no significant change of performance level on those basic abilities (Fleishman 1964, pp. 8-14; Fleishman 1967, p. 351).

The model which Fleishman has developed is termed a "changing task" model by Alvares and Hulin (1972). In this model, abilities are conceived to be stable determinants of behaviour. This is not assumed in the changing subject model where ability measures are "little different from any other measure of current performance level" (Alvares and Hulin 1972, p. 305).

Fleishman's experimental design requires a battery of his psychomotor tests to be given before learning/training and then performance scores to be obtained at stages during the learning. If the assumption that the ability levels are remaining constant whilst their necessary contribution to task performance is changing does hold, then there is no problem with the experimental design. However, the design does not allow us to check or test the assumption of overlearning.

If the abilities are not overlearned, then some subjects may have a high degree of competence in an ability, whilst others may not have been exposed to tasks which develop this ability. If the latter group predominated in a study then the changes in abilities which Fleishman states take place during learning may be the acquisition of new abilities, and therefore a "changing subject model" (Alvares and Hulin 1972) would be required to understand the learning process.

If indeed the abilities are overlearned, then scores on the tests which identify the abilities in the factor analysis will show a significant correlation when given at the beginning of the learning (as Fleishman does) with scores on the same tests when given during or at the end of the learning of the criterion task. Further there should be no significant increase in the means of the scores obtained at the beginning and end of the learning.

Another possibility is that even if they are overlearned abilities, we might expect some change in test performance and thus the changing task model would still be appropriate. That is, differences in performance might occur because these abilities had not been practised lately. Consequently, the differences in performance might be the effect of short term learning which necessarily produces a short but sharp learning curve. To overcome this confounding we can use a control group of matched subjects who are not, however, undergoing similar training. This is important because, if the assumption does not hold, then practice on the criterion task may also influence ability measures in such a way as to affect the variance of certain of the test scores. Thus, the control group must not be learning a task which will affect the ability measures.

Method

The training task chosen was that of typing because it is a psychomotor task which is learnt under the same environmental conditions over a long period, in this case 41 weeks, and there are regular performance assessments carried out. Access was gained to a group of 40 trainee typists on a secretarial course at a local college. One of the subjects subsequently dropped out and thus the experimental group consisted of 39 subjects.

The control group was chosen from the same college and consisted of 35 girls of similar age but who did not do any typing. The course allocated as the control group was a nine-month domestic science course. The students in all the groups came from similar residential areas and were of similar age (about 16/17 years). All were girls.

The tests used were four tasks used by Fleishman in his identification of basic psychomotor abilities in 1954 and described by Theologus and Fleishman (1971). Another task, similar to the Gibson Spiral Maze (Gibson 1965), was used as a printed substitute for the Rotary Pursuit task. The latter was used by Fleishman et al but it requires apparatus and it was not possible to administer the tests individually and, therefore, the Spiral Maze test was used which requires movements similar to the Rotary Pursuit but uses pencil and paper and can be administered to a group. This is the same Spiral Maze test as used in the other two studies described in Chapter 3.

The five tests were the same as used in the other two studies of sewing machinists and the Lego assembly task. The following is a schematic representation of the experimental design, which is similar to an experimental design in Cattell 1978 (p. 358).

GROUP	September	February		June		
Experimental	All tests	5 Perf. Measures	All tests	5 Perf. Measures	All tests	Exam
Control	All tests		All tests		All tests	
	STAGE 1		STAGE 2		STAGE 3	

The performance measures were number of words correctly typed within a set time period.

Analysis and results

The scores on the tests for the first (Stage 1) test administration were correlated with the scores obtained from the final test administration (Stage 3). This was carried out for both the experimental group and the control group. 'Student's t' test was also applied to the two sets of scores to establish whether significant changes in the means had occurred. The correlations and the 'Student's t' value were also obtained for comparing the first with the second administration (Stage 2) and the second with the third administration of the tests (Stage 3). These results are shown in Exhibits 4.1 and 4.2 and an assessment is made of their statistical significance at $p \leqslant .05$.

The second part of the analysis was to subject the Stage 1 test scores together with the eleven performance scores to a factor analysis, then the Stage 2 scores together with the eleven performance scores and, finally, the Stage 3 scores together with the eleven performance scores. This would allow for an assessment of the stability of the factors over the

Exhibit 4.1 EXPERIMENTAL GROUP STAGE 1, STAGE 2, STAGE 3

TEST	STAGES	CORRELATION	P	SIGNIFICANCE at P ≤ .05	t VALUE	P	SIGNIFICANCE at P ≤ .05
AIMING	1 - 2	.763	.000	SIG	-4.11	.000	SIG
	2 - 3	.506	.001	SIG	-3.83	.000	SIG
	1 - 3	.669	.000	SIG	-7.89	.000	SIG
STEADINESS	1 - 2	.708	.000	SIG	-8.65	.000	SIG
	2 - 3	.598	.000	SIG	-1.17	.250	NS
	1 - 3	.664	.000	SIG	-9.51	.000	SIG
STEADINESS ERRORS	1 - 2	.536	.000	SIG	-4.00	.000	SIG
	2 - 3	.505	.001	SIG	- .08	.934	NS
	1 - 3	.684	.000	SIG	-4.23	.000	SIG
SPIRAL MAZE	1 - 2	.488	.002	SIG	-5.98	.000	SIG
	2 - 3	.487	.002	SIG	.82	.419	NS
	1 - 3	.264	.104	NS	-4.43	.000	SIG
SPIRAL MAZE ERRORS	1 - 2	.566	.000	SIG	-2.52	.016	SIG
	2 - 3	.571	.000	SIG	-3.60	.001	SIG
	1 - 3	.260	.109	NS	-4.92	.000	SIG
D R T	1 - 2	.397	.012	SIG	.57	.569	NS
	2 - 3	.608	.000	SIG	-2.46	.019	SIG
	1 - 3	.398	.012	SIG	- .77	.444	NS
D R T ERRORS	1 - 2	.652	.000	SIG	-2.89	.006	SIG
	2 - 3	.452	.004	SIG	1.40	.170	NS
	1 - 3	.351	.028	SIG	-1.10	.278	NS
PERCEPTUAL SPEED	1 - 2	.495	.001	SIG	-7.12	.000	SIG
	2 - 3	.216	.187	NS	-3.95	.000	SIG
	1 - 3	.386	.015	SIG	-10.01	.000	SIG
PERCEPTUAL SPEED ERRORS	1 - 2	.246	.131	NS	-5.23	.000	SIG
	2 - 3	.229	.161	NS	-3.16	.003	SIG
	1 - 3	.357	.026	SIG	-7.62	.000	SIG

Exhibit 4.2 CONTROL GROUP STAGE 1 = Pre course test administration, STAGE 2 = MID course test administration, STAGE 3 = END of course test administration

TEST	STAGES	CORRELATION	P	SIGNIFICANCE at P ≤ .05	t VALUE	P	SIGNIFICANCE at P ≤ .05
AIMING	1 - 2	.485	.003	SIG	.59	.556	NS
	2 - 3	.635	.000	SIG	-3.62	.001	SIG
	1 - 3	.283	.100	NS	-2.07	.046	SIG
STEADINESS	1 - 2	.782	.000	SIG	-1.42	.165	NS
	2 - 3	.700	.000	SIG	-4.05	.000	SIG
	1 - 3	.651	.000	SIG	-4.90	.000	SIG
STEADINESS ERRORS	1 - 2	.518	.001	SIG	- .61	.547	NS
	2 - 3	.599	.000	SIG	-3.62	.001	SIG
	1 - 3	.401	.017	SIG	-3.19	.003	SIG
SPIRAL MAZE	1 - 2	.559	.000	SIG	2.85	.007	SIG
	2 - 3	.728	.000	SIG	-1.83	.077	NS
	1 - 3	.544	.001	SIG	1.65	.109	NS
SPIRAL MAZE ERRORS	1 - 2	.273	.113	NS	-2.75	.010	SIG
	2 - 3	.703	.000	SIG	-2.22	.033	SIG
	1 - 3	.470	.004	SIG	-4.88	.000	SIG
D R T	1 - 2	.400	.017	SIG	.67	.509	NS
	2 - 3	.571	.000	SIG	-1.07	.293	NS
	1 - 3	.405	.016	SIG	- .03	.977	NS
D R T ERRORS	1 - 2	.254	.142	NS	.50	.619	NS
	2 - 3	.568	.000	SIG	.06	.951	NS
	1 - 3	.364	.031	SIG	.55	.589	NS
PERCEPTUAL SPEED	1 - 2	.546	.001	SIG	-7.13	.000	SIG
	2 - 3	.536	.001	SIG	1.54	.134	NS
	1 - 3	.154	.377	NS	-4.3	.000	SIG
PERCEPTUAL SPEED ERRORS	1 - 2	.271	.115	NS	-3.44	.002	SIG
	2 - 3	.419	.012	SIG	.33	.741	NS
	1 - 3	.181	.298	NS	-3.1	.004	SIG

learning period. The data were subjected to a Principal Components analysis to obtain the eigenvalues with communalities of unity. These were then plotted and the 'Scree test' applied (Exhibit 4.3). This was carried out to determine the number of common factors. The data was then re-analysed producing an intercorrelation matrix (Exhibit 4.4) and subjected to a Principal Factor analysis with the number of factors to be extracted set at that figure determined by the Scree test. The Principal Factor solution (Exhibit 4.5) was rotated using the 'Varimax' rotation method which produced a final pattern (Exhibit 4.6). This process was carried out for each of the three sets of data separately. The data was not combined into a "variable-tied design", as Cattell (1978) suggests that that design has "shortcomings".

Interpretation of results

In order to assess the similarity of the three sets of factor patterns, the congruence coefficient was calculated for all possible pairings of factors between the three factor patterns (Exhibit 4.7). The Scree test had accepted a different number of factors for each of the stages, that is, six for Stage 1, five for Stage 2 and seven for Stage 3. This suggests that if the factor patterns are similar then there are probably only four or five common factors. The Kaiser-Guttman criteria gave four factors for all three stages and, indeed, the seventh factor only contributes 2.8% of the variance, the sixth factor 3.3% of the variance, and the fifth factor only 4.2% of the variance, to Stage 3. Similarly for Stages 1 and 2 the fifth factor contributes a maximum of only 4.6% of the variance. However, the Scree test has been used in all the other studies and it is less damaging to

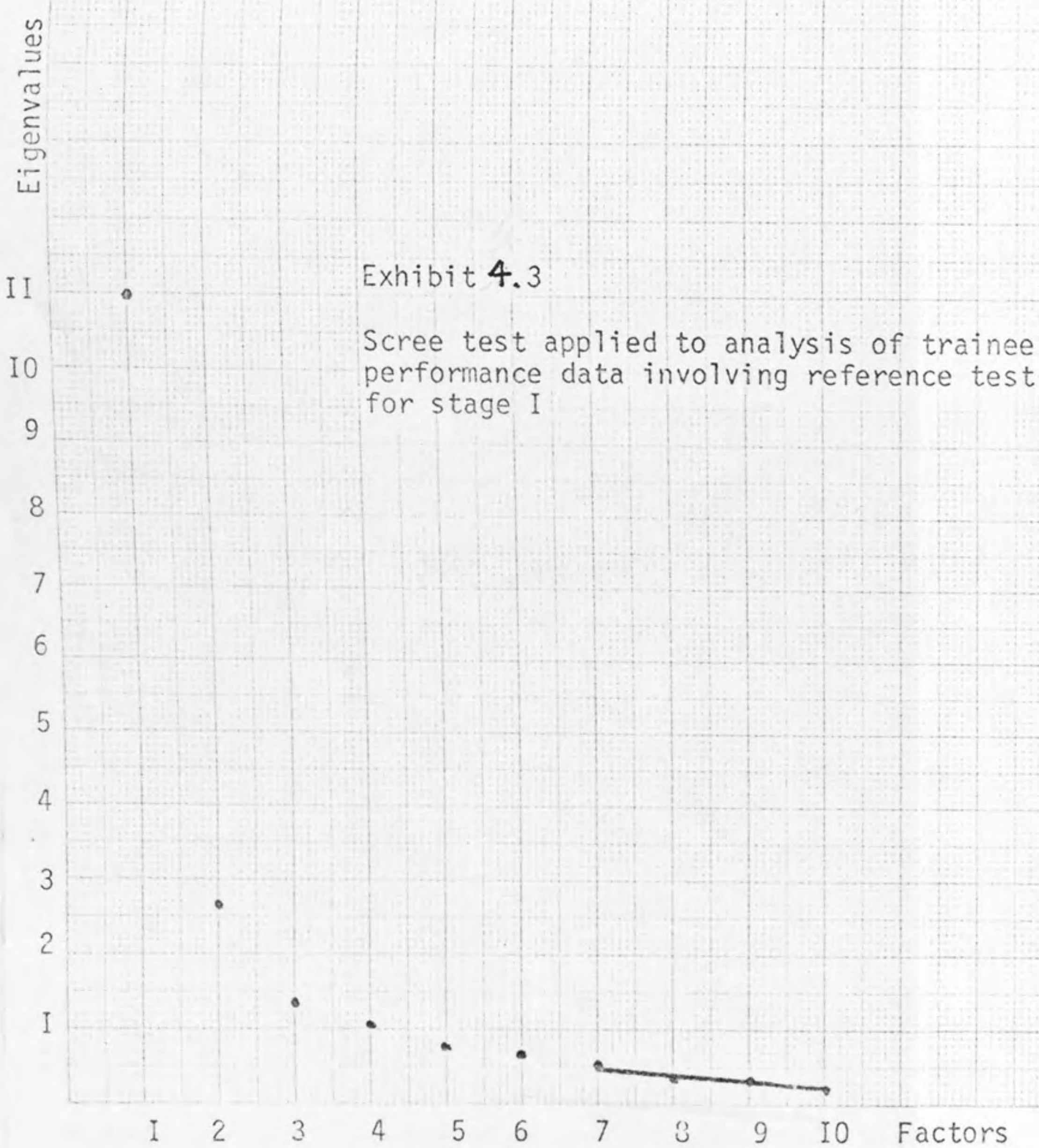


Exhibit 4.3

Scree test applied to analysis of trainee typist performance data involving reference test scores for stage I

Exhibit 4.3

Scree test applied to analysis of trainee typist performance data involving reference test scores for stage 2.

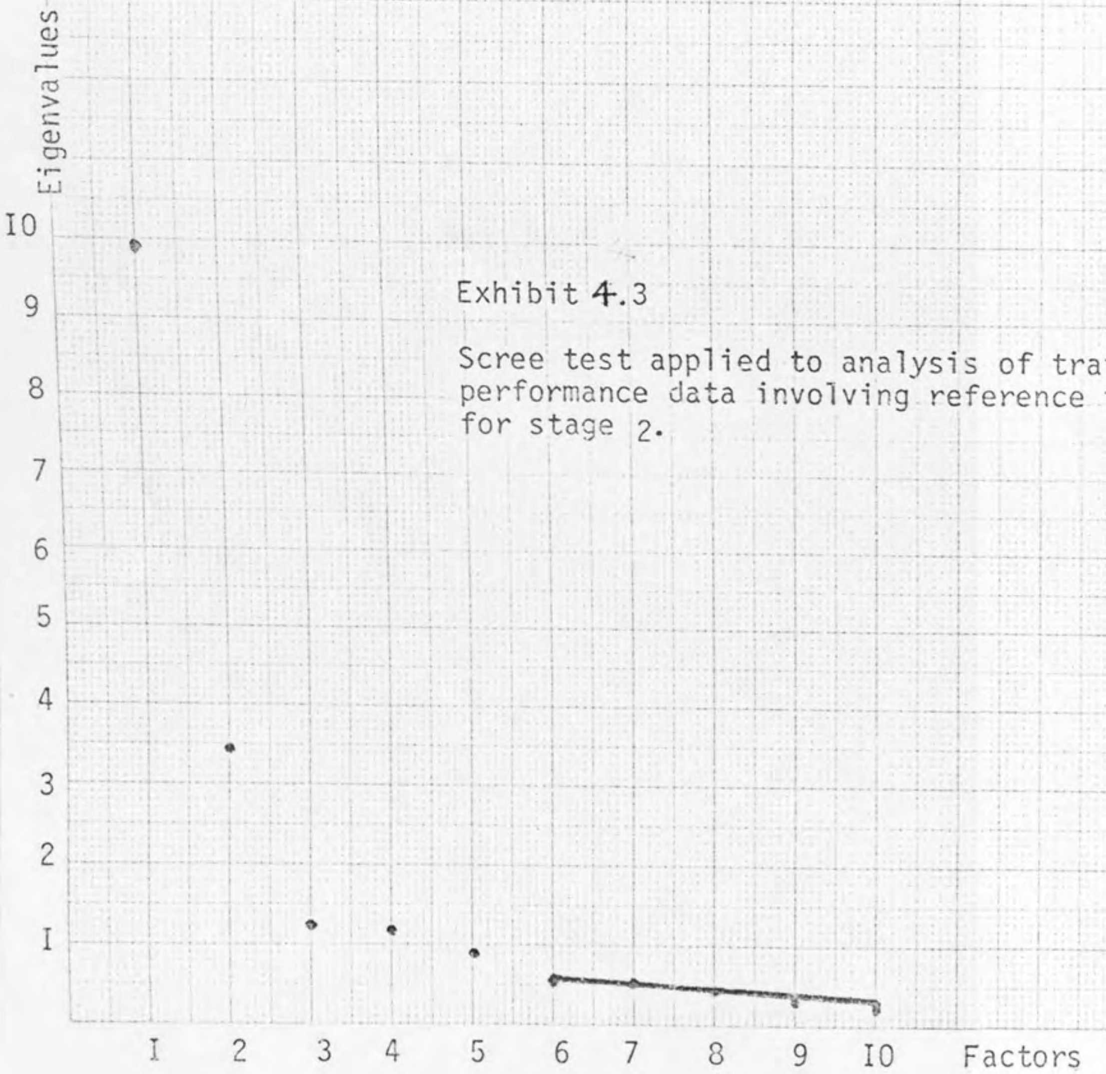


Exhibit 4.3

Scree test applied to analysis of trainee typist performance data involving reference test scores for stage 3

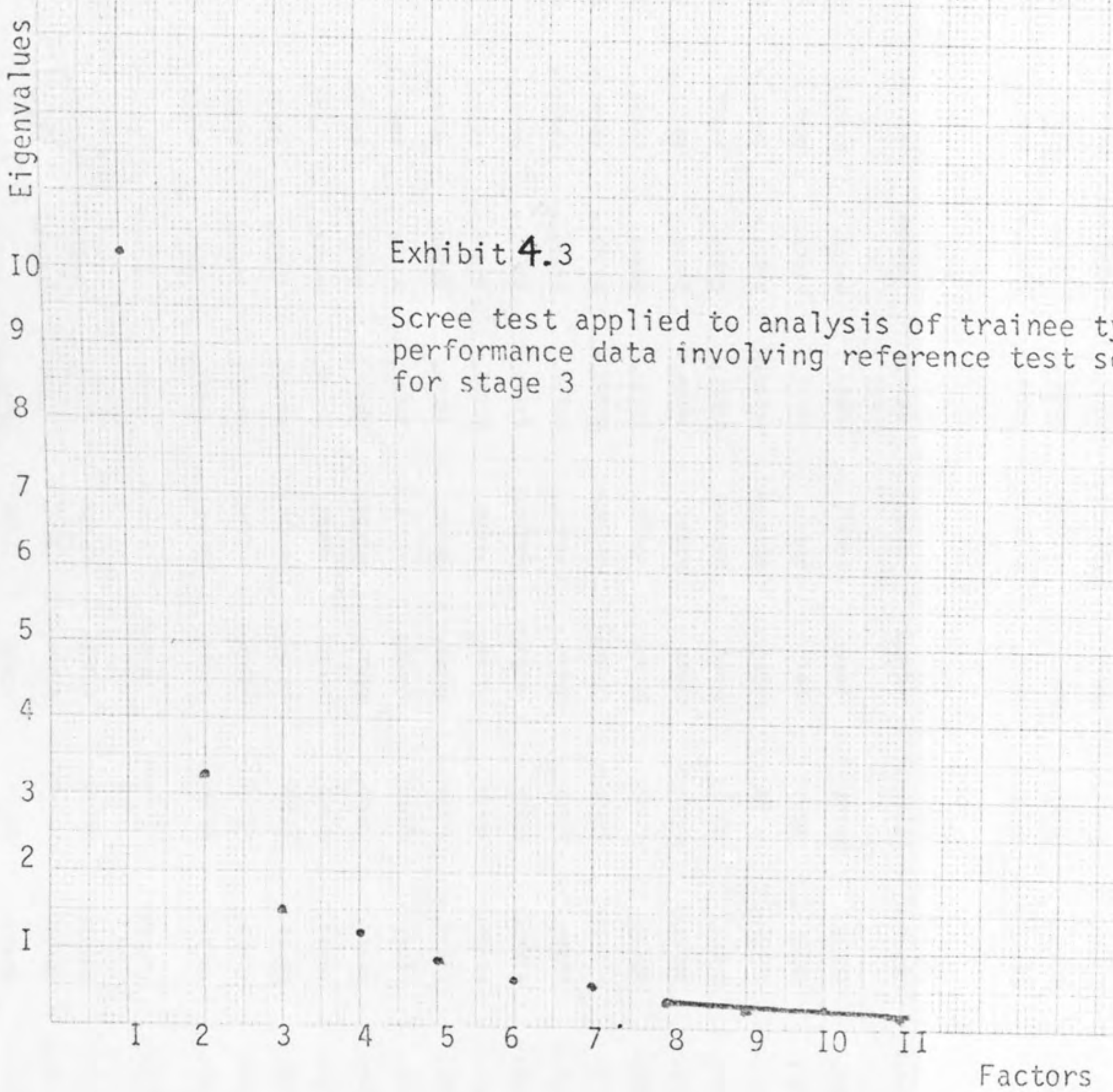


Exhibit 4.4 Correlation matrix for the experimental group of 39 typists involving reference test scores for Stage 2. Stage 1 correlation matrix is shown in …

	AIM08	STEAD08	ERRST08	SPIR08	ERRSP08	DCR05	ERRDCR05	PS05	ERRPS	05	PERF01
AIM08	1.00000	.57723	.27967	.66122	.29854	.41889	-.12867	.23195	.186	63	.63762
STEAD08	.57723	1.00000	.78977	.72591	.54052	.79201	.03256	.37093	.241	35	.21814
ERRST08	.27967	.78977	1.00000	.51882	.65800	.05890	.04479	.22679	.244	83	-.03785
SPIR08	.66122	.72591	.51882	1.00000	.54181	.14483	.15043	.28774	.262	18	.44190
ERRSP08	.29854	.54052	.65800	.54181	1.00000	-.00286	.07146	.25744	.206	25	.05187
DCR05	.41889	.29201	.05890	.14483	-.00286	1.00000	-.12632	.09365	.048	76	.22416
ERRDCR05	-.12867	.03256	.04479	.15043	.07146	-.12632	1.00000	.06478	.102	94	-.11007
PS05	.23195	.37093	.22679	.28774	.25744	.09365	.06478	1.00000	.478	17	-.12777
ERRPS05	.18663	.24135	.24483	.26218	.20625	.04875	.10294	.47817	1.000	00	-.09140
PERF01	.63762	.21814	-.03785	.44190	.05187	.22416	-.11007	-.12777	-.091	40	1.00000
PERF02	.60344	.23334	-.04698	.42712	.01522	.15747	-.13655	-.12779	-.103	85	.96331
PERF03	.49612	.12821	-.13447	.29575	-.12068	.11547	-.06980	-.13483	-.165	88	.86173
PERF04	.53266	.13479	-.12910	.34058	-.00668	.24050	-.11218	-.21458	-.266	66	.89617
PERF05	.56204	.20953	-.01334	.32387	-.06204	.16942	-.24572	.01885	-.080	73	.85572
PERF06	.55321	.16433	-.12130	.40588	.00809	.15857	-.01145	-.08938	-.042	90	.90311
PERF07	.53479	.11255	-.11745	.38802	.00913	.10449	-.06783	-.07255	-.037	54	.85771
PERF08	.55124	.19495	-.04746	.38232	-.08486	.08570	-.12276	.02872	-.042	12	.87596
PERF09	.54451	.22720	-.09149	.45409	-.04154	.11690	-.09894	-.00877	-.063	19	.81186
PERF10	.58125	.16701	-.13820	.38738	-.11169	.15869	-.10384	-.05471	-.051	10	.91491
EXAM	.41349	.11999	-.08658	.22717	-.18508	.22137	-.25220	-.05959	-.117	51	.69929

	PERF02	PERF03	PERF04	PERF05	PERF06	PERF07	PERF08	PERF09	PERF1	0	EXAM
AIM08	.60344	.49612	.53266	.56204	.55321	.53479	.55124	.54451	.581	25	.41349
STEAD08	.23334	.12821	.13479	.20953	.16433	.11255	.19495	.22720	.167	01	.11999
ERRST08	-.04698	-.13447	-.12910	-.01334	-.12130	-.11745	-.04746	-.09149	-.138	20	-.08658
SPIR08	.42712	.29575	.34058	.32387	.40588	.38802	.38232	.45409	.387	38	.22717
ERRSP08	.01522	-.12068	-.00668	-.06204	.00809	.00913	-.08486	-.04154	-.111	69	-.18508
DCR05	.15747	.11547	.24050	.16942	.15857	.10449	.08570	.11690	.158	69	.22137
ERRDCR05	-.13655	-.06980	-.11218	-.24572	-.01145	-.06783	-.12276	-.09894	-.103	84	-.25220
PS05	-.12779	-.13483	-.21458	.01885	-.08938	-.07255	.02872	-.00877	-.054	71	-.05959
ERRPS05	-.10385	-.16588	-.26666	-.08073	-.04290	-.03754	-.04212	-.06319	-.051	10	-.11751
PERF01	.96331	.86173	.89617	.85572	.90311	.85771	.87596	.81186	.914	91	.69929
PERF02	1.00000	.83985	.84933	.86554	.89440	.83884	.87878	.83340	.906	23	.69817
PERF03	.88985	1.00000	.82917	.81543	.83661	.82699	.83354	.78953	.841	23	.57164
PERF04	.84933	.82917	1.00000	.77825	.82107	.80279	.79861	.76246	.842	79	.58805
PERF05	.86554	.81543	.77825	1.00000	.85709	.79035	.89744	.78619	.837	12	.64375
PERF06	.89440	.83661	.82107	.85709	1.00000	.86105	.86057	.81482	.890	64	.65331
PERF07	.83884	.82699	.80279	.79835	.86105	1.00000	.88085	.89262	.886	68	.62837
PERF08	.87878	.83354	.79861	.89744	.86057	.88685	1.00000	.89702	.939	21	.78520

	PERF02	PERF03	PERF04	PERF05	PERF06	PERF07	PERF08	PERF09	PERF1	0	EXAM
PERF09	.83340	.78953	.76246	.78619	.81482	.89062	.89702	1.00000	.913	49	.68406
PERF10	.90623	.84123	.84279	.83712	.89064	.88668	.93021	.91349	1.000	00	.71867
EXAM	.69817	.57164	.58825	.64375	.65331	.62837	.78520	.68406	.718	67	1.00000

Exhibit 44 (continued) Correlation matrix for the experimental group of 32 typists involving reference test scores for Stage 3

	AIM12	STEAD12	ERRST12	SPIR12	ERRSP12	DCR09	ERRDCR09	PS01	ERRPS	09	PERF01
AIM12	1.00000	.68756	.31264	.40290	.30138	.59714	-.26249	.35214	.126	75	.24558
STEAD12	.68756	1.00000	.80338	.67726	.50671	.36483	-.06882	.26773	.050	45	.09985
ERRST12	.31264	.80338	1.00000	.53816	.62401	-.06029	-.03963	.22137	-.119	32	-.00441
SPIR12	.40290	.67726	.53816	1.00000	.45060	.29630	.32741	.38138	.106	16	.03127
ERRSP12	.30138	.50671	.62401	.45060	1.00000	.09171	-.20644	.35989	.300	14	.39635
DCR09	.59714	.36483	-.06029	.29630	.09171	1.00000	-.28669	.13539	.089	90	.18989
ERRDCR09	-.26249	-.06882	-.03963	.32741	-.20644	-.28669	1.00000	-.01372	.074	02	-.43915
PS01	.35214	.26773	.22137	.38138	.35989	.13539	-.01372	1.00000	.365	19	.50900
ERRPS09	.12675	.05745	-.11932	.10616	.30014	.08900	.07402	.36519	1.000	00	.44229
PERF01	.24558	.09985	-.00441	.03127	.39635	.18989	-.43918	.50900	.442	29	1.00000
PERF02	.29338	.17905	.08868	.07959	.41911	.17369	-.44600	.50811	.374	05	.96331
PERF03	.23311	.16325	.01563	.04943	.34853	.19769	-.33089	.41393	.359	91	.86173
PERF04	.31537	.15693	-.01719	.01617	.34850	.26339	-.38112	.40117	.448	50	.89617
PERF05	.26481	.13128	.01090	-.02154	.22797	.16562	-.38924	.44684	.265	99	.85572
PERF06	.24295	.10253	-.01015	-.00624	.36662	.22358	-.41905	.45064	.446	40	.90311
PERF07	.16583	.10841	-.04491	.06503	.28011	.22489	-.37062	.34617	.435	45	.85771
PERF08	.26894	.15497	-.03328	.08032	.25694	.24630	-.33727	.40427	.437	39	.87596
PERF09	.30359	.23531	.05107	.25079	.32851	.26033	-.25341	.40843	.392	47	.81186
PERF10	.28952	.08211	-.11371	.09973	.31513	.29812	-.34137	.47916	.454	86	.91491
EXAM	.06601	-.10435	-.13579	-.01584	.25807	.12970	-.30878	.32515	.279	47	.69929

	PERF02	PERF03	PERF04	PERF05	PERF06	PERF07	PERF08	PERF09	PERF1	0	EXAM
AIM12	.29338	.23311	.31537	.26481	.24295	.16583	.26894	.30359	.289	52	.06601
STEAD12	.17905	.16325	.15693	.13128	.10253	.10841	.15497	.23531	.082	11	-.10435
ERRST12	.08868	.01563	-.01719	.01090	-.01015	-.04491	-.03328	.05107	-.113	71	-.13579
SPIR12	.07959	.04943	.01617	-.02154	-.00624	.06503	.08032	.25079	.099	73	-.01584
ERRSP12	.41911	.34853	.34850	.22797	.36662	.28011	.25694	.32851	.315	13	.25807
DCR09	.17369	.19769	.26339	.16562	.22358	.22489	.24630	.26033	.298	12	.12970
ERRDCR09	-.44600	-.33089	-.38112	-.38924	-.41905	-.37062	-.33727	-.25341	-.341	37	-.30878
PS01	.50811	.41393	.40117	.44684	.45064	.34617	.40427	.40843	.479	16	.32515
ERRPS09	.37405	.35991	.44850	.26599	.44640	.43545	.43739	.39247	.454	86	.27947
PERF01	.96331	.86173	.89617	.85572	.90311	.85771	.87596	.81186	.914	91	.69929
PERF02	1.00000	.88985	.84033	.86554	.89440	.83884	.87878	.83340	.906	23	.69817
PERF03	.88985	1.00000	.82917	.81543	.83661	.82699	.83354	.78953	.841	23	.57164
PERF04	.84033	.82917	1.00000	.77805	.82107	.80279	.79861	.76246	.840	79	.58005
PERF05	.86554	.81543	.77805	1.00000	.85709	.79035	.80744	.78619	.837	12	.64375
PERF06	.89440	.83661	.82107	.85709	1.00000	.86105	.86057	.81482	.890	64	.65331
PERF07	.83884	.82699	.80279	.79035	.86105	1.00000	.88685	.89062	.886	08	.62837
PERF08	.87878	.83354	.79861	.80744	.86057	.88685	1.00000	.89702	.930	21	.70520
	PERF02	PERF03	PERF04	PERF05	PERF06	PERF07	PERF08	PERF09	PERF1	0	EXAM
PERF09	.83340	.78953	.76246	.78619	.81482	.89062	.89702	1.00000	.913	49	.68406
PERF10	.90023	.84123	[illegible]	.83710	.89084	.88688	.93021	.91340	1.000	00	.71067
EXAM	.69817	.57164	.58005	.64375	.65331	.62837	.70520	.68406	.710	67	1.00000

FACTOR MATRIX USING PRINCIPAL FACTOR WITH ITERATIONS FOR STAGE 2 REFERENCE TEST SCORES WITH TYPING PERFORMANCE SCORES. The equivalent factor matrix for Stage I may be seen in Exhibit 3.23.

EXHIBIT 4.5

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
AIM08	.66388	.47115	.10484	-.24760	.16403
STEAD08	.27623	.84995	-.09908	-.13456	-.05956
ERRST08	-.02524	.84072	-.31702	.00054	-.28285
SPIR08	.47865	.70370	-.04220	.16906	.16589
ERRSP08	.01199	.69065	-.23651	.15132	.03512
DCR05	.21442	.18076	.10432	-.56973	.25047
ERRDCR05	-.12745	.11229	-.00589	.38762	.30321
PS05	-.04217	.49729	.55181	.04984	-.05995
ERRPS05	-.06955	.42738	.44985	.13027	.02607
PERF01	.96367	-.02947	-.10347	-.02459	.08084
PERF02	.95588	-.04871	-.09599	.01070	-.01207
PERF03	.88098	-.16526	-.06975	.06895	.03051
PERF04	.88339	-.14294	-.22318	-.07211	.16310
PERF05	.89673	-.05283	.05716	-.07003	-.20776
PERF06	.92325	-.07380	.00940	.11890	.10438
PERF07	.90575	-.09079	.04275	.16965	.02754
PERF08	.94569	-.06771	.12898	.11503	-.20076
PERF09	.90223	-.04068	.08816	.10805	-.05424
PERF10	.95748	-.11161	.10162	.05385	-.00704
EXAM	.71382	-.13037	.07964	-.19681	-.17090

FACTOR MATRIX USING PRINCIPAL FACTOR WITH ITERATIONS FOR STAGE 3 REFERENCE TEST SCORES WITH TYPING PERFORMANCE SCORES

EXHIBIT 4.5

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6	FACTOR 7
AIM12	.36032	.57973	-.47137	.19850	-.12728	.02949	.19033
STEAD12	.23497	.91533	-.17526	-.03000	.18943	.19176	.03502
ERRST12	.06192	.83002	.16808	-.47009	.18723	.04442	-.01181
SPIR12	.14282	.76722	.21230	.34872	.14911	-.19285	-.11519
ERRSP12	.44177	.57797	.29219	-.28093	-.36310	-.05546	-.18721
DCR09	.29350	.27676	-.58041	.37644	-.12707	-.08089	-.13103
ERRDCR09	-.41294	.10007	.56193	.48887	.19915	.05334	.13763
PS01	.52705	.31959	.28704	.10622	-.31920	-.18813	.25218
ERRPS09	.45429	-.01261	.28710	.30666	-.29863	.33517	-.07867
PERF01	.95734	-.11687	.04809	-.08754	-.08190	.00848	.04801
PERF02	.95784	-.04443	.03604	-.14156	.03457	-.04592	.07778
PERF03	.88374	-.07814	.03004	-.04891	.07504	.08432	.05739
PERF04	.88154	-.07608	-.04489	-.00512	-.05941	.16834	.03072
PERF05	.88808	-.13259	-.04299	-.10054	.16268	-.07076	.26322
PERF06	.92468	-.12433	.01096	-.06026	-.03751	.06170	.01006
PERF07	.90240	-.14753	.02277	.02980	.14269	.10290	-.18185
PERF08	.93709	-.11776	-.00208	.07596	.16747	.01186	.00143
PERF09	.90632	.00886	.05245	.13751	.23464	-.06162	-.14867
PERF10	.95889	-.13317	.00666	.14174	.01657	-.06891	-.04373
EXAM	.70003	-.22348	.07129	-.01634	-.01664	-.25288	-.11527

EXHIBIT 4.6

VARIMAX ROTATED FACTOR MATRIX
AFTER ROTATION WITH KAISER NORMALIZATION
FOR STAGE 2 REFERENCE TESTS AND TYPING PERFORMANCE SCORES. The equivalent factor matrix for stage I may be seen in Exhibit 3.23

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
AIMØ8	.56026	.41128	.22555	.47671	.02738
STEADØ8	.14947	.82645	.24765	.24254	.06832
ERRSTØ8	-.12950	.91677	.09628	-.06344	.13201
SPIRØ8	.40695	.67517	.25694	.15498	-.26585
ERRSPØ8	-.05772	.71295	.09726	-.00160	-.19003
DCRØ5	.10254	.07824	.05709	.65851	.15277
ERRDCRØ5	-.08831	.05755	.07348	-.11725	-.49073
PSØ5	-.06263	.20488	.71365	.06646	.00583
ERRPSØ5	-.07668	.17485	.59800	.02855	-.11244
PERFØ1	.93730	.11658	-.13514	.19229	.00407
PERFØ2	.94002	.11073	-.12257	.10663	.05725
PERFØ3	.88887	-.01582	-.14182	.05925	-.00474
PERFØ4	.85651	.04518	-.30231	.23285	-.03409
PERFØ5	.88314	.05971	.01956	.06008	.26600
PERFØ6	.92913	.02634	-.03332	.09546	-.09355
PERFØ7	.92521	.00839	.00423	.00933	-.06161
PERFØ8	.96386	.02759	.10299	-.06472	.15651
PERFØ9	.91118	.04207	.06422	.02110	.03840
PERF1Ø	.96481	-.02909	.03304	.08808	.04411
EXAM	.69389	-.04995	-.01129	.14123	.31107

VARIMAX ROTATED FACTOR MATRIX
AFTER ROTATION WITH KAISER NORMALIZATION
FOR STAGE 3 REFERENCE TESTS AND TYPING PERFORMANCE SCORES

EXHIBIT 4.6

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6	FACTOR 7
AIM12	.15887	.34113	.75421	-.06173	.16911	.02489	-.19321
STEAD12	.06245	.85386	.48056	.09730	-.04261	.02411	-.15089
ERRST12	-.05279	.97623	-.04856	-.03185	.07702	-.11434	-.03127
SPIR12	.02124	.58246	.35292	.53636	.18540	.01451	.24871
ERRSP12	.23127	.64842	.00955	-.17031	.45781	.28713	.26151
DCR09	.14916	.00086	.79753	-.07401	-.01894	.03240	.12660
ERRDCR09	-.33847	-.03296	-.21483	.78329	.02929	.13159	-.05680
PS01	.37707	.22995	.12823	.13943	.64419	.16738	-.02320
ERRPS09	.36267	-.03151	.04738	.14459	.15507	.64107	.00527
PERF01	.91437	.04325	.05368	-.17725	.22283	.16418	-.01939
PERF02	.92243	.13105	.05510	-.16225	.21736	.05719	-.03170
PERF03	.87095	.08951	.06213	-.08309	.07801	.12757	-.08206
PERF04	.82848	.04887	.15232	-.15887	.08742	.25346	-.09303
PERF05	.91002	.02691	.06512	-.08491	.15389	-.11518	-.20426
PERF06	.89136	.03572	.07585	-.16594	.13317	.17957	-.02197
PERF07	.91481	.03955	.07224	-.05190	-.08945	.18800	.10868
PERF08	.94919	.02061	.13496	.01485	.02124	.07539	-.00298
PERF09	.91245	.12702	.16815	.12448	-.01383	.05959	.16704
PERF10	.93767	-.05146	.18679	-.00382	.14158	.13355	.09814
EXAM	.71425	-.11254	-.00682	-.08174	.18373	-.02284	.24294

Exhibit 4.7 Matrix of congruence coefficients - Comparison of the three stages

		Stage 2 Factors				
		1	2	3	4	5
Stage 1 Factors	1	0.971	0.163	0.029	0.478	0.356
	2	0.297	0.901	0.427	0.499	0.178
	3	0.421	0.326	0.715	0.394	0.089
	4	0.609	0.398	0.132	0.754	0.384
	5	-0.084	0.672	0.278	-0.285	-0.320
	6	0.308	0.084	0.322	0.155	0.156

		Stage 3 Factors						
		1	2	3	4	5	6	7
Stage 2 Factors	1	0.914	0.153	0.409	-0.189	0.361	0.358	0.047
	2	0.140	0.980	0.463	0.177	0.476	0.227	0.094
	3	0.038	0.384	0.330	0.409	0.546	0.443	0.075
	4	0.342	0.262	0.909	-0.187	0.203	0.191	0.004
	5	0.336	-0.059	0.216	-0.689	-0.026	-0.318	-0.134

		Stage 3 Factors						
		1	2	3	4	5	6	7
Stage 1 Factors	1	0.949	0.156	0.461	-0.239	0.492	0.454	0.101
	2	0.274	0.919	0.662	-0.011	0.393	0.135	-0.122
	3	0.536	0.244	0.476	-0.007	0.735	0.720	-0.090
	4	0.578	0.374	0.693	-0.231	0.420	0.276	0.261
	5	-0.025	0.715	-0.122	0.131	0.382	0.192	0.411
	6	0.290	0.082	0.280	0.241	0.414	-0.097	0.276

overfactor than to underfactor, consequently the number of common factors as determined by the Scree test has been used to limit the number extracted.

The congruence coefficients, which were calculated are statistically significant when greater than 0.63 approximately. This figure is obtained by interpolating the values given by Korth in Exhibit 6.23 in Chapter 6. However, the closest number of factors for which the values are calculated is four and as the number compared is five, six and seven in the three matrices it is necessary to increase the size of r_c to 0.7 before it can be accepted as significant. The matrices in Exhibit 4.7 can then be diagonalised and list only those r_c values greater than, or close to 0.7 (Exhibit 4.8) and at least greater than 0.63.

From Exhibit 4.8 it may be seen that factor 1 and 2 of Stage 1 are highly congruent with factors 1 and 2 of both Stage 2 and Stage 3. Factor 3 of Stage 1 is highly congruent with factor 3 in Stage 2 and factors 5 and 6 of Stage 3. These latter two factors have probably been produced from one factor by factor fission as discussed in Chapter 6. Factor 4 of Stage 1 is highly congruent with factor 4 in Stage 2 and factor 3 in Stage 3.

Therefore it would appear that the four main factors are carried through all three stages, and indeed would be found to be even more similar if the same number of factors (say five) was extracted from each stage. However, it has been shown that the same main factors are found in all three stages. The high congruence of these factors may be due mainly to the inclusion of the same eleven performance variables in each matrix and consequently the variance for eleven of the variables will be the same in

Exhibit 4.8 Congruence coefficients greater or close to 0.7 for the three matrices representing the rotated factor solution for each of the three stages.

		Stage 2 Factors				
		1	2	3	4	5
Stage I Factors	1	0.971				
	2		0.901			
	3			0.715		
	4				0.754	
	5					
	6					

		Stage 3 Factors			
		1	2	3	4
Stage 2 Factors	1	0.914			
	2		0.980		
	4			0.909	
	5				- 0.689

		Stage 3 Factors					
		1	2	3	5	6	7
Stage I Factors	1	0.949					
	2		0.919				
	4			0.693			
	3				0.735	0.720	
	5		0.715				
	6						

each matrix. What this analysis will show is whether the same variable, and therefore the same abilities which the subjects manifest at each stage, account for the performance variance. This is assessed by inspecting factor 1 of each stage (Exhibit 4.9) because most of the performance variance is accounted for by that one factor. From Exhibit 4.9 it may be seen that if a loading of about 0.3 is considered as psychometrically significant, then factor 1 for Stage 1 is defined by the reference tests with their respective loadings:

Aiming: .34
Discrimination Reaction Time: .51
and Discrimination R.T. errors: .30

However, in Stage 2 although this is the same factor as regards performance variance, the factors which are defining this factor are:

Aiming: .56
and Spiral Maze: .41

and by Stage 3 are:

Discrimination R.T. errors: - .34
Perceptual Speed: .38
and Perceptual Speed errors: .36

This suggests that, although the loadings are not high, the abilities which the subjects have at the beginning which best account for the performance variance change during learning. As the performance scores are identical in the three analyses it follows that it must be the subjects' scores on the reference tests that are changing and, thus, the subjects' relative abilities are changing. Another way of analysing the data to determine what changes are taking place and whether they are the result of practice on

Exhibit 4.9

Factor I			
	Stage 1	Stage 2	Stage 3
Aiming	34	56	16
Steadiness	12	15	06
Steadiness errors	-05	-13	-05
Spiral Maze	26	41	02
Spiral Maze errors	-03	-06	23
Discrimination R.T.	51	10	15
Discrimination R.T. errors	-30	-09	-34
Perceptual Speed	27	-06	38
Perceptual Speed errors	26	-08	36
Performance 1	88	94	91
" 2	87	94	92
" 3	85	89	87
" 4	81	86	83
" 5	86	88	91
" 6	86	93	89
" 7	92	93	91
" 8	96	96	95
" 9	89	91	91
" 10	93	96	94
Examination	67	69	71

Comparison of loadings on the first factor of all three stages. Decimal points are omitted.

the typing task is to inspect the correlations and t values of both the experimental group and the control group which are shown in Exhibits 4.1 and 4.2.

If the subjects' abilities are overlearned and are frequently in use it would follow that the correlations between the scores on the different stages would be highly significant and that the t values would not be significant. That is, that no significant change in scores had taken place. From Exhibit 4.2 it may be seen that for the control group the Discrimination Reaction Time test was the only test to satisfy this condition including the error scores (except for Stage 1 and 2 correlation). With the experimental group there was a statistically significant change in group mean from Stage 2 to Stage 3, but overall between Stage 1 and 3 there was no change. Similarly for Discrimination R.T. errors there was a statistically significant change in group mean between first and second stage, but overall there was no change. It would appear that whatever ability or abilities the Discrimination Reaction Time Test is dependent on (identified as Response Orientation and Perceptual Speed in Chapter 7 Exhibits 7.23 and 7.22), the ability is overlearned and is frequently practised such that no significant learning or relearning takes place.

If the abilities were overlearned but not practised frequently then some initial change in scores would take place with relearning. This would be seen as a significant change in the group means between Stages 1 and 2 but not 2 and 3. Also if there were no real individual differences in the overlearned abilities then the correlation would be highly significant. This condition occurs with the Perceptual Speed and Spiral Maze tests which have a highly significant change of mean between Stage 1 and 2 but not between Stages 2 and 3 in the control group. In the experimental group the condition holds for the Spiral Maze but not the Perceptual Speed test, with the latter having changes of means between all three stages. This would suggest that learning to type has an effect on the Perceptual Speed ability which is over and above the learning effect of repeating the test and suggests that this ability is not overlearned. The non-significant correlation between Stage 1 and Stage 2 for the control group and between Stage 2 and 3 for the experimental group also suggests significant individual differences in the 'strength' of this ability. That is, some subjects may have overlearned the ability which the test involves but other subjects may not have overlearned this ability.

If a test involves an ability which is overlearned by all the subjects but is rarely used by any of the subjects, then it would be expected that the more practice available to the subjects, the more change would take place; though the subjects' scores relative to one another would stay very similar. This would be seen in large t values and significant correlations between all stages. Furthermore, if the learning task of typing involves this ability then the experimental group will have far greater exposure to practise of this ability and so the t values will be far greater for the experimental group than for the control group. This condition may be seen for both the Aiming and Steadiness tests, where the correlations are high for both the control and the experimental group, but the t values are much larger for the experimental group than the control group.

The results from the correlational analysis can be set alongside the results from the factor analysis described earlier. The Stage 1 loadings suggest that factor 1 is defined by the Discrimination Reaction Time test and by the Aiming test. This would suggest that this factor is most likely to be the Response Orientation ability (Chapter 7, Exhibit 7.23), and that the subjects bring to the task this ability which is overlearned. As the Discrimination R.T. test was the dominant reference test, this ability is well practised. However, as learning carries on, the task requirements change and the subject's competence on the other abilities also changes and so the tests which are most related to the learning tasks will not be different. Thus in Stage 2 the reference tests which load highest on factor 1 are now Aiming and Spiral Maze, which have now been practised sufficiently for large significant changes in the group mean to have occurred. These two reference tests probably represent the ability labelled as Aiming (Chapter 7 Exhibit 7.21) which has the Aiming test as a prominent reference test and the apparatus test 'Tracing' which is similar to the printed Spiral Maze. This would suggest that the Aiming ability is not used frequently and that the amount of "relearning" which takes place is far greater than the re-administration of the tests, in this case eight trials, allows. This is shown by the experimental group mean changing far more than that of the control group, yet the correlations remaining highly significant.

These changes continue to Stage 3 with the Perceptual Speed test most related to factor 1. Again there were very large differences in the group mean (even larger than for the Aiming and Spiral Maze tests) especially for the experimental group. The interpretation of these changes is similar to that for Stage 2, except that the relearning which has been promoted by the typing task is far greater for this ability than for that involved in Stage 2, and now the dominant ability which the subjects bring to the task of learning to type is that of Perceptual Speed (Chapter 7 Exhibit 7.22).

Analysis of reference tests

The previous analysis was carried out on the reference test and the performance variable scores. A number of researchers, in particular Bechtoldt (1962), criticise the way Fleishman et al in their studies of learning have included the performance variables in the data matrix. To overcome this criticism the reference test scores may be factor analysed separately for each of the three stages. This allows for the assessment of any changes in factor pattern, and thereby any changes in abilities which contribute to performance on the reference tests. The factor analysis was carried out with five factors being extracted. This may still be overfactoring but it will allow for a further study, which will be discussed later, in which a comparison is made with the previous analysis which included performance variables.

The scores of the 39 subjects on the reference tests were intercorrelated (Exhibit 4.10). The error scores were taken from odd numbered trials and the score of number correct was taken from even numbered trials for the four tests where errors were included. This was to ensure experimental independence of the nine variables. The number of factors extracted was five and a Principal Factor analysis (Exhibit 4.11) was carried out followed by a Varimax rotation (Exhibit 4.12). The size of the factor coefficients (loadings) which may be considered significant can be calculated using Holzinger and Harman's table in Appendix 3. The average correlations of the three matrices are 0.34, 0.33 and 0.33 for Stages 1, 2 and 3 respectively. From the table in Appendix 3 it may be seen that for an

CORRELATION COEFFICIENTS FOR REFERENCE TEST SCORES
ONLY FOR STAGE I OF TRAINEE TYPISTS

EXHIBIT 4.10

	AIM04	STEAD04	ERRST04	SPIR04	ERRSP04	DCR01	ERRDCR01	PS01	ERRPS01
AIM04	1.00000	.61787	.44258	.31259	.08743	.50781	-.31894	.61741	.42723
STEAD04	.61787	1.00000	.79346	.55135	.38166	.34868	-.24185	.42318	.15800
ERRST04	.44258	.79346	1.00000	.38105	.49635	.15079	-.24198	.18610	.12450
SPIR04	.31259	.55135	.38105	1.00000	.26450	.43240	-.30585	.42551	.14869
ERRSP04	.08743	.38166	.49635	.26450	1.00000	-.18250	-.05527	.15797	.03024
DCR01	.50781	.34868	.15079	.43240	-.18250	1.00000	-.51166	.40430	.41703
ERRDCR01	-.31894	-.24185	-.24198	-.30585	-.05527	-.51166	1.00000	-.25497	-.23404
PS01	.61741	.42318	.18610	.42551	.15797	.40430	-.25497	1.00000	.72964
ERRPS01	.42723	.15800	.12450	.14869	.03024	.41703	-.23404	.72964	1.00000

CORRELATION COEFFICIENTS FOR REFERENCE TEST SCORES ONLY FOR STAGE 2 OF TRAINEE TYPISTS

EXHIBIT 4.10

	AIM08	STEAD08	ERRST08	SPIR08	ERRSP08	DCR05	ERRDCR05	PS01	ERRPS01
AIM08	1.00000	.57723	.27967	.66122	.29854	.41889	-.12867	.67427	.49447
STEAD08	.57723	1.00000	.78977	.72591	.54052	.29201	.03256	.50540	.34126
ERRST08	.27967	.78977	1.00000	.51802	.65800	.05890	.04479	.12595	.11547
SPIR08	.66122	.72591	.51802	1.00000	.54181	.14483	.15043	.51451	.40432
ERRSP08	.29854	.54052	.65800	.54181	1.00000	-.00286	.07146	.30181	.28672
DCR05	.41889	.29201	.05890	.14483	-.00286	1.00000	-.12632	.22064	.06401
ERRDCR05	-.12867	.03256	.04479	.15043	.07146	-.12632	1.00000	-.06749	-.02952
PS01	.67427	.50540	.12595	.51451	.30181	.22064	-.06749	1.00000	.72964
ERRPS01	.49447	.34126	.11547	.40432	.28672	.06401	-.02952	.72964	1.00000

CORRELATION COEFFICIENTS FOR REFERENCE TEST SCORES ONLY FOR STAGE 3 OF TRAINEE TYPISTS

EXHIBIT 4.10

	AIM12	STEAD12	ERRST12	SPIR12	ERRSP12	DCR09	ERRDCR09	PS01	ERRPS01
AIM12	1.00000	.68756	.31264	.40290	.30138	.59714	-.26249	.35214	.28433
STEAD12	.68756	1.00000	.80338	.67726	.50671	.36483	-.06882	.26773	.09325
ERRST12	.31264	.80338	1.00000	.53816	.62401	-.06029	-.03963	.22137	.08510
SPIR12	.40290	.67726	.53816	1.00000	.45060	.29630	.32741	.38138	.10019
ERRSP12	.30138	.50671	.62401	.45060	1.00000	.09171	-.20644	.55909	.53341
DCR09	.59714	.36483	-.06029	.29630	.09171	1.00000	-.28669	.13539	.11059
ERRDCR09	-.26249	-.06882	-.03963	.32741	-.20644	-.28669	1.00000	-.01372	-.22659
PS01	.35214	.26773	.22137	.38138	.55909	.13539	-.01372	1.00000	.72964
ERRPS01	.28433	.09325	.08510	.10019	.53341	.11059	-.22659	.72964	1.00000

FACTOR MATRIX USING PRINCIPAL FACTOR WITH ITERATIONS
FOR REFERENCE TEST SCORES ONLY FOR STAGE I OF TRAINEE TYPISTS

EXHIBIT 4.11

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
AIM04	.75045	-.11576	.00601	-.29712	.13946
STEAD04	.61472	.44734	-.07196	-.11303	.21553
ERRST04	.65252	.61051	.00043	-.18403	-.20212
SPIR04	.61606	.12466	-.18289	.44074	.11434
ERRSP04	.29533	.54736	.29087	.20969	-.17635
DCR01	.62687	-.43502	-.49212	.00328	-.06377
ERRDCR01	-.45034	.14168	.29434	-.07056	.25157
PS01	.75567	-.39116	.43210	.13536	.14127
ERRPS01	.54315	-.49801	.35925	-.06337	-.22132

FACTOR MATRIX USING PRINCIPAL FACTOR WITH ITERATIONS
FOR REFERENCE TEST SCORES ONLY FOR STAGE 2 OF TRAINEE TYPISTS

EXHIBIT 4.11

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
AIM08	.77628	-.36490	-.27700	.10722	-.18741
STEAD08	.68835	.27186	-.18359	-.05129	.26281
ERRST08	.66430	.67026	-.04136	-.20879	-.04261
SPIR08	.83161	.08446	.08945	.39094	-.05085
ERRSP08	.61220	.34518	.22723	-.07328	-.17547
DCR05	.27067	-.19827	-.49402	-.01382	.04029
ERRDCR05	.00759	.17442	.22455	.29210	.15625
RS01	.72466	-.53477	.18129	-.12485	.10465
ERRPS01	.57431	-.42693	.34863	-.15186	.01175

EXHIBIT 4.11

FACTOR MATRIX USING PRINCIPAL FACTOR WITH ITERATIONS FOR REFERENCE TEST SCORES ONLY FOR STAGE 3 OF TRAINEE TYPISTS

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
AIM12	.69740	-.07969	-.49354	.08388	.22045
STEAD12	.87049	.39390	-.18139	-.11455	.14143
ERRST12	.72496	.42305	.27019	-.41887	.04488
SPIR12	.71236	.39263	.11551	.41486	-.18609
ERRSP12	.74040	-.18718	.32041	-.21956	-.23518
DCR09	.39665	-.12956	-.67551	.23168	-.19422
ERRDCR09	-.14235	.43083	.39613	.53309	.10375
PS01	.61118	-.47474	.31548	.26892	.09357
ERRPS01	.47243	-.70325	.25022	.06678	.07371

EXHIBIT 4.12

VARIMAX ROTATED FACTOR MATRIX
AFTER ROTATION WITH KAISER NORMALIZATION
FOR REFERENCE TEST SCORES ONLY FOR STAGE I
OF TRAINEE TYPISTS

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
AIM04	.44252	.28840	.04039	.63150	.07023
STEAD04	.10133	.18355	.43473	.76736	.32634
ERRST04	-.00306	.21889	.71393	.56179	.09186
SPIR04	.12164	.34305	.26247	.19674	.62910
ERRSP04	.06058	-.09969	.67904	.06516	.15912
DCR01	.25528	.77600	-.22664	.26324	.20117
ERRDCR01	-.13598	-.57700	-.09292	-.09381	-.09297
PS01	.87785	.11059	.06547	.23520	.32648
ERRPS01	.80413	.26077	.03774	.04540	-.08348

VARIMAX ROTATED FACTOR MATRIX
AFTER ROTATION WITH KAISER NORMALIZATION
FOR REFERENCE TEST SCORES ONLY FOR STAGE 2 OF
TRAINEE TYPISTS

EXHIBIT 4.12

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
AIMØ8	.24344	.52904	.63604	-.07961	.33[illegible]25
STEADØ8	.76473	.30442	.48392	.17084	-.16625
ERRSTØ8	.96471	-.01810	.08184	.01392	-.02[illegible]44
SPIRØ8	.52457	.40858	.35203	.42802	.33370
ERRSPØ8	.68944	.24594	-.06537	.08283	.18649
DCRØ5	.02574	.06464	.56923	-.17199	-.01775
ERRDCRØ5	.04915	-.03585	-.12156	.41493	-.00172
PSØ1	.13525	.88220	.27101	-.02231	.00201
ERRPSØ1	.13067	.79758	.02205	-.02266	.05136

VARIMAX ROTATED FACTOR MATRIX
AFTER ROTATION WITH KAISER NORMALIZATION
FOR REFERENCE TEST SCORES ONLY FOR STAGE 3 OF
TRAINEE TYPISTS

EXHIBIT 4.12

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
AIM12	.34107	.23982	.74258	-.09619	-.23961
STEAD12	.84546	.06900	.48798	.08834	-.11963
ERRST12	.97129	.09225	-.04786	.00693	.02003
SPIR12	.53951	.19355	.38757	.58366	.24960
ERRSP12	.58055	.57652	.03518	-.12860	.30658
DCRØ9	-.02130	.04029	.82982	-.11285	.13566
ERRDCR09	-.03997	-.09721	-.21697	.77392	-.04548
PSØ1	.15110	.84654	.14551	.13712	-.00890
ERRPSØ1	.01243	.87042	.07061	-.16547	-.01060

N of 40 and an r of 0.35 the standard error of the factor coefficient is 0.182 . Therefore to be safe, as Harman (1976, p. 441) suggests, we may accept a loading of 0.4 or larger as significant. Exhibit 4.13 shows only those variables with factor loadings greater than or equal to 0.4 on one or more variables.

Only three of the factors loaded significantly on more than two variables and these are shown in Exhibit 4.13. It is noticeable that there is a strong similarity of significant loadings throughout the three stages and this similarity is further enhanced by the fact that the variables which are not included all had loadings of less than 0.4 in any of the stages. However, there were some changes, during the stages, from significant to non-significant and vice versa.

If these factors represent basic abilities, and a consistent loading on a variable suggests that the ability is overlearned as in Factor A which may be the Perceptual Speed ability, then changes of loadings on some variables would not be the result of learning or relearning that ability. One possible explanation is that performance on a task involves the use of a strategy, such as going for speed and ignoring errors in the initial stages, but in later trials trying to be as accurate as possible. This is, in effect, changing the task as learning proceeds. The fact that a variable is found to increase significantly in loadings over the three stages in one factor, such as Spiral Maze errors in Factor A, but remains at a high loading throughout all three stages, such as in Factor C, suggests that the task has been changed over these three stages and that different abilities are contributing to the performance variance at the three different stages. This would not preclude that some abilities are important no matter what

Exhibit 4.13

FACTOR A

	Stage 1	Stage 2	Stage 3
Aiming	44	53	24
Perceptual Speed	88	88	85
Perceptual Speed, errors	80	80	87
Spiral Maze	12	41	19
Spiral Maze, errors	06	25	58

FACTOR B

	Stage 1	Stage 2	Stage 3
Aiming	63	64	74
Steadiness	77	48	49
Steadiness errors	56	08	-05
Discrimination R T	26	57	83

FACTOR C

	Stage 1	Stage 2	Stage 3
Steadiness	43	76	85
Steadiness errors	71	96	97
Spiral Maze errors	68	69	59
Spiral Maze	26	52	54

strategy is taken for performing a task as in the case of the Perceptual Speed test in Factor A: but if trials on any one of these tests are administered one after the other, then terminal performance is reached within three to four trials. As all these tests were administered a number of times to the subject before a performance score was obtained it would seem that the learning of the criterion performance task, that is typing, has had an interaction effect and that this effect was the determination of the strategy used for carrying out the task.

This is one explanation for the results found in this analysis, and it may be that the change in loadings of some variables is because a higher loading should be required before significance is accepted when there are 39 subjects. For example, if a loading had to be greater that 0.6 then there would be stability of factors over the three stages with only one exception, the D.R.T. test in Factor B. This latter explanation is more parsimonious and should be accepted until further studies are carried out.

The identification of abilities contributing towards performance on the reference tests

The study of 39 trainee typists was designed to assess the adequacy of both the changing task model and the changing subject model and required the inclusion of a control group of 35 subjects who were non-typists. The typists scores on the reference tests in Stage 1 were obtained under identical administration conditions to the reference test scores obtained from the control group. As the typist group had as yet no typing experience when they were administered the tests in Stage 1, then the data from the two groups may be combined and factor analysed. This provides an N = 74 and nine variables.

The scores on these nine variables of the 74 subjects were intercorrelated (Exhibit 4.14) and a Principal Component analysis carried out. This analysis gives the eigenvalues for each factor when the communalities are equal to unity. The Kaiser-Guttman criteria gave three common factors and the Scree test (Exhibit 4.15) also gave three factors. However, it may be that four more factors could be common factors as they each contributed between 5.0% and 8.4% of the variance, but from the evidence of the two tests it would be more consistent to extract only three factors. This is also consistent with the previous analysis of the same data, but with fewer subjects, where it was found that it was reasonable to identify only three factors. The intercorrelation matrix was re-analysed using the Principal Factor (Exhibit 4.16) method and the resulting pattern was rotated using the Varimax rotation method (Exhibit 4.17).

Using Holzinger and Harman's tables in Appendix 3 for an N = 70 and an average correlation coefficient of 0.26, the standard error of the factor coefficient (loading) is 0.174. To be more stringent, as suggested by Harman (1976, p. 441), loadings greater than 0.3 will be accepted as significant. Exhibit 4.18 shows those variables with loadings greater than or equal to 0.3

Identification of the factors

Factor A (Exhibit 4.18) is heavily loaded on the steadiness test, both total

CØRRELATIØN CØEFFICIENTS FOR ALL 74 SUBJECTS OF TRAINEE TYPISTS AND CONTROL GROUP ON REFERENCE TESTS ONLY OF STAGE I

EXHIBIT 4.14

	AIM04	STEAD04	ERRST04	SPIR04	ERRSP04	DCR01	ERRDCR01	PS01	ERRPS01
AIM04	1.00000	.38078	.20118	.21929	.01895	.37597	-.01138	.50262	.29109
STEAD04	.38078	1.00000	.81215	.63283	.43987	.07544	.19028	.25553	.21536
ERRST04	.20118	.81215	1.00000	.42496	.47174	-.10814	.19218	.08579	.12673
SPIR04	.21929	.63283	.42496	1.00000	.49184	.13788	.12747	.24803	.12586
ERRSP04	.01895	.43987	.47174	.49184	1.00000	-.03901	.34168	.14066	.01553
DCR01	.37597	.07544	-.10814	.13788	-.03901	1.00000	-.05441	.46238	.39720
ERRDCR01	-.01138	.19028	.19218	.12747	.34168	-.05441	1.00000	-.02301	.09224
PS01	.50262	.25553	.08579	.24803	.14066	.46238	-.02301	1.00000	.59050
ERRPS01	.29109	.21536	.12673	.12586	.01553	.39720	.09224	.59050	1.00000

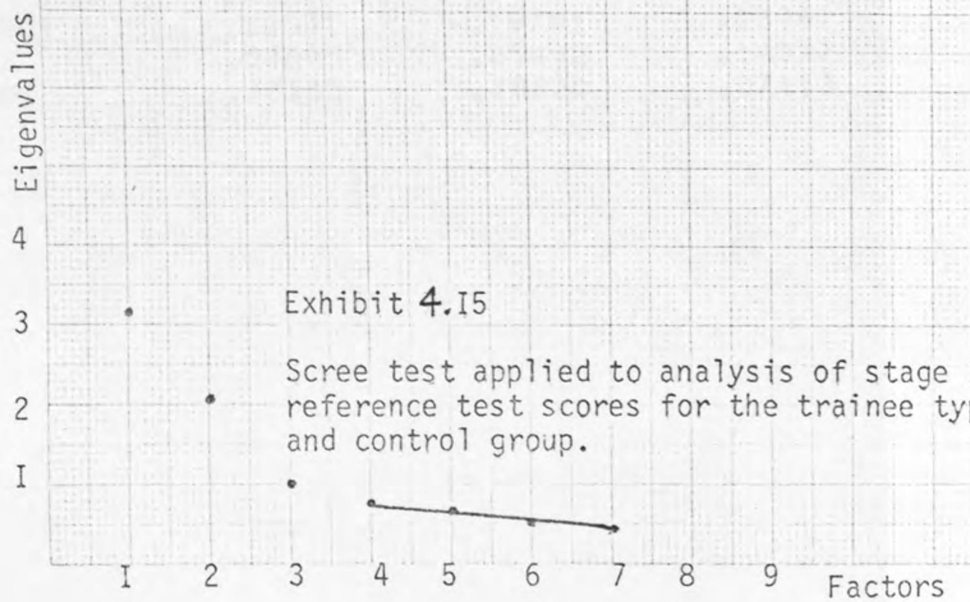


Exhibit 4.I5

Scree test applied to analysis of stage I reference test scores for the trainee typist and control group.

EXHIBIT 4.16

FACTOR MATRIX USING PRINCIPAL FACTOR WITH ITERATIONS FOR ALL 74 SUBJECTS ON REFERENCE TESTS FOR STAGE I

	FACTØR 1	FACTØR 2	FACTØR 3
AIM04	.46396	.39892	-.17644
STEAD04	.91878	-.26039	-.31818
ERRST04	.70029	-.39954	-.18554
SPIR04	.62943	-.13966	.08609
ERRSP04	.56226	-.39032	.49073
DCR01	.25716	.56753	.05704
ERRDCR01	.22031	-.19701	.23967
PS01	.53065	.65482	.14827
ERRPS01	.39183	.48820	.07113

EXHIBIT 4.17

VARIMAX RØTATED FACTØR MATRIX
AFTER RØTATION WITH KAISER NØRMALIZATIØN
FOR ALL 74 SUBJECTS ON REFERENCE TESTS ONLY
FOR STAGE I

	FACTØR 1	FACTØR 2	FACTØR 3
AIM04	.30507	.55220	-.08681
STEAD04	.95451	.19765	.25108
ERRST04	.76541	-.01452	.31369
SPIR04	.46632	.20630	.40383
ERRSP04	.27285	.00815	.79674
DCR01	-.04096	.62202	-.05376
ERRDCR01	.09524	-.02868	.36729
PS01	.07898	.84509	.10931
ERRPS01	.07862	.62326	.04785

Exhibit **4.18** Variables with loadings greater or equal to 0.3 on the three factors extracted in the study of typists (N = 74)

Factor A (Speed of Forearm)

Aiming	31
Steadiness	96
Steadiness errors	77
Spiral Maze	47

Factor B (Perceptual Speed)

Aiming	55
Discrimination reaction time	62
Perceptual speed	85
Perceptual speed errors	62

Factor C (Movement Error Correction)

Steadiness errors	31
Spiral Maze	40
Spiral Maze errors	80
Discrimination R T errors	37

score and number of errors. (These scores are experimentally independent.) The Spiral Maze test also has a moderately high loading. Both of these tests require fast and accurate movements of the forearm which suggests that the factor should be labelled Speed of Forearm, which is not one of the six abilities identified in Chapter 7. The low but significant loading of the Aiming test supports this as movement around the pattern of circles is required, though not just as fast or precisely as in the case of the other two tests. The other tests, Discrimination R.T. and Perceptual Speed, do not require fast forearm movements. This is similar to Fleishman's Speed of Arm Movement ability, though in his definition of this ability (Fleishman 1967, p. 353) he suggests that accuracy is not required. The strength of the evidence for this ability identified by Fleishman was examined in Chapter 5 and it was concluded that there was little evidence for this ability, and the evidence which did exist suggested that it would more accurately be labelled Speed of Forearm and Hand movement.

In the re-analysis of Fleishman's studies described in Chapter 7 this ability was not identified in two or more studies and the only factor which may be similar is Factor I (Exhibit 7.18) found in the re-analysis of Fleishman 1958A. The latter factor was heavily loaded on Track Tracing, Steadiness Precision and Steadiness Tremor, all of which require control of the forearm and hand to make very accurate movements. However, as none of the tests was common to both studies, the similarity between these factors remains unproven.

Factor B (Exhibit 4.18) is heavily loaded on the Perceptual Speed test which requires the subject to compare two patterns and decide whether they are the same or different. This test was developed specifically to represent the ability of Perceptual Speed described by Theologus, Romashko and Fleishman (1970, p. 80). They define this ability as:

> "Common to tasks requiring quick and accurate judgement of figural and symbolic information as to similarity or diversity. Such decisions are based on minor aspects of the information."

Factor C in Exhibit 7.22 was given this label because of high loadings of reference tests such as Pattern Comprehension, Instrument Comprehension and Speed of Identification, all of which require the comparison of a previously seen pattern with another pattern. The only test in common between the reference tests administered to the 74 subjects in the study of typists and those reference tests used in the studies cited in Exhibit 7.22 is the Discrimination Reaction Time test. In the typist study (Exhibit 4.18) this test had a loading of 0.62 and in the two main studies in Exhibit 7.22 the loadings were 0.39 and 0.61. The low loading of 0.26 in the third study in Exhibit 7.22 is not easily explained, but it should be noted that three out of the four test loadings were lower in that study than in the other two studies.

Factor C in Exhibit 4.18 is mainly loaded on the error variables and this may reflect an ability to recognise small movements as leading to an error. This is also suggested in the significant loading of the Discrimination Reaction Time test which requires the subject to determine the direction (above, below, to the right and to the left) of one stimulus relative to another stimulus. All these tasks have to be carried out very quickly. The label given to such an ability could be "Movement Error correction". No such ability has been identified in the studies re-analysed in Chapter 7 and therefore any conclusions are extremely tentative.

From this study of 74 subjects tested on nine variables, three factors were identified but only one, Perceptual Speed, could be linked to the studies re-analysed in Chapter 7. The other two factors extracted were tentatively labelled "Speed of Forearm" and "Movement Error correction". Both of these factors would require identification in at least two other studies before they are given serious consideration.

Summary

The results from this study, which combined both an experimental and a correlational design, showed that the abilities which contribute to performance change as practice continues but this was partly due to changes in task demands and partly the results of changes in ability levels of the subjects. It appears that in general some abilities are overlearned and some are not and that there are individual differences with regard to which abilities are overlearned and those which are not. This suggests the need for a more complex combination of the changing task and changing subject model.

Further, three factors were identified throughout the learning which were tentatively identified.

SECTION 3

SECTION 3

In the previous section it was concluded that there was a discrepancy between the findings of the three Atkinson studies and those of Fleishman (1972, 1978). Further, it was suggested that this could be the result of using different factor analytic methods and procedures. In this section an assessment is made of the method and procedures by which Fleishman concluded that the same ability had been identified in two or more studies. This assessment is carried out by applying the more rigorous decision procedures, for the identification of factors, currently in use. Similarly, there follows an assessment of the evidence cited by Fleishman for a changing pattern of abilities model of learning. It was found that there was only partial support for the conclusions regarding the identification of abilities and the changes in the pattern of abilities during learning. This suggested the need for a comparison of the Centroid factor analysis and Zimmerman rotation methods as used in the original studies and known to be approximate, with a more modern computerised factor analysis and rotation method. This comparison was necessary to understand the reasons for any differences between the factors produced by the two methods. It was found that there were important differences between the final rotated factors obtained from the two methods.

CHAPTER 5

CRITIQUE OF FLEISHMAN'S FACTOR ANALYTIC APPROACH

Fleishman states in his 1978 article, "I have had a vision, shared by a few others, that it might be possible to develop systems for classifying tasks that would improve our predictions and generalisations about factors affecting human performance." This "vision" has grown from his first studies in the early '50s which were to improve the psychomotor test prediction of pilot success.

Fleishman's approach to the study of psychomotor skills has to be seen in conjunction with the concurrent development of Factor Analysis, principally by Thurstone in his book in 1947, and with the refinement by Zimmerman of a graphical method of rotation in 1946. The development of Factor Analysis as a means of reducing large amounts of data to a few dimensions came at a time when the need for recruiting large numbers into the Armed Forces meant a need for efficient selection and training. The analysis of skill acquisition data using correlations and multiple regression analysis had been carried out in the '20s and '30s. Two of the foremost of these investigators during and after World War II were Jack A. Adams and B. Reynolds, who were both at Lackland Air Force Base, San Antonio, Texas, where Fleishman began work in this area in the early '50s. Indeed it would appear that much of the early Factor Analysis by Fleishman was using data collected by Jack Adams (Fleishman 1954, 1957).

The application of Factor Analysis to learning data had been carried out in the 1930's; for example, Buxton's article in 1938 on "The application of factorial methods to the study of motor abilities", and in 1939 Woodrow published an article on "The application of factor-analysis to problems of practice". However, the way in which it was employed by Fleishman in some of his studies was unique. The uniqueness lies in the way in which he included criterion performance variables during stages of learning with what he calls reference tests. This method has been criticised by some specifically (Bechtoldt 1969) and in general by others (Hackman 1969). The validity of this use of Factor Analysis will be discussed in Chapter 8.

Fleishman has not exclusively used Factor Analysis but also used multiple regression analysis and simple correlations. Indeed, he later states (1972) that there is a need for combining what Lee Cronbach (1957) referred to as "the two disciplines of scientific psychology - experimental and correlational psychology". To this end he carried out some experiments, that is studies, where the independent variables were varied systematically (see Fleishman 1957B, and Wheaton et al 1976).

In his studies over the years he has attempted to clarify and develop four main areas:

1. The identification of the organisation of basic abilities which will predict performance on psychomotor tasks. (Fleishman 1954; Fleishman and Hempel 1954A; Hempel and Fleishman 1955; Fleishman and Hempel 1956; Fleishman 1958A; Fleishman 1958B; Fleishman, Roberts and Friedman 1958; Fleishman and Ornstein 1960; Fleishman and Ellison 1962; Fleishman and Rich 1963.)

2. The relationship of basic abilities to performance during the learning of a psychomotor task. (Fleishman 1953A; Fleishman and

Hempel 1954B; Fleishman and Hempel 1955; Fleishman 1957A; Fleishman and Fruchter 1960; Fleishman 1960; Parker and Fleishman 1960, 1961; Fleishman and Fruchter 1965.)

3. The development of a task taxonomy based on ability requirements (Fleishman 1957B; Wheaton, Eisner, Mirabella and Fleishman 1976).

4. The development of a task taxonomy based on 'objective' properties of tasks. (Farina and Wheaton 1973; Wheaton and Mirabella 1972.)

In this appraisal of the work of Fleishman and his colleagues, only the first three areas will be reviewed in depth as these form the basis for the developments in the fourth area.

The organisation of basic abilities

In one of his earliest papers (Fleishman 1953B, p. 256) he states that, "There is an assumption here that it is possible to break down the variance in performance of complex psychomotor tasks into simpler, more fundamental psychomotor functions." This assumption is also implicit in his conceptualisation of the terms "Ability" and "Skill". For him an ability is "a more general trait of the individual which has been inferred from certain response consistencies on certain kinds of tasks" (Fleishman 1967). Whereas the "term 'skill' refers to the level of proficiency on a specific task" (Fleishman 1972), and the assumption is "that the skills involved in complex activities can be described in terms of the more basic abilities" (Fleishman 1967, 1972). Although he does not define the difference between a basic ability and an ability, he does state that the "purpose is to define the fewest independent ability categories which might be most useful and meaningful in describing performance in the widest variety of tasks" (Fleishman 1978). This is attempted by administering an "experimental battery of tasks . . . to several hundred subjects and the correlation patterns examined" (Fleishman 1978). This examination has usually involved the use of Factor Analysis.

Fleishman claims that this series of studies has led to the identification of nine or ten psychomotor abilities and nine physical proficiency abilities which seem "to account for most of the variance in several hundred tasks investigated over many years" (Fleishman 1978). It was also possible to identify the measures most diagnostic of these ability categories.

More specifically, the following are the main claims made by Fleishman in his investigation into the organisation of basic abilities:

1. There are nine or ten psychomotor abilities and nine physical proficiency abilities which are basic abilities (Fleishman 1967, 1978).

2. These basic abilities account for most of the variance in the several hundred tasks investigated (Fleishman 1978).

3. The measures which are most diagnostic of these abilities have been identified (Fleishman 1978).

As was stated at the end of Chapter 3, we can re-assess the studies which are cited as evidence for these claims to determine whether we would accept the arguments and conclusions with today's knowledge of factor analysis in general and factor identification in particular. Although in one of his most recent papers (Fleishman 1978) he refers to "nine or ten" psychomotor abilities and cites his book "The Structure and Measurement of Physical Fitness" (1964) as the reference, we find that in other articles he refers to a different number of basic abilities, namely eleven. These eleven basic abilities are labelled as:

1. Multi-limb Co-ordination
2. Response Orientation
3. Manual Dexterity
4. Finger Dexterity
5. Arm-hand Steadiness
6. Reaction Time
7. Speed of Arm Movement
8. Rate Control
9. Control Precision
10. Wrist finger speed
11. Aiming

This list is given in two of his articles (Fleishman 1967, 1972) and is different from the list given in Fleishman 1956 where the last three abilities are not included, but three others are identified as:

Fine Control Sensitivity

Postural Discrimination

Response Integration

The method he used to determine these eleven basic abilities is to carry out a factor analysis on the correlation matrix obtained from intercorrelating the scores of a large number of subjects on a battery of tests which were selected to involve a wide range of abilities. The subjects were almost all Air Force personnel and almost all trainees. The conclusions therefore must be treated more cautiously when generalised to other populations (Whiting 1975). The numbers involved in the studies ranged from 63 to about 1,000 subjects. The Factor Analytic method used on all occasions except one was Thurstone's (1947) Centroid method and then the factors were rotated using on most occasions Zimmerman's Graphical Rotation method (Zimmerman 1946); on three occasions it is not stated by what method the rotation is achieved and in one study (Fleishman and Ornstein 1960) he states that the rotation was carried out 'blind' by an IBM 630 programme. Only in two of the other studies is it stated that the rotation was carried out either 'blind', that is, by a mathematical procedure such as 'Varimax' or by an "independent skilled analyst" who had no knowledge whatsoever of the nature of the variables (Fleishman 1954).

In any study where factor analysis is used, a factor is defined mathematically by those tests which have significant loadings on that factor. A number of methods of assessing whether a loading is significant exist but in many studies a loading greater than or at least equal to 0.3 is required for significance (Child 1970, p. 45). This is a psychometric decision and the decision is one where the loading is reflecting psychological significance and not necessarily statistical significance. Fleishman, in his studies, has taken 0.2, 0.25 and 0.3 as significant loadings in different studies. However, he has usually taken, especially in later studies, 0.3 as the threshold for the significance of a loading.

Those tests which are significantly loaded on a factor are then examined to find out what ability is common to all of them. This common ability defines the label given to this factor. This examination of the relevant tests is qualitative and not quantitative and requires an interpretation which is not always conclusive. Fleishman appears to use both the interpretation of the ability common to the relevant tests and the existence of a similar pattern of tests as having a significant loading on a factor when he claims that a factor is the same in two or more studies. However, he does not state the method or criterion for determining the 'existence' of an ability over a number of studies. His articles suggest that he relies more heavily on the interpretation of the common ability as the link between factors found in different studies and this will be seen to lead to conclusions regarding factor invariance which would not be drawn from the same data using current decision procedures. The latter refers to the method or procedures taken by which decisions are reached regarding factor invariance. That is, the factor loading which will be accepted as psychometrically significant, the minimum number of studies in which a factor must be identified, the number of marker tests which are common to all the studies, are the main decisions which must be made.

He describes in words the common ability identified by the factor in a study and then in subsequent studies compares these descriptions to obtain evidence for the same factor recurring in different studies. This method has led Fleishman to make claims for the existence of the same factor in a number of different studies, which would not be upheld using current methods. The method which must be used to determine the similarities of factors found in different studies is to compare the tests which have significant loadings on a particular factor in the different studies and compare the magnitude of these loadings. If there are sufficient tests involved in three or more studies then the coefficients of congruence may be calculated. The latter will be explained in Chapter 6 but not utilised here, as the initial inspection of the magnitude of loadings and the number of tests and studies involved does not warrant it.

The most recent definition by Fleishman of the basic psychomotor abilities and the supporting evidence is given in Fleishman 1967. The Ability definitions given here are all quoted from that article.

The first is that of **Control Precision:**

> "This factor is common to tasks which require fine, highly controlled, but not overcontrolled muscular adjustments, primarily where larger muscle groups are involved . . . . This ability extends to arm-hand as well as to leg movements. It is most critical where such adjustments must be rapid but precise."

Fleishman cites three articles as sources of evidence. The first (Fleishman 1958B) of these studies was concerned with 'movement reactions' as defined by Brown and Jenkins (1947). However, from the Factor Analysis using Thurstone Centroid method (1947) and the Zimmerman (1946) rotation method no factor was identified as 'Control Precision'. The nearest to it would be 'Fine Control Sensitivity' which, it is suggested, is the same as the factor obtained and labelled 'Psychomotor

Co-ordination' in a previous study (Fleishman and Hempel 1956). This latter study is the second study cited as evidence for the 'Control Precision' basic ability. In neither of these studies is that label used though this in itself is not damaging, as labels may change as factors are refined. The doubt arises when we compare the tests on which these three supposedly identical factors were significantly loaded (Exhibit 5.1).

Six tests were common to all three studies but only two of those tests were significantly loaded in all the studies. The difference in loadings for two of the six tests, Pursuit Confusion and Two Hand Coordination in each study is very marked. It would be very difficult to show evidence here that the same factor is being extracted. It is even more difficult to relabel it as 'Control Precision', as the magnitude of the loadings for the six tests common to all three studies is only similar for the 'Rotary Pursuit' and 'Rudder Control' tests.

Multi-limb Coordination:

> "This is the ability to coordinate the movements on a number of limbs simultaneously and is best measured by devices involving multiple controls . . . . This factor has been found general to tasks requiring coordination of the two feet, two hands, and hands and feet."

The same studies are cited for this factor as for the previous factor. Again we find that the factor is relabelled. In the earlier study (Fleishman and Hempel 1956) it is called 'Psychomotor Coordination II' and it is noted in the other study, Fleishman 1958B, that "Multiple Limb Coordination . . . is labelled 'Psychomotor Coordination II' in the previous study."

TEST	FLEISHMAN & HEMPEL 1956	FLEISHMAN 1958B	PARKER & FLEISHMAN 1960
ROTARY PURSUIT	.47	.5	.60
RUDDER CONTROL	.40	.48	.40
COMPLEX CO-ORDINATION	.5	.35	.28
RATE CONTROL	.24	.3	.19
PURSUIT CONFUSION	.48	.12	.38
TWO HAND CO-ORDINATION	.46	.25	.25
COMPENSATORY BALANCE	.32	NOT USED	NOT USED
CONTROL ADJUSTMENT	NOT USED	.46	NOT USED
RUBBER CONTROL/TARGET	NOT USED	.44	NOT USED
DIAL SETTING	NOT USED	.40	NOT USED
MOTOR JUDGEMENT	NOT USED	.40	.28
TWO PLATE TAPPING	NOT USED	NOT USED	.41
CONTROL SENSITIVITY	NOT USED	NOT USED	.38
PURSUIT CONFUSION (ERRORS)	NOT USED	NOT USED	.37
BI-MANUAL MATCHING	NOT USED	NOT USED	.37
DISCRIMINATION REACTION TIME	.10	.19	.30
PURDUE PEGBOARD	NOT USED	NOT USED	.33
RATE OF MANIPULATION (PLACING)	NOT USED	NOT USED	.35
RATE OF MANIPULATION (TURNING)	NOT USED	NOT USED	.33

EXHIBIT 5.1 LOADINGS ON FACTORS LABELLED AS 'CONTROL PRECISION'

Exhibit 5.2 shows that there is considerable similarity not only in the fact that the three tests common to all three studies were significantly loaded but that there was a strong similarity in the relative magnitude of the test loadings.

One other test, namely 'Plane Control', was fairly highly loaded in two of the studies but was not used in the third study. Two other tests, "Multidimensional Pursuit" and "Rate Control" show too great a discrepancy in their loadings and are not significantly loaded in all the studies in which they were used.

A tentative conclusion could be drawn that a factor common to the three studies was identified which may be labelled "Multi-limb Coordination".

Response Orientation:

> "This ability factor has been found general to visual discrimination reaction psychomotor tasks involving rapid directional discrimination and orientation of movement patterns . . . . It appears to involve the ability to select the correct movement in relation to the correct stimulus, especially under highly speeded conditions."

Five studies are given as evidence for this factor (Fleishman 1957A, 1957B; Fleishman and Hempel 1956; Parker and Fleishman 1960). In the study by Fleishman and Hempel (1956) we find it is noted that the factor labelled as "Spatial Relations II" is alternatively defined as "response orientation or choice". This label of "Response Orientation" is used in subsequent studies. If we compare the tests which load significantly on the factor called "Response Orientation" in the studies cited as evidence (Exhibit 5.3), we find that there is little evidence for a common factor. Only two tests are

TEST	FLEISHMAN & HEMPEL 1956	FLEISHMAN 1958B	PARKER & FLEISHMAN 1960
RUDDER CONTROL 3 TARGET	.56	.48	.40
PLANE CONTROL	.50	.41	NOT USED
COMPLEX CO-ORDINATION	.37	.30	.38
TWO HAND CO-ORDINATION	.36	.33	.30
MULTI-DIMENSIONAL PURSUIT	.38	.05	NOT USED
RATE CONTROL	.31	.17	.25
RUDDER CONTROL/TARGET	NOT USED	.52	NOT USED
TWO HAND PURSUIT	NOT USED	.32	NOT USED

EXHIBIT 5.2 - LOADINGS ON FACTOR LABELLED AS 'MULTILIMB COORDINATION'

In Parker and Fleishman 1960, we do not know if Rudder Control is for single or triple target and it is assumed here to be the latter.

TEST	1956 FLEISHMAN & HEMPEL	1957A FLEISHMAN	1957B FLEISHMAN	58B FLEISHMAN	1960 PARKER & FLEISHMAN
COMPLEX CO-ORDINATION	.22	.34	.40	.09	.23
DISCRIMINATION REACTION TIME	.50	.4	.38	.67	.29
PLANE CONTROL	.07	.33	Not Used	.12	Not Used
PATTERN COMPREHENSION	Not Used	.26	.40	Not Used	.06
PRINTED DISCRIMINATION REACTION TIME	.41	Not Used	Not Used	.52	.38
INSTRUMENT COMPREHENSION	Not Used	.02	.69		.28
AERIAL ORIENTATION	Not Used	Not Used	.61		.05
FORMATION VISUALISATION	Not Used	Not Used	.51		Not Used
DIRECTION CONTROL	.27	Not Used	.44		.27
KINAESTHETIC CO-ORDINATION		.35		Not Used	
UNDIMENSIONAL MATCHING		.19			
TWO HAND MATCHING		.7			
DIAL SETTING	Not Used				
MULTI-DIMENSIONAL PURSUIT B/H*				.43	Not Used
VISUAL COINCIDENCE			Not Used	.41	
SIGNAL DISCRIMINATION	.52			.36	
COMPLEX MULTIPLE REACTION	.41	Not Used			
CHOICE REACTION TIME					.39
FORCED LANDINGS	Not Used			Not Used	.36
SIGNAL INTERPRETATION					.30

* B/H = BANK & HEADING

EXHIBIT 5.3 - LOADINGS ON FACTOR LABELLED AS 'RESPONSE ORIENTATION'

common to all five studies; they are "Complex Coordination" and "Discrimination Reaction Time" and neither of these is significantly loaded in all five studies. However, "Discrimination Reaction Time" is significantly loaded in four studies and is marginal at a loading of 0.29 in the fifth study. This common loading on this test is further enhanced by the printed version of the test having significant loadings in the three studies in which it was used. There is no other test which has consistent significant loadings in the studies in which it was used.

Consequently, there is no evidence for a "Response Orientation" factor based on these studies.

Reaction Time:

> "This represents simply the speed with which the individual is able to respond to a stimulus when it appears. There are consistent indications that individual differences in this ability are independent of whether the stimulus is auditory or visual and are also independent of the type of response required."

Fleishman (1967) lists four articles as evidence, namely: Fleishman 1954, Fleishman 1958B, Fleishman and Hempel 1955, and Parker and Fleishman 1960. However, Fleishman 1954 does not appear in the references to his 1967 article and one can only presume that it refers to his 1954 article "Dimensional Analysis of Psychomotor abilities". This will be assumed throughout the rest of the review.

Only four tests were found to be significantly loaded (Exhibit 5.4) in the three studies (1954, 1955, 1958B) and only two of these are common to all four studies. All the four tests are designed to test specifically for

TEST	FLEISHMAN 1954	1955 FLEISHMAN & HEMPEL	1958B FLEISHMAN	1960 PARKER & FLEISHMAN
VISUAL REACTION TIME	.73	.72	.56	.48
AUDITORY REACTION TIME	.68	.68	.63	.51
JUMP VISUAL REACTION TIME	NOT USED	.73	.54	.52
JUMP AUDITORY REACTION TIME	NOT USED	.70	.64	.48

EXHIBIT 5.4 - LOADINGS ON FACTOR LABELLED AS 'REACTION TIME'

Reaction Time and indeed they are very similar both in design, procedure and scoring.

> **Visual Reaction Time:** "The S keeps his finger on a button, merely depressing it in response to a single amber light before him. A click provides him with a ready signal before each light stimulus is presented with the fore period (between click and light) varying in a random order between 0.5 to 1.5 seconds. Score is the cumulative reaction time for a series of 20 reactions."

> **Auditory Reaction Time:** "Same procedure and scoring as Visual Reaction Time except that S responds to buzzer when it sounds instead of a light."

> **Jump Visual Reaction Time:** "Same procedure and scoring as Visual Reaction Time except S does not keep his finger on the response button, but must move his hand six inches from a cross to the button as each light stimulus appears."

> **Jump Auditory Reaction Time:** "Same as Jump Visual except response is to a buzzer instead of light."

The above four descriptions are taken from Fleishman and Hempel 1955. From these descriptions it may be seen that the four tests are very similar and specifically designed to test for Reaction time. Consequently it is not surprising that the loadings are all high and very similar ranging from 0.54 to 0.73. Because of this test specificity and similarity and, because there are no loadings on any of the other reference tests in any of the studies, it is not possible to label this factor with any degree of confidence as 'Reaction Time', as it may be a task specific factor. Other tests would have to be included which would be expected to require a significant amount of this ability and yet were not so specifically designed to test Reaction Time.

Indeed it is extraordinary that there were no significant loadings on this factor of any of the huge number of tests used in all the studies where they were included nor on any of the criterion tasks. This suggests it may well be a task specific factor and also that it is of little use in the prediction of psychomotor performance. It may be misleading to interpret this factor as 'Reaction Time'.

Speed of Arm Movement:

> "This represents simply the speed with which an individual can make a gross, discrete arm movement where accuracy is not the requirement. There is ample evidence that this factor is independent of the reaction time factor."

Two tests are common to all (Exhibit 5.5) four studies given as evidence (Fleishman and Hempel 1954B; Fleishman and Hempel 1955; Fleishman 1958B; Parker and Fleishman 1960) but only "Jump Visual Reaction Time" is significantly loaded in all four studies. "Jump Auditory Reaction Time" is significantly loaded in the three studies in which it was used and "Rate of Movement" had fairly high loadings in the two studies in which it was used. The common ability with these three tests is to move the hand and forearm rapidly through a short distance of about six inches.

Consequently, there may be evidence to suggest tentatively that there is a factor common to these studies and label it as 'Speed of Arm Movement', though, probably, it would be more accurately labelled as 'Speed of Forearm and Hand Movement.'

Rate Control:

> "This ability involves the timing of continuous anticipatory motor adjustments relative to changes in speed and direction of

TEST	1954B FLEISHMAN & HEMPEL	1955 FLEISHMAN & HEMPEL	1958 FLEISHMAN	1960 PARKER & FLEISHMAN
RATE OF MOVEMENT	.48	.45	NOT USED	NOT USED
PLANE CONTROL	.33	NOT USED	.11	NOT USED
ROTARY PURSUIT	.34	.21	.17	.02
ROTARY AIMING	NOT USED	.57	.38	.02
JUMP VISUAL REACTION TIME	.54	.36	.54	.36
JUMP AUDITORY REACTION TIME	NOT USED	.33	.44	.31
SANTA AND DEXTERITY	NOT USED	.31	NOT USED	NOT USED

EXHIBIT 5.5 - LOADINGS ON FACTOR LABELLED AS 'SPEED OF ARM MOVEMENT'

a continuously moving target or object. This factor is general to tasks involving compensatory as well as following pursuit, and extends to tasks involving responses to changes in rate. Our research has shown that adequate measurement of this ability requires an actual response in relation to the changing direction and speed of the stimulus object, and not simply judging the rate of the stimulus alone."

Although three studies are given as sources of evidence for this factor, one of these studies (Fleishman and Hempel, 1955) makes no mention of 'Rate Control', nor was any factor similar in any way obtained from the Factor Analysis carried out in the study. Consequently, we are left with but two studies which themselves give little justification for confidence to be placed in this factor.

From Exhibit 5.6 it can be seen that four tests were common to both studies, but only one test - 'Rate Control' - was significantly loaded in both. Of the other three tests one test - Single Dimensional Pursuitometer - was as highly loaded as Rate Control in one study, but totally independent of that factor in the other study.

The other four tests were not used in both studies. It is not possible to say more than that the factor may be defined in part by the test "Rate Control".

Manual Dexterity:

> "This ability involved skilful, well directed arm-hand movements in manipulating fairly large objects under speed conditions."

Fleishman cites one of his earliest articles (Fleishman 1953B) as one of the six sources of evidence for this factor, but there is no quantitative data in

TEST	FLEISHMAN & HEMPEL 1956	FLEISHMAN 1958B
RATE CONTROL	.58	.30
SINGLE DIMENSIONAL PURSUITOMETER	.55	-.06
PURSUIT CONFUSION	.17	.37
TWO-HAND CO-ORDINATION	.17	.32
MOTOR JUDGEMENT	NOT USED	.40
TWO-HAND PURSUIT	NOT USED	.37
MULTI-DIMENSIONAL PURSUIT; BANK & ALTITUDE	NOT USED	.37
COMPENSATORY BALANCE	.39	NOT USED

EXHIBIT 5.6 - LOADINGS ON FACTOR LABELLED AS 'RATE CONTROL'.

the article, nor is it an empirical study but a review in mainly qualitative terms of the evidence from previous factor analytic studies of "underlying factors of motor ability". Consequently, it provides no further evidence for this factor but reviews previous evidence.

In Exhibit 5.7 the test loadings on this factor from the other five studies are given. One of these studies (Hempel and Fleishman 1955) has no tests in common with the other studies and the Fleishman and Hempel study (1954B) has only one test which is significantly loaded and no other tests common to any of the other studies. Therefore, we are left with only three studies which would provide us with evidence for this factor. Only the two forms of the Minnesota Rate of Manipulation test are significantly loaded in all three studies. Consequently there is little evidence for a factor which goes beyond the Minnesota Rate of Manipulation Test.

Finger Dexterity:

> "This is the ability to make skilful controlled manipulations of tiny objects involving, primarily, the fingers."

As with the previous ability the article by Fleishman, 1953B, is cited as one of six studies which provide evidence for Finger Dexterity (Fleishman 1954; Fleishman and Hempel 1954A; Hempel and Fleishman 1955; Parker and Fleishman 1960; Fleishman and Ellison 1962). For the same reason as previously, given the former article (Fleishman 1953B) provides no evidence for this factor. Of the remaining five articles, one study (Hempel and Fleishman 1955) has not one test in common with any of the other studies (Exhibit 5.8). Consequently we are left with four studies which have two tests which have high loadings in all

TEST	FLEISHMAN 1954	FLEISHMAN & HEMPEL 1954B	HEMPEL & FLEISHMAN 1955	PARKER & FLEISHMAN 1960	FLEISHMAN & ELLISON 1962
Minnesota Rate of Manipulation - PLACING	.32	Not Used	Not Used	.38	.53
Minnesota Rate of Manipulation - TURNING	.38	N U	N U	.40	.52
Ten Target Aiming (Correct)	.05	N U	N U	.42	.13
Ten Target Aiming (Errors)	.43	N U	N U	.35	.09
Purdue Pegboard (Assembly)	.21	N U	N U	.33	.32
Discrimination Reaction Time (Printed)	.26	N U	N U	.15	.34
Two Plate Tapping	.24	N U	N U	.35	N U
Rotary Pursuit	.17	.48	N U	-.06	N U
Santa Ana Dexterity	.47	N U	N U	N U	N U
Marble Board	NU	N U	.51	N U	N U
VDL Rings	NU	N U	.44	N U	N U
Dowel Manipulation	NU	N U	.40	N U	N U

EXHIBIT 5.7 - MANUAL DEXTERITY

TEST	1954 FLEISHMAN	FLEISHMAN & HEMPEL 1954A	HEMPEL & FLEISHMAN 1955	PARKER & FLEISHMAN 1960	FLEISHMAN & ELLISON 1962
PURDUE PEGBOARD BOTH HANDS	.61	.61	N U	N U	.66
PURDUE PEGBOARD ASSEMBLY	.55	.57	N U	.43	.59
O'CONNOR FINGER DEXTERITY	.53	.55	N U	.49	.59
MINNESOTA RATE OF MANIPULATION-TURNING	.34	.39	N U	.27	.34
MINNESOTA RATE OF MANIPULATION-PLACING	.31	.29	N U	.36	.37
AIMING	.12	N U	N U	N U	.30
PINSTICK	.19	.25	N U	N U	.34
SPEED OF MANIPULATION 'A'	N U	N U	.45	N U	N U
BALL & PIPE	N U	N U	.45	N U	N U
NUT & BOLT	N U	N U	.39	N U	N U
RESTRICTED MANIPULATION	N U	N U	.35	N U	N U

EXHIBIT 5.8 - FINGER DEXTERITY

four studies. These are Purdue Peg Board Assembly and O'Connor Finger Dexterity. The 'Purdue Peg Board - both hands' has a high loading in the three studies in which it was used. The Minnesota Rate of Manipulation test in both its forms is marginally significant in three studies but just below 0.3 loading in one study.

The evidence is limited to four studies and involves only two tests - the Purdue Peg Board and the O'Connor Finger Dexterity - which are extremely similar. Again we have little evidence for a factor which goes much beyond the specific task of picking up small pegs and placing them in holes under speed conditions. However, the loadings on the Minnesota Rate of Manipulation test suggest that there might be such a factor which could be labelled "Finger Dexterity".

Arm-hand Steadiness:

> "This is the ability to make precise arm-hand positioning movements where strength and speed are minimised; the critical feature, as the name implies, is the steadiness with which such movements can be made. The ability extends to tasks in which a steady arm or hand position is to be maintained."

As in the previous two factors in the article Fleishman 1953B is cited and will not be treated as relevant for the reasons given previously. In the remaining five studies (Fleishman 1954; Hempel and Fleishman 1955; Fleishman 1958A; Fleishman 1958B; Parker and Fleishman 1960) there is only one test which is common to all (Exhibit 5.9), and that is "Track Tracing". This has a high loading in all studies. The test "Steadiness-Precision" also has fairly high loadings in the four studies it was used and, similarly, for "Steadiness-Aiming" in the two studies in which

TEST	FLEISHMAN 1954	HEMPEL & FLEISHMAN 1955	FLEISHMAN 1958A	FLEISHMAN 1958B	PARKER & FLEISHMAN 1960
TRACK TRACING	.61	.56	.61	.50	.42
STEADINESS - AIMING	.60	N U	N U	N U	.40
STEADINESS - PRECISION	.50	N U	.56	.43	.34
PUNCH BOARD	.30	N U	N U	N U	N U
STEADINESS	.31	N U	N U	N U	N U
STEADINESS TREMOR	N U	N U	.63	N U	N U
ARM TREMOR	N U	N U	.36	N U	N U
ARM DRIFT	N U	N U	.31	N U	N U
TARGET AIMING	N U	N U	.34	N U	N U
PURSUIT CONFUSION (ERRORS)	N U	N U	N U	.36	-.04
COX EYE BOARD	N U	.47	N U	N U	N U
HEX NUT STEADINESS	N U	.42	N U	N U	N U
SANTA ANA PEG TURNING	N U	.32	N U	N U	N U

EXHIBIT 5.9 - ARM HAND STEADINESS

it was used. A high loading was obtained in the one study which used the test "Steadiness-Tremor".

There would seem to be no contradictory evidence for this factor and some evidence for labelling it "Arm-Hand Steadiness" and it could be regarded as tentative. However, as only one test was common to all five studies and one other test common to four studies, the conclusion must be viewed as provisional.

Wrist, Finger Speed:

> "This ability has been called "Tapping" in many previous studies through the years. It has been used in a variety of different studies primarily because these are in the form of printed tests which are quick and easy to administer. However, our research shows that this factor is highly restricted in scope and does not extend to many tasks in which apparatus is used. It has been found that the factor is best measured by printed tests requiring rapid tapping of the pencil in relatively large areas."

In the three studies (Fleishman 1954; Fleishman and Hempel 1954A; Fleishman and Ellison 1962) given as sources of evidence for this factor, only four tests are common to all three studies; only one of those, "Large Tapping", is significantly loaded (Exhibit 5.10) in all three studies. However, in two of the studies there is a high loading for four other tests. But these five tests are all very similar versions of Pursuit Aiming, Aiming and Tapping. There may be some tentative grounds for a factor of "Wrist Finger Speed" though it may be more specifically "Wrist Movement Speed".

Aiming:

> "This ability appears to be measured by printed tests which

TEST	FLEISHMAN 1954	FLEISHMAN & HEMPEL 1954A	FLEISHMAN & ELLISON 1962
MEDIUM TAPPING	.74	N U	.77
LARGE TAPPING	.74	.43	.75
PURSUIT AIMING II	.48	N U	.54
AIMING	.45	N U	.52
PURSUIT AIMING I	.50	N U	.52
SQUARE MARKING	.29	.09	.46
DISCRIMINATION REACTION TIME	.16	N U	N U
TWO PLATE TAPPING	.36	N U	N U
ROTARY AIMING	.36	N U	N U
DISCRIMINATION REACTION TIME (PRINTED)	.14	N U	.30
PIN STICK	.23	.50	.08
SMALL TAPPING	N U	.42	N U
SANTA ANA DEXTERITY	.26	.33	N U
PUNCH BOARD	.25	.31	N U
MINNESOTA RATE OF MANIPULATION TURNING	.20	.31	.09

EXHIBIT 5.10 - WRIST FINGER SPEED

provide the subject with very small circles to be dotted in, where there are a large number of circles and when the test is highly speeded. The subject typically goes from circle to circle placing one dot in each circle as rapidly as possible. This factor has not been found to extend to apparatus tests and, hence, the naming of this factor as "aiming" or as other investigators have called it, "eye-hand co-ordination", seems much too broad."

As with previous factors the reference to Fleishman 1953B provides no empirical evidence for this factor and will not be included here. We are left with three studies (Fleishman 1954; Hempel and Fleishman 1955; Fleishman and Ellison 1962) in which only two tests are common to all three studies (Exhibit 5.11). These tests are "Pursuit Aiming I" and "Square Marking". The former has very high loadings in all three studies but "Square Marking" is marginally loaded in two studies and very high in the other. Pursuit Aiming and Square Marking are very similar tasks, the former is putting dots in circles and the latter is putting X's in squares.

There is little evidence for a factor which goes beyond the specific task of placing a dot or X in a small space under speed.

Conclusions

Since the studies reviewed and re-assessed here were carried out, a great deal of research, both on the psychological and mathematical aspects of interpreting factors and the matching of factors in different studies, has led to changes in the decision procedures which were used in the 1950's and 1960's. The method mainly used by Fleishman and his co-workers in the original studies was to interpret a factor by inspecting the predominant loadings and to label that factor with an abilitiy description. It was from

TEST	FLEISHMAN 1954	HEMPEL & FLEISHMAN 1955	FLEISHMAN & ELLISON 1962
PURSUIT AIMING I	.63	.82	.63
PURSUIT AIMING II	.68	N U	.63
AIMING	.63	N U	.57
MARKING ACCURACY	.37	N U	N U
SQUARE MARKING	.30	.71	.31
MINNESOTA RATE OF MANIPULATION (PLACING)	.15	N U	.34
TEN TARGET AIMING - CORRECT	.24	N U	.31
CIRCLE DOTTING	N U	.69	N U
TWO HAND CO-ORDINATION (PRINTED)	N U	.58	N U
ROTARY AIMING	.14	.38	N U
PATTERN DISCRIMINATION (PRINTED)	N U	.36	N U
SANTA ANA PEG TURNING	.10	.33	N U
SPEED OF MANIPULATION 'A'	N U	.32	N U
COX PIN BOARD	N U	.31	N U

EXHIBIT 5.11 - AIMING

the post-interpretative stage that similar factors were then identified, usually by a brief description of the ability and sometimes merely by the descriptive label. This method has been shown in this chapter to lead sometimes to factors in different studies being identified as the same, when actually the factor patterns may be very different, or when there are only two or three marker tests in common and their loadings may not be very similar. Some of these ability factors had been identified from only two studies. None of these would satisfy the conditions for identifying factors which would be acceptable today (Cattell 1978, p. 526). The minimum requirement is to inspect factor loadings for similarity on a minimum of six tests common to at least three studies. The stronger technique of calculating congruence coefficients will be described and used in Chapters 6 and 7.

Consequently, Fleishman's conclusion that it is possible to account for performance on a wide range of tasks in terms of a relatively small number of abilities (Fleishman 1972) would not now be accepted as having been established.

It is important not only to list the labels given to supposedly similar factors as may be found in Appendix A of Parker and Fleishman 1960, but also to compare the patterns of loadings and their magnitude for the factor in each study which is supposed to identify a given ability. If it is the same ability then the same test given to another group of subjects will be similarly loaded on that factor. If it has not a similar loading then a number of possible situations may have given rise to this difference; from differences in the administration of the test to the factors being qualitatively different. Whatever the reason for difference, we cannot assume that the factor is the same between the studies. To establish the consistency of a factor from study to study, we need at least two tests, which are not highly similar, to be found to have significant loadings on the factor in a number of studies. From the comparisons which have been made in this investigation it would appear that it is necessary to have data from three studies, but preferably five studies, before confidence may be placed in the factor and, consequently, the ability which has been identified.

If only one test is common to all the studies then the factor may be task specific.

To summarise, it has been found from applying current methods for assessing factor invariance between studies:

1. That there is little evidence for the claim that consistent factors have been found which can be labelled:

   Control Precision

   Response Orientation

   Reaction Time

   Rate Control

   Manual Dexterity

   Aiming

2. There is some evidence for a tentative conclusion that a factor has consistently found and can be labelled:

   Multi-limb Co-ordination

   Speed of Arm Movement

Finger Dexterity

Wrist Finger Speed

3. There is some evidence to suggest that "Arm-hand Steadiness" is a factor which has been found to be consistent in relevant studies.

4. It may be more appropriate to label "Speed of Arm Movement" as "Speed of Forearm Movement" and to change the label of "Wrist Finger Speed" to "Wrist Movement Speed".

Consequently, there would appear to be provisional evidence for only five of the "abilities" rather than the nine or ten psychomotor abilities as stated by Fleishman (1967, 1978).

The second claim, that these basic abilities account for most of the variance in the several hundred tasks investigated, is based on the assumption that nine or ten psychomotor abilities have been identified. As this has been shown not to be the case, this claim cannot stand. Unless studies have been carried out which have not been published in learned journals, that is, studies carried out under military contracts which may only have been published in a local report, then it is also clear that the number of different tasks is not of the order of several hundred but only about one hundred and seventy. This figure was obtained by listing all the tests, both reference and criterion, used in all the studies by Fleishman and his co-workers which are cited in the references and comparing not only titles but descriptions of the tests (Appendix 4). In many cases it would be inappropriate to claim that "these abilities account for most of the variance in the several hundred tasks", because a fairly high loading on any test on a factor is about 0.40 and 0.45 which means that only 16% to 20% of the variance on that test is accounted for by that factor. Rarely does a test load as high as this on three factors and, consequently, the vast majority of the tests have less than half their variance accounted for by the factors. If the "tasks" refer to the criterion task rather than the reference tests then we have only a small number of those, not several hundred. Neither would it be valid to make this claim for the criterion tests. If we take, for example, the study which used the Discrimination Reaction Time task (Fleishman and Hempel 1955) as the criterion task then we find that included in the presentation of the variance accounted for is the criterion task specific factor. This should not be done as it is not claimed that the latter is an ability. If we recalculate the percentage variance accounted for by the eight factors labelled as abilities (that is, excluding the Criterion Task Specific and the two residual factors), we find the following for each stage of practice on the criterion task:

Stage 1	52%
Stage 2	54%
Stage 3	51%
Stage 4	54%
Stage 5	53%
Stage 6	41%
Stage 7	39%
Stage 8	46%

It would not be accurate in such studies to say that most of the variance has been accounted for even though a large part has been.

The third claim that the measures which are most diagnostic of these abilities have been identified needs to be reassessed in the light of the foregoing discussion on the lack of consistent evidence for many of the abilities.

The following list shows the highest loadings for a test on a factor.

Factor	Highest loading	
Arm-hand Steadiness	.61	Exhibit 5.9
Multi-limb Co-ordination	.56	Exhibit 5.2
Speed of Arm Movement	.57	Exhibit 5.5
Finger Dexterity	.66	Exhibit 5.8
Wrist Finger Speed	.77	Exhibit 5.10

The range of maximum variance accounted for by any one test is from 31% to 59%. The loadings or correlations are not additive and, in order to determine the amount of variance accounted for by a number of tests with regard to any one factor, it would be necessary to carry out some kind of analysis such as Multiple Regression Analysis. The conclusion is that there is little evidence for the claim that the measures which are most diagnostic of these 'abilities' have been identified, if one adopts current decision procedures for the identification of factors.

The relationship of basic abilities to performance during the learning of a psychomotor task

Fleishman in one of his very first articles, (Fleishman 1953B), which was mainly a review of "previous factor analysis studies in the area of psychomotor performance", suggests as a possible research approach "investigations into the effects of continued practice on the performance of complex motor tasks (which) might suggest which tasks bring into play different abilities at different stages of task performance."

Fleishman in another article published the same year (Fleishman 1953A) suggests that: "There is also some indication that even during the short time period of the administration of a single psychomotor test, the ability or abilities sampled may shift materially in importance. If this is true, then it becomes important to know (1) at what stages in the task these systematic changes in function occur; (2) at which stage the task is most complex in the number of abilities measured; and (3) at which stage the task is most nearly measuring one ability at a time." In the same article he suggests the means by which this may be done by Factor Analysis: "to include criterion scores in the correlation matrix of trials . . . . The loadings of the criterion scores on each factor should indicate the unique contribution to be expected to the validity from each factor." He goes on to conclude that "such studies should lead to a better understanding of the influence of systematic changes in function involved at different stages in performance of psychomotor tasks." (Fleishman 1953A.)

It is striking how similar these ideas and hypotheses are to the conclusions which he draws after more than twenty years of studies. He summarises his findings in this area in a number of articles (Fleishman 1967, 1969, 1972, 1978) and states that "these studies with a great variety of practice tasks, show that:

(a) the particular combinations of abilities contributing to performance on a task change as practice on this task continues:

(b) these changes are progressive and systematic and eventually, become stabilised:

(c) in perceptual-motor tasks, for example, the contribution of non-motor abilities (e.g. verbal or spatial) may play a role early in learning, but their contribution decreases systematically with practice, relative to motor abilities:

(d) these is also an increase in a factor specific to the task itself not common to the more general abilities."

These four conclusions are stated almost identically in all the four articles from 1967 to 1978.

It is important to assess the evidence from which these conclusions are drawn. The validity of using Factor Analysis in the way which Fleishman has done will be examined in Chapters 6 and 7.

One of Fleishman's first studies (Fleishman and Hempel 1954B) was a re-analysis of data obtained from a study carried out by Dr. Jack Adams. The aim was to investigate "changes in ability patterns which seem to occur as practice continues." The criterion practice task was the Complex Coordination test in which 197 subjects were given 64 trials each of two minutes' duration. The test was administered over two days. In addition there were twelve printed tests and six apparatus tests. Five factors were found to load significantly on the criterion task. From the Factor Analysis carried out it was concluded that the results:

> ". . . indicate that the Complex Coordination Test was most complex (showed higher loadings on more factors) during the first stage of practice, and that the test became less complex factorially as practice was continued. Thus the last four stages of practice show significant loadings on only three factors, while during the first two stages significant loadings were obtained on seven different factors."

This conclusion relies on the minimum factor loading said to be significant as 0.25 and not as in most studies 0.3. The determination of the point at which factor loadings may be said to be of significant magnitude is not straightforward. This problem is discussed in more detail in Chapter 6. In Fleishman's studies there is no indication of how he had determined the point at which the loadings are to be considered significant. In this study Fleishman and Hempel state that:

> "Variables having orthogonal projections of .30 or larger on the rotated axes were considered in defining a factor. However, loadings of .25 or higher are considered significant."

But if they are significant at 0.25 then much information will be missed by using 0.3 as the cut off when labelling a factor; and if it is the case that 0.3 is the level of significance then we may well be misled into concluding that there is greater complexity of factors than there actually is if loadings greater than 0.25 are included. Fleishman and Hempel mention three ways of assessing complexity:

1. Number of factors involved at each stage.

2. Number of different factors involved in groups of stages.

3. Combination of size of loading and number of factors.

They conclude, using the first way of assessing complexity, that fewer factors are involved as practice continues and therefore a concurrent decrease in complexity. In the study by Fleishman and Hempel (1954B) the following are the number of significant factors involved at each stage of learning:

		Stages of learning							
		1	2	3	4	5	6	7	8
Significance	0.25	4	4	5	5	3	3	3	3
Level of Loadings	0.30	3	2	3	3	3	3	3	3

In terms of the number of factors involved at each stage, there is no change during the eight stages if loadings greater than 0.3 are considered, other than the second stage involving only two factors, as against three for all other stages. Even if we accept loadings greater than or equal (and this is important as two of the loadings are 0.25) to 0.25 then, in terms of the number of factors involved the results are mixed, with the middle stages of learning having more factors involved than either early or later stages.

However, Fleishman and Hempel in this study do not assess complexity simply in terms of the number of factors involved at each stage, but also in terms of the number of different factors involved.

Exhibit 5.12 identifies the factors involved at each stage by the label given to them by Fleishman and Hempel. They state, in support of their conclusion, that factor structure of the criterion task becomes less complex with practice, that the last four stages involve only three significant factors, whilst the first two stages have significant loadings on seven different factors. This is true if loadings greater than or equal to 0.25 are considered significant, but if we only accept loadings greater than or equal to 0.3 then we find that in the first two stages of practice only four factors are involved, with three being involved in stages three to eight. This does not suggest that there is, even in Fleishman's and Hempel's terms, a "considerable change" in the factor pattern during learning.

The other method of assesssing the decrease in complexity which is stated by Fleishman and Hempel to have taken place is that:

> "The results indicate that the Complex Coordination Test was most complex (showed higher loadings on more factors) during the first stage of practice, and that the test became less complex factorially as practice was continued."

This is a more specific claim and implies a way of defining and assessing complexity of a factor pattern by including the magnitude of the factor loadings rather than just the number of factors at each stage or just the number of different factors at each stage or just the number of different factors in any group of stages.

However, though it may be more specific it is not stated how one should make the comparison between one stage and another. The two criteria suggested in the above quotation are number of factors and the magnitude

Exhibit 5.12 Abilities identified in Fleishman and Hempel, 1954B, contributing to the stages of practice

Significance level of loading	STAGE 1	2	3	4	5,6,7 & 8
0.25	PC, SR, VZ, ME	CC, PC, RM, P	CC, PC, RM, SR, P	CC, PC, RM, P, ME	CC, PC, RM
0.3	PC, SR, VZ	CC, PC	CC, PC, RM	CC, PC, RM	CC, PC, RM

Where CC = Complex Coordination test specific
PC = Psychomotor Coordination
RM = Rate of Movement
SR = Spatial Relations
P = Perceptual Speed
VZ = Visualization
ME = Mechanical Experience

of these loadings, with "higher loadings on more factors" being more complex; but more complex than what? Would higher loadings on fewer factors be less complex or would lower loadings on more factors?

Fleishman and Hempel do not state the method by which complexity may be determined, however, they suggest and use three different criteria of complexity though they are mixed up in the analysis.

The factor loadings for each practice stage are shown in Exhibit 5.13. The right hand column gives the total variance accounted for by factors with loadings $\geqslant$ 0.25 and the left hand column by those loadings $\geqslant$ 0.3. From Exhibit 5.13 it may be seen that stages 3 and 4 may be said to be more complex with high loadings on more factors and account for a large amount of the variance. Problems arise when we compare Stage 1 with Stage 2 or even Stage 1 with Stage 8, because Stage 8 has higher loadings but one less factor involved. However, the total variance accounted for may be important here because in the case of Stage 1 the total variance accounted for is only 52.6% (or 60% for loadings $\geqslant$ 0.25) whereas for Stage 8 it is 73.8%. It could be argued that, with only 52.6% of the variance accounted for, if other tests had been included then other factors with significant factor loadings may have been obtained, which would have added to the complexity of Stage 1. This would be less likely the greater the total amount of variance accounted for.

From the foregoing it is evident that there is no clear way to assess complexity and thereby show changes in the complexity of the factor pattern during learning. Also, the evidence from this study (Fleishman and Hempel 1954B) suggests the following if the more usual significance level for a loading is used, that is $\geqslant$ 0.3.

Exhibit 5.13 Factor loadings for each stage of practice - Fleishman and Hempel 1954B

Stage	Total % variance for loadings > 0.3	Factor loadings					Total % variance for loadings > 0.25
1	52.6	.48	.39	.38	.28		60.4
2	58.4	.45	.62	.26	.26		72
3	63.7	.41	.60	.33	.29	.27	79
4	73	.62	.45	.38	.25	.25	85.5
5	79.5	.65	.46	.40			79.5
6	80.4	.63	.47	.43			80.4
7	75	.60	.48	.40			75
8	73.8	.62	.47	.37			73.8

1. There is no change in the number of factors involved at each stage of learning.

2. There was a change from four different factors involved in the first two stages to three factors being involved in the remaining six stages. This does not suggest a considerable change in the factor pattern.

3. There is no way of measuring complexity and that "higher loadings on more factors" is not sufficient criteria for judging complexity, as variations in the magnitude of loadings make comparisons difficult and total variance accounted for an important attribute.

4. Even using the crude measure of complexity of "higher loadings on more factors" it would appear that greater complexity may well have occurred during the third and fourth stages, with little difference between the initial and final stages. This may fit in better with the notion of a change from non-motor abilities to motor abilities with learning where it might be expected, that a more complex pattern of non-motor and motor abilities would be evident at the changeover period. The former notion will be examined later.

5. The 'non-motor' factors were evident only in Stage 1 with at least one 'motor' factor involved at every stage of learning.

6. There was an increase in a factor specific to the task from Stage 1 to Stage 4 whereafter the loadings remained the same through to the final stage.

7. The two other main factors also stabilised, in terms of magnitude of loadings, from Stage 4 onwards.

Fleishman and Hempel carried out another study (Fleishman and Hempel 1955) "concerned with the organization of abilities at different stages of practice in complex psychomotor learning." Again the problem arises of the magnitude of factor loadings which are to be considered significant and a rather vague statement is made regarding this - "In general, loadings of 0.25 and above are consistent with the interpretations given." This is not consistent with the labelling of some of the factors; for example, Factor 5 is labelled 'Verbal Comprehension' and Factor 6 is labelled 'Rate of Arm Movement' with reference being made, in both cases, to only two tests, whereas the former loaded on seven tests greater than 0.3 and one test with a loading of 0.25. Factor 6 was loaded on six tests above 0.25.

Indeed, when the analysis of ability patterns in relation to stages of practice is carried out the criterion has changed in that "the abilities contributing more than 5% of the variance" are included: but 5% variance represents a loading of 0.224 and no justification is given for this lowering of the criterion.

Although this study is almost identical with their previous study (Fleishman and Hempel 1954B) and it is mainly a Factor Analysis, little is made of the data and findings from the Factor Analysis. A more traditional analysis is used whereby the subjects are grouped into high and low scores on tests and their learning curves plotted, but there is also little use made of this data.

However, it is possible to further analyse the data to find out if there is any change in the factor pattern, as suggested by Fleishman and Hempel (1955) when they say,

> "These results generally confirm previous findings obtained with another complex motor task (Fleishman and Hempel 1954B). As before, considerable changes occurred in the particular combinations of abilities contributing to individual differences on the task as practice continued."

If we use the more usual criterion of $\geqslant$ 0.3 for a loading to be considered significant, then the factor pattern for each stage of learning may be shown as in Exhibit 5.14. It can be seen that in terms of just the number of factors involved at each stage of learning, or even the number of different factors involved in the first few stages compared with the last few stages, the results are the opposite of those conclusions drawn by Fleishman and Hempel. The number for both loadings $\geqslant$ 0.3 and $\geqslant$ 0.25 of factors involved is shown in Exhibit 5.14. Thus on this criterion (Exhibit 5.14) we find no evidence for a change from a complex to a simpler factor pattern, but rather the opposite if loadings $\geqslant$ 0.3 are used.

It may be concluded that there is a change in the combinations of factors contributing to each stage as practice continues and that for factors 1 and 9 the change appears systematic, but this is not the case for factors 2 and 6, nor is there any evidence for the claim that the combinations of factors become stabilised.

EXHIBIT 5.14 Significnat factor loading for each stage of practice in Fleishman and Hempel 1955

Stage	Factor 1	2	3	4
1	.41	*	*	.6
2	.47	*	*	.58
3	.56	*	*	.56
4	.52	*	*	.58
5	.52	*	.39	.52
6	.60	*	.37	.39
7	.62	*	.30	.31
8	.59	.30	.41	.33

* = Non significant loading

Number of factors involved at each stage of practice for two levels of significance in the study by Fleishman and Hempel 1955

	STAGE							
1	1	2	3	4	5	6	7	8
No. of Factors involved ≥ 0.3	2	2	2	2	3	3	3	4
≥ 0.25	3	3	2	3	3	3	3	4

There is some evidence for the conclusion that there is a change from non-motor to motor abilities during learning. That is, there was a decrease in the contribution of factor 9, as identified as "Spatial Relations" ability, with learning whilst only at later stages did "Rate of Arm Movement" (factor 6) and "Reaction Time" (factor 2) contribute significantly. However, it is very difficult to interpret the role of factor 1, identified as Discrimination Reaction Time Specific. This is because it is the practice task and also the loadings for this factor increase with practice. In other studies (e.g. Fleishman 1960B) this task is found to define in large part an ability labelled as "Spatial Orientation" and this is a non-motor ability. This raises the question of how a factor specific to the task itself should be interpreted and this will be discussed later. There is an increase in loadings of the factor specific to the learning task as practice continues.

Fleishman (1957A) used a different experimental design to see whether these within-task factors (are) really confined to each individual task or is there something in common between these different tasks which is found only at advanced levels of proficiency on these tasks. The method was to administer a battery of reference tests and seven psychomotor tasks. On each of the latter, subjects received extended practice (although this only consisted of between seven and a half minutes and half an hour) except for one task, the Complex Coordination Test, on which considerably longer practice was given over a two-day period. This was called the Criterion Practice Task.

The analysis was made by the Factor Analysis of all reference tests, Criterion task scores and the early stage scores for the six experimental tasks and also by the Factor Analysis of all reference test, Criterion Task scores and the late stage scores for the six experimental tasks. In this study, loadings over .30 on one or both analyses were used in the interpretation of factor loadings.

In this design it is the analysis which includes the early scores for the six experimental tasks which is most similar to the previous studies. Again it is possible to further analyse the data for evidence of changing factor pattern. Exhibit 5.15 shows the factor loadings for those factors which loaded significantly on at least one stage of practice on the criterion task.

From Exhibit 5.15 it may be seen that the particular combination of factors contributing to performance on the criterion task did change. The similarity between stages 3 and 4 suggest that stability in the factor pattern may have occurred though with only two stages involved this can only be tentative. There does not seem to be any evidence for a "systematic" or "progressive" change except in the progressive contribution of a factor specific to the criterion task.

There is no clear change from non-motor to motor factors. Even though "Speed of Arm Movement" is important later and "Visualization" and "Spatial Orientation" important only at the very beginning, which fits well with the non-motor to motor hypothesis, there is no clear change in "Response Orientations" nor in "Fine Control Sensitivity" loadings throughout the stages. The former being non-motor it would be expected to decrease and the latter to increase as a predominantly motor factor.

Exhibit 5.15 Factor loadings greater or equal to 0.3 for each stage of practice in Fleishman 1957A

	FACTORS					
Complex Co-ord. STAGES	Speed of arm movement	Visual Action	Spatial Orien-tation	Response Orien-tation	Fine Control Sens-itivity	Complex Coord. Specific
1	*	35	35	38	42	*
2	*	*	*	47	46	41
3	42	*	*	38	47	52
4	43	*	*	34	40	58

Stage 1 = Trials 1-5; 2 = 12-16; 3 = 49-53; 4 = 60-64

DECIMALS OMITTED * = NON SIGNIFICANT LOADING

The substitution of late scores for the six experimental tasks makes little or no difference to the factor pattern as far as this analysis is concerned. With the inclusion of early scores the number of factors involved at each stage is 4, 3, 4, and 4 whilst with late scores it is 4, 4, 4, and 4. Thus one extra loading is just significant (0.32) whilst all the other loadings have remained very similar. In neither case is there any evidence for a change in the number of factors during learning, nor for a change in the complexity of the factor patterns.

In an attempt to establish what abilities are involved at different stages on the Rotary Pursuit task, Fleishman (1960B) administered 17 reference tests and 15 trials of the Practice test, that is, the Rotary Pursuit task. However, the practice was not very extensive with only 25 minutes of practice in total for each of the 224 subjects.

The results showed Practice Task loadings greater than 0.3 on four factors (Exhibit 5.16). Two of the factors showed no significant loadings on the reference tests but loaded on the Rotary Pursuit Test. These Fleishman labelled as R.P. Specific I and R.P. Specific II. These results suggest that there is a fairly progressive change from four different factors involved in the early trials, to three factors in the middle trials, and to two factors in the last two trials. The loadings of R.P. Specific I in the final trials do not appear stable though this may be the case with the "Control Precision" factor, but it would require data from many more trials to be confident about such a conclusion. The finding that "Control Precision" (in previous studies labelled as Psychomotor Coordination I) "remains important in its contribution to individual differences in performance on Rotary Pursuit at all stages of practice" and that this would be considered a motor task,

Exhibit 5.16 Factor loadings greater than 0.3 for each stage of practice in Fleishman 1960B

	FACTORS			
	R.P. Specific I	R.P. Specific II	Control Precision	Rate Control
Trial 1	*	51	52	31
Trial 3	32	60	48	31
Trial 5	50	58	38	*
Trial 7	61	51	39	*
Trial 9	65	36	41	*
Trial 11	68	31	45	*
Trial 13	72	*	48	*
Trial 15	64	*	49	*

* Non significant loading Decimal points omitted

suggest that motor abilities may be important throughout learning.

These results give no indication of the role of non-motor abilities. However, they do suggest that there is an increase in a factor specific to the task but this is complicated here by the presence of another factor specific to the Practice task which progressively decreases in importance with practice.

In another study (Parker and Fleishman 1960) a more complex practice task was used. This task "roughly simulated that performed by a pilot during the attack phase of an airborne radar intercept mission". Even though a battery of 43 reference tests was used, from the Factor Analysis only a small proportion (at most 25%) of the performance variance was accounted for by all the factors combined. Five measures of performance were obtained at each practice stage. These were, four error scores and a Time-on-target score. On all five performance measures with each having scores for ten stages of the practice task, no factors were obtained with any loadings of greater than 0.3 and only three loadings were 0.3. Indeed, loadings of greater than 0.2 are noted in the discussion even though no justification is given for using loadings of this magnitude. Parker and Fleishman go on to say that "only Spatial Orientation and Multi-limb Coordination show systematic changes in importance during the course of practice." However, there is little or no evidence for this. Exhibit 5.17 shows the loadings for Integrated Absolute Error and for Time-on-target scores (the former is a combination of the other three error scores). It may be that Factor 15 is increasing in importance, but the fact that only one of the loadings is 0.3 does not allow for even reasonable speculation. That this task was much more complex than practice tasks which were

Exhibit 5.17   Factor loadings for factors 1 and 15 for each stage of practice in Parker and Fleishman 1960

Integrated Absolute Error			Time-on-target		
STAGE	FACTOR 1	FACTOR 15	STAGE	FACTOR 1	FACTOR 15
1	20	06	1	22	03
2	20	12	2	11	08
3	14	09	3	17	06
4	23	17	4	19	09
5	30	18	5	30	21
6	25	16	6	27	19
7	14	28	7	19	23
8	16	22	8	17	22
9	18	22	9	17	21
10	11	29	10	25	30

Decimal point omitted   FACTOR 1 = Spatial Orientation
FACTOR 15 = Multilimb Coordination

previously used in similar studies suggests that six hours of practice is not long enough for a significant factor pattern to emerge. This possibility is supported by the learning curves obtained for each of the performance measures. These suggest that there is still a long way to go before highly skilled performance is reached. Nevertheless, this study produces no evidence for progressive and systematic changes in abilities nor for an increase in a factor specific to the practice task as practice continues.

In another study Fleishman and Fruchter (1960) conclude that progress in learning Morse Code, "at later proficiency levels appears to be less a function of general ability variables and more a function of specific habits acquired in training." However, this does not follow from the data analysis. No factor specific to the task itself was identified nor could it have been. This is because they used the Factor Analysis carried out by Fleishman, Roberts and Friedman (1958) on the 14 aptitude tests administered to 310 airmen, and then estimates of the loadings of the four stages of learning the Practice Task on the "rotated ability factors, were obtained by means of Mosier's extension method, as outlined by Fruchter (1954)." As the Factor Analysis did not include performance scores on the Practice Task, then no factor specific to that task would be obtained.

Neither is there any evidence of systematic changes in factor pattern. If we only consider factors with loadings $\geqslant$ 0.3 then the pattern shown in Exhibit 5.18 emerges. This factor pattern (Exhibit 5.18) gives no evidence for or against any of the questions raised in this review and does not allow the conclusions which were drawn by Fleishman and Fruchter, namely, that:

Exhibit 5.18 Factor loadings greater than or equal to 0.3 for each stage of progress in Fleishman and Fruchter 1960

No. of days required	FACTORS		
	APS	AR	CS
to reach 4 gpm	.48	.37	*
Progress from 4 to 6 gpm	*	*	.36
Progress from 6 to 10 gpm	*	*	*
Progress from 10 to 4 gpm	*	*	*

APS = Auditory Perceptual Speed

AR = Auditory Rhythm Perception

CS = Speed of Closure

* = Non significant Loading

> "the results obtained . . . are consistent with earlier findings . . . . In each study it has been found (a) that the pattern of abilities . . . changes progressively with practice and (b) there is an increase in a factor specific only to the stages of practice on each of the tasks."

It would appear that neither of these conclusions can be drawn from the data in the study by Fleishman and Fruchter (1960). These data and conclusions were used as the basis for the redesign of a training programme described in Parker and Fleishman 1961.

Fleishman and Rich (1963) reported an interesting study in which an attempt was made to test the hypothesis suggested by Fitts (1951) and later by Fleishman that visual control is important early on and proprioceptive feedback is more important later on in the learning. Forty subjects were given extended practice on the Two-Hand Coordination task and given a standardized test of Spatial Orientation and also a newly developed test of kinaesthetic sensitivity. This latter test was based on the "classical psychophysical procedure of determining difference limens for judgements of lifted weights." No factor analysis was carried out but correlations of scores between successive trials of the practice task and the scores on the two tests were obtained. Exhibit 5.19 shows those correlations. This suggests a systematic change of a decrease in the contribution of Aerial Orientation with an increase in Kinaesthetic Sensitivity as practice continues. This fits in with the suggestion of non-motor abilities giving way to motor abilities as practice continues. However, these correlations reflect scores on tests which are not measures of one ability but probably involve a number of abilities. Consequently, this study does not add to our understanding of changes in 'abilities' required during learning, but does show that certain tests may not predict early

Exhibit 5.19 Correlations between the two test scores and successive trials of the practice task in Fleishman and Rich 1963

Two Hand Coordination	Aerial Orientation	Kinaesthetic Sensitivity
Trial 1	.36**	.03
Trial 2	.28*	.19
Trial 3	.22*	.15
Trial 4	.19	.15
Trial 5	.08	.10
Trial 6	.07	.09
Trial 7	.09	.23*
Trial 8	.05	.28*
Trial 9	.02	.38**
Trial 10	.01	.40**

* $p \leqslant .05$

** $p \leqslant .01$

performance but will be predictive to a significant amount of advanced proficiency levels on psychomotor task.

The correlational method of investigation was combined with the experimental method by Wheaton and Fleishman and reported in an article by Wheaton et al (1976). The aim of the study was to identify the "nature of changes, if any, that may occur in the patterns of abilities accounting for individual differences in performance as the characteristics of a criterion task are systematically varied." This study is not directly relevant to the area of Psychomotor Abilities because the criterion task was an "auditory signal identification task similar to that confronting a passive sonar operator." However, what is the case for one type of task may be the case for other types of tasks.

The task was carried out under two variable conditions, signal-to-noise-ratio and signal duration, each of which had three possible settings. Consequently, there were nine different conditions on the criterion task.

A battery of 24 tests was administered to 127 male University students and the scores were intercorrelated and Factor Analysed using a Principal components solution and a Varimax rotation was carried out. The loadings of various criterion condition were projected onto the rotated factor structure using the procedure by Mosier (1938) and Stoloff (1973).

Only one of the factors was found to be related to performance on the criterion task under either of the two task conditions. It appears that short length signals (3 seconds) under the two higher background noise levels

(0dB and 5dB signal-to-noise-ratio) demanded this one factor, that is, an "Auditory Perceptual" factor. Otherwise, there was no evidence of a change in the pattern of abilities related to 'identification' performance across training trials.

Fleishman and Fruchter (1965) carried out a further analysis on part of the data obtained in the earlier study by Parker and Fleishman (1960). In the latter study the scores on the 50 Reference tests were Factor Analysed and the intercorrelations of the criteria of performance on the Practice task were projected on to the rotated axes defined by the battery of Reference tests.

This "projection" technique was first presented by Dwyer (1937) for single variable projections and extended to group variable projections by Mosier (1938) and provides an estimate of the factor loadings and is used when the variables are not included in a test battery, but the correlations between the variables and the tests in the battery are known. However, this is not the case in the study reported by Parker and Fleishman (1960). It is not clear why this projection technique was used instead of Factor Analysing the complete 100 variable intercorrelation matrix.

Fleishman and Fruchter (1965) carried out a Factor Analysis only on the intercorrelation of the five criteria of performance for each of ten segments of the Practice task. Therefore, because no reference tests were included in the Factor Analysis, it was not possible to analyse the results in terms of 'abilities'. Indeed Fleishman and Fruchter do confine their discussion to common motions required between the performance criteria which are commonly loaded at different stages on each factor. They conclude no more than that "the study is primarily methodological".

Conclusions

The studies which were concerned with the identification of abilities and changes in ability pattern during learning were reviewed and the evidence for Fleishman's conclusions which were described at the beginning of this chapter was re-assessed. This re-assessment involved the application of current thinkin on the minimum conditions that must obtain before a factor may be said to be well founded or invariant between studies. The decision procedure used here was based on the arguments and review of the relevant studies by Cattell (1978). In Chapter 6 the measure of congruence coefficient will be utilised as a further stage in the identification of factors between studies.

The re-assessment has also involved analysing the data in some of the studies in a different way to the analysis carried out in the original study. Further, the interpretation of the data analysis was scrutinised to assess whether the same conclusions would be reached today as when the original studies were carried out.

It is not that the original studies were wrongly analysed or that the arguments were wrong. But progress has been made in statistical and psychometric procedures since Fleishman's original studies were carried out and this has led to the drawing of different conclusions from the same studies. Indeed, it is because the studies were so well designed that it is possible to re-assess the claims made by Fleishman (1967, 1969, 1972,

1978) that these studies have shown systematic and progressive changes in the pattern of 'abilities' involved as practice continues on a criterion task. More specifically this re-assessment has found that:

1. There is some evidence for changes in the combinations of 'abilities' contributing to performance on the criterion tasks, but

2. There is no evidence of a systematic and progressive change in the pattern of abilities.

3. In two of the studies (Fleishman and Hempel 1954B, Fleishman 1960B) there was some evidence for some of the factors becoming stabilised but practice trials did not continue long enough to allow for confidence to be placed in this finding.

4. In none of the studies was a clear progression from 'non-motor' to 'motor' abilities found. Indeed in some studies (Fleishman 1957A, 1960B) it was found that 'motor' abilities were involved throughout practice. There was some evidence for 'non-motor abilities' to decrease in contribution to performance as practice continued.

5. In those studies whose design allowed the identification of a factor specific to the task (Fleishman and Hempel 1954B, 1955, Fleishman 1957A, and 1960B) such a factor was found to increase steadily as practice continued.

In one of the early studies Fleishman and Hempel (1954B) introduced the notion of complexity of factor pattern. They say that the findings indicate that the factor pattern becomes less complex with each stage of practice. They actually mention three possible ways of measuring complexity, but do not clearly differentiate between them:

* Number of factors involved at each stage
* Number of different factors involved at groups of stages
* Combination of size of loading and number of factors.

From an examination of the subsequent studies, no evidence is found for a change in the number of factors with practice and only slight changes in the number of different factors involved at successive groups of stages. Neither is there evidence for greater complexity, in terms of higher loadings on more factors, at the beginning of practice and decreasing with continued practice. Indeed, if the findings suggest anything, it is of greater complexity in the middle stages of practice (Fleishman 1957A). In one study (Fleishman and Hempel 1955) there was an increase in the number of factors involved as practice continued.

In general, then, there is no clear evidence regarding the characteristics of the changes in factor patterns during learning. This is the result of variations in design of the studies, in the tests used in the reference batteries, and in the differing complexity of the criterion tasks used and many other aspects of the studies including the lack of explicit rules to determine the significance of factor loadings and the consequent changes in the criteria for significance of loadings.

CHAPTER 6

METHODOLOGICAL CONSIDERATIONS
IN THE USE OF FACTOR ANALYSIS

It would not be appropriate or useful to go deeply into the nature of factor analysis as there exist already, several excellent accounts of the technique. The main ones are "Multiple Factor Analysis" by Thurstone 1947, "Introduction to Factor Analysis" by Fruchter (1954), "Factor Analysis" by Cattell (1952), "The Essentials of Factor Analysis" by Child (1970) and the very thorough texts "Factor Analysis" by Gorsuch (1974), "Modern Factor Analysis" by Harman (1976) and "The Scientific Use of Factor Analysis in Behavioural and Life Sciences" by Cattell (1978).

The origins of factor analysis, from the work of Charles Spearman, who developed a psychological theory of intelligence, beginning with his paper "General Intelligence, Objectively Determined and Measured", published in 1904 and the complementary statistical work of Karl Pearson who first published an article on "The Method of Principal Axes" in 1901, up until the modern techniques of factor analysis is well described in Harman (1976).

A number of methods have been developed which differ either in the basic assumptions employed or in their degree of difficulty of calculating the factor pattern. In general though, "factor analysis is the resolution of a set of variables linearly in terms of (usually) a small number of categories or 'factors'" (Harman 1976).

In the studies which are reviewed in Chapter 5, the 'Centroid' method of factor analysis was used in the majority of cases and in one the 'Principal Axes' method was used. When assessing the evidence for the claims made by Fleishman and colleagues in the articles cited, it is important to critically assess the methodological adequacy of the studies. An important aspect of the methodology is the particular factor analytic method employed. Consequently, an examination of the 'Centroid' and 'Principal Axes method' will be carried out and also a comparison with the Factor patterns produced from the application of the 'Principal Factor' methods will be made. A further comparison will be made between the Zimmerman method of hand rotation used by Fleishman and his colleagues and the modern 'objective' rotation obtained using the 'Varimax' method. These comparisons will be carried out on the nine studies of Fleishman et al which included the intercorrelation matrix in the published article.

Centroid Method:

This was one of the most popular methods in factor analysis until the use of computers became more common in the late fifties and early sixties. It was popular because it was able to approximate closely the results obtained using the principal-factor method, whilst offering considerable savings in labour if the calculations were carried out by hand, which was necessary before the introduction of computer programmes for carrying out the computations. However, there are characteristics of the Centroid method which differ from those of the principal-factor solution and consequently the resulting factors extracted may be different for the two methods. The main differences are that the "centroid solution is not unique for a given set of variables nor does it have the other interesting mathematical properties of the principal-factor solution" (Harman 1976, p. 101). Indeed Thurstone who developed the method described it (Thurstone 1947) as a "computational compromise" but it is a method of obtaining factors which Harman (1976) found to approximate closely the modern computer produced principal-factor solution. He concludes that "All that can be said for the Centroid method is that it produces without much arithmetic one of many possible sets of axes which account for the variance in a manner approximating the optimal situation of the principal axes." (Harman 1976, p. 5.)

The question arises, with the studies which are under review here, to what extent are the factors obtained from the Centroid method used in these studies the same as or very closely approximating the factors which would be obtained from a principal factor method applied to the same data. Of the sixteen empirical studies which Fleishman published in journals, nine were chosen for re-analysis. Five (Hempel and Fleishman, 1955; Fleishman and Hempel, 1956; Fleishman, 1957A; Fleishman and Fruchter, 1960; and Fleishman and Fruchter, 1965) could not be re-analysed because an intercorrelation matrix of the variable raw data was not included in the article. The other two studies (Fleishman and Hempel, 1954A; and Fleishman, 1958A) which were not included in the re-analysis were an analysis of a small number of very similar tests, and there is no mention of the rotation method used in the Fleishman and Hempel article of 1954A. However, these two studies were subsequently re-analysed in Chapter 7.

Of the sixteen studies, nine had the intercorrelation matrix published on which the factor analysis was carried out. Consequently, it was possible to carry out a factor analysis on these intercorrelation matrices using the principal factor method as used by the S.P.S.S. programme. The factor patterns can then be compared. For example, the results of the Centroid Factor Analysis carried out by Fleishman (1954) are shown in Exhibit 6.4 and the factors extracted from the application of the principal factor method are also shown. The first point to note is the difference in the number of factors extracted by the two methods. Whereas Fleishman and Hempel continued with factor extractions "beyond the point where any meaningful factor variance was suspected to be present", the S.P.S.S.

programme only extracts those factors whose latent roots (eigenvalues) are greater than or equal to 1.0. This would only be applied to a principal components analysis of the intercorrelation matrix from which the latent roots are determined. This is known as 'the Kaiser-Guttman method' or 'Kaiser's criterion' suggested by Guttman and adapted by Kaiser. In any factor analysis it is necessary to determine the number of factors extracted which represent the common variance and not the unique variance or error variance. Consequently we must first consider how we may determine the number of factors which should be extracted.

Determining the number of factors to be extracted

There are two main approaches, namely the statistical method and the psychometric method. In psychological studies the latter approach is most applicable, as it may be the case that another common factor may be extracted but contributes such a small amount to the total variance that it is not considered worthwhile to include it in the model. The contributions of the factors to the total variance, in a principal-factor solution, decrease with each succeeding factor and Harman points out that this provides "a rough statistical guide as to the maximum error that might be introduced by stopping the analysis too soon. If the last factor retained contributes 5% to the total variance, it is known that the next factor, or any succeeding one will not contribute as much as 5%." (Harman 1976, p. 161.)

With regard to the statistical method a "number of methods have been given by Bartlett, Burt, Sokal and others on a theory and by Humphreys, Horn, Linn and others on a Monte Carlo basis" (Cattell 1978, p. 90). These are all forms of a residual testing method and it is suggested that they are to be used "as an additional check when vital theoretical issues hang on the decision" (Cattell 1978). Otherwise, the psychometric approach is used and the determination of the number of 'significant' common factors to be extracted may be achieved by the use of the following methods:

1. Kaiser-Guttman method (K-G) (Kaiser 1960)
2. Cattell's Scree Test
3. Lower bound communalities method of Guttman
4. Sokal's test of distribution of residuals

The last two will not be used here as they have been found to require greater computation, whilst not providing greater precision than the first two methods. For example, Gorsuch (1974) states that method 3 tends to give more factors than other methods.

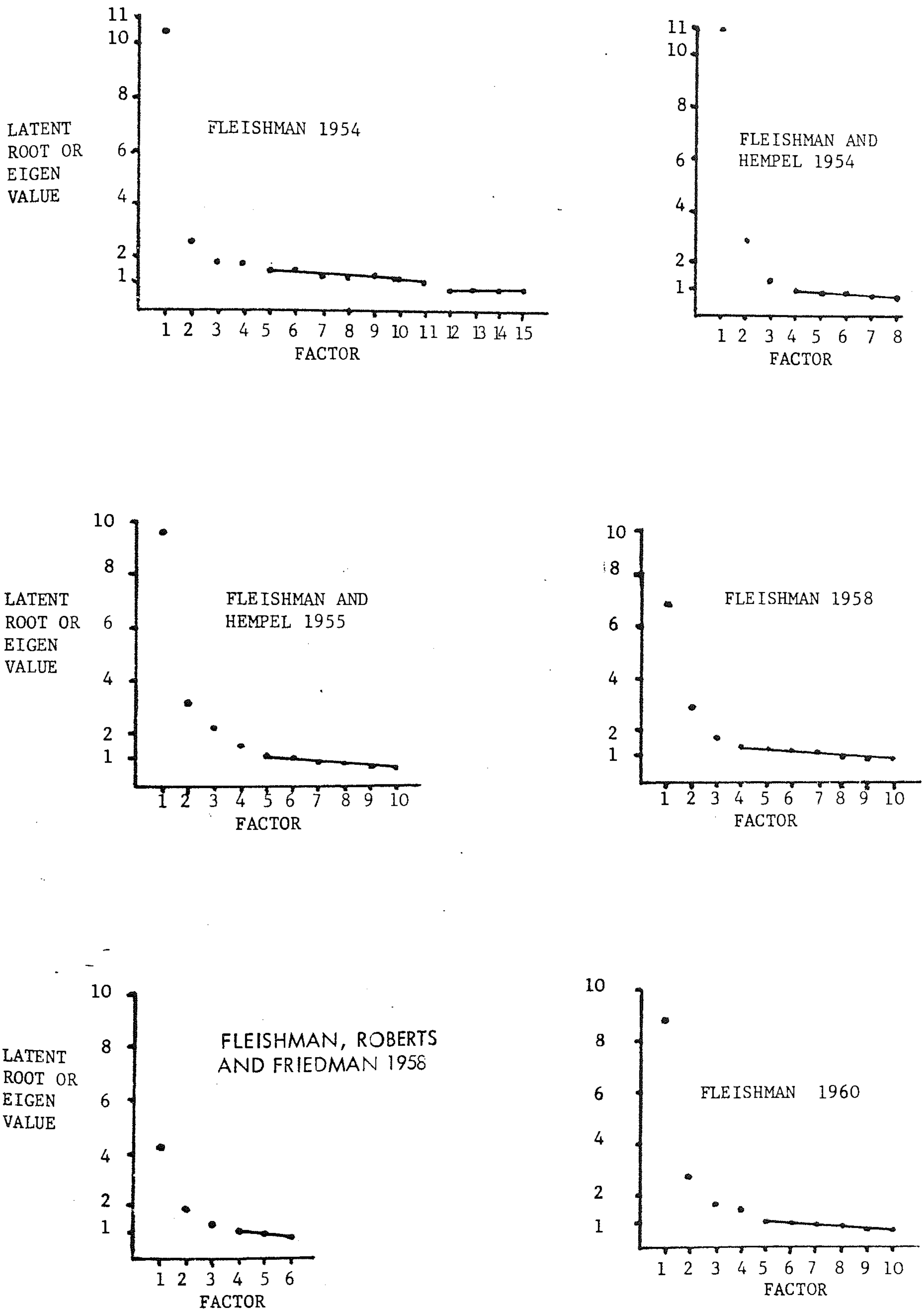
As had been noted, the S.P.S.S. programme uses the K-G method for deciding how many factors are to be extracted, and Exhibit 6.1 shows the number of factors extracted originally in the nine studies and compares that with the number extracted when applying the K-G method. The number of factors extracted when applying the 'Scree test' has also been included for comparison. The guidelines for applying the Scree test were obtained from the latest description by Cattell (1978, pp. 76-86). The plots of the latent roots (eigenvalues) for the factor analysis carried out in the re-analysis of the original data in the nine studies are given in Exhibit 6.2 . Cattell says that the number of factors "coincided with the point on the roots plot where the downward descending curve relatively suddenly straightened into a much more gentle even slope . . . the upper

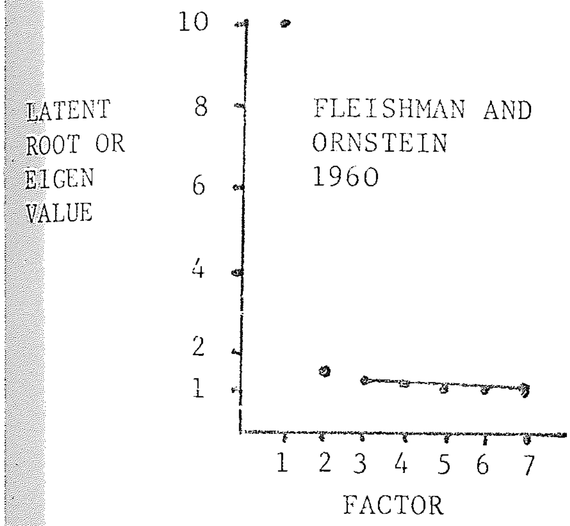
Exhibit 6.1

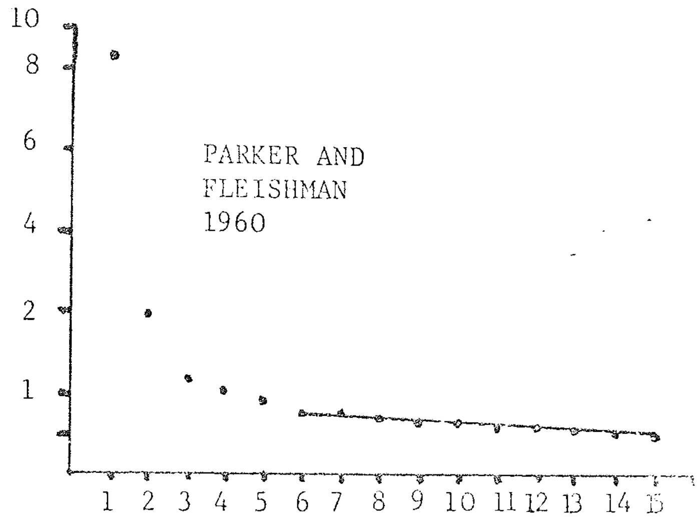
Comparison of number of factors extracted in the original study with the number extracted in the reanalysis of the intercorrelations in the nine studies.

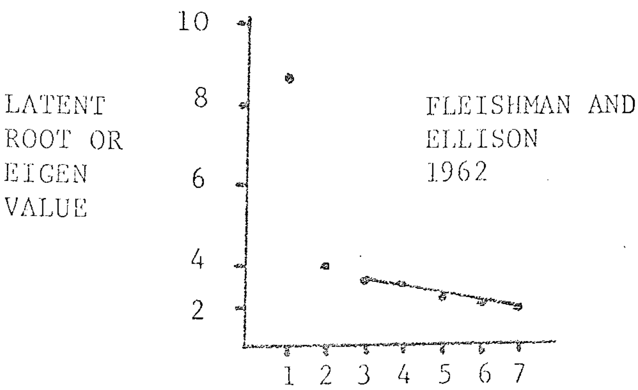
Reference of Study	Original analysis: Type of Factor Analysis Numbers of Variables: Numbers of subjects	Number of Factors extracted	Number of Factors 'identified'	Reanalsis by Principal Factors: Using K-G criterion	Using Scree Test
Fleishman 1954	Centroid 40:400	12	10	11	4
Fleishman and Hempel 1954B	Centroid 26:197	10	9	4	3
Fleishman and Hempel 1955	Centroid 27:264	11	9	5	4
Fleishman, Roberts and Friedman 1958	Centroid 15:310	6	5	4	3
Fleishman 1958B	Centroid 31:204	10	7	8	3
Fleishman 1960	Centroid 25:224	11	10	5	4
Parker and Fleishman 1960	Principal Axes 50:203	15	15	15	5
Fleishman and Ornstein 1960	Centroid 24:63	6	6	7	2
Fleishman and Ellison 1962	Centroid 22:760	7	5	6	3
Reanalysed in Chapter 6					
Fleishman 1958A	Centroid 13:200	3	3	5	4
Fleishman and Hempel 1954	Centroid 15:400	6	5	4	2

EXHIBIT 6.2 DETERMINATION OF FACTORS TO BE EXTRACTED USING THE SCREE TEST



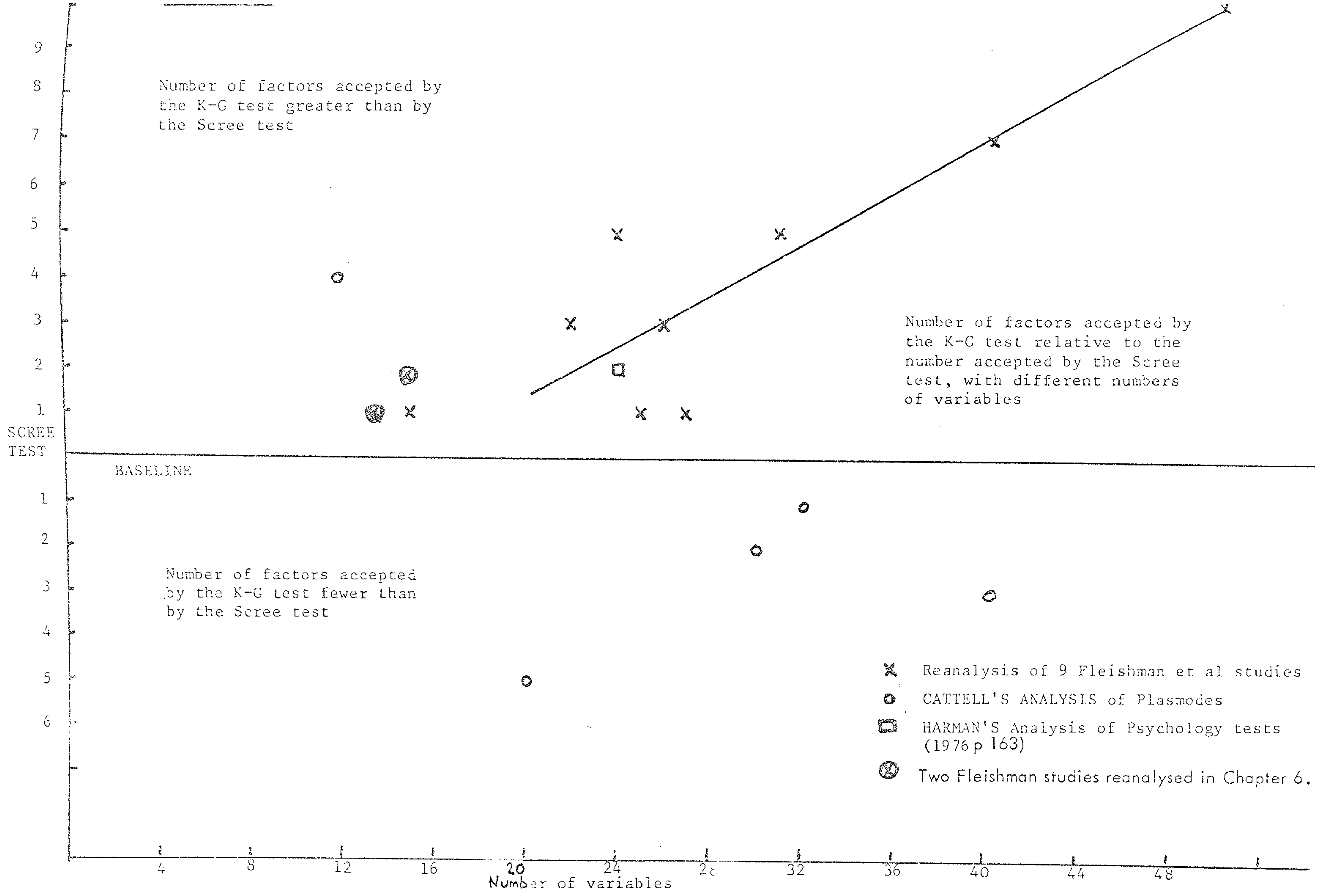

LATENT ROOT OR EIGEN VALUE
FLEISHMAN AND ORNSTEIN 1960
10
8
6
4
2
1
1 2 3 4 5 6 7
FACTOR


PARKER AND FLEISHMAN 1960
10
8
6
4
2
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15


LATENT ROOT OR EIGEN VALUE
FLEISHMAN AND ELLISON 1962
10
8
6
4
2
1 2 3 4 5 6 7

end of the Scree marks the (k + 1) factor when the true number of the factors is k" (Cattell 1978). There is a discrepancy here with the guidelines given in an earlier article by Cattell (1966) where he says that from his experience he has "noticed that this Scree invariably began at the K^{th} latent root when K was the true number of factors." The former guideline has been used in the analysis here as it is the latest statement by Cattell. He cites a number of studies "which give 'strong support' for the Scree test and states that the K-G test underestimates when few variables are involved and overestimates when many variables are involved." The evidence he presents for these statements in his book (Cattell 1978) is mainly derived from 'plasmodes', that is, examples using generated data which has a known number of factors. The results of applying the K-G criterion and the Scree test to the analysis of these plasmodes can be compared. In five out of the six cases the Scree test determined the correct number of factors. Exhibit 6.3 compares the difference in the number of factors accepted by the two methods with the Scree test as the base line. This is plotted against a number of variables. With so few data points no pattern emerges. However, the same comparison has been made using the nine studies which have been re-analysed in this chapter. With this 'real' data we get a very different result and a tentative pattern. The K-G test in these nine cases accepts that there are more common factors than does the Scree test and this difference increases as the number of variables increases. With the 'real' data we do not know the actual number of factors involved and, consequently, we can only conclude that the two methods do produce different results: that the difference increases with an increase in number of variables and that the evidence is different when the tests are applied to plasmodes, from the case where they are applied to 'real' data.

EXHIBIT 6.3



Number of factors accepted by the K-G test greater than by the Scree test
Number of factors accepted by the K-G test relative to the number accepted by the Scree test, with different numbers of variables
Number of factors accepted by the K-G test fewer than by the Scree test
SCREE TEST
BASELINE
9
8
7
6
5
4
3
2
1
1
2
3
4
5
6
4
8
12
16
20
24
28
32
36
40
44
48
Number of variables
Reanalysis of 9 Fleishman et al studies
CATTELL'S ANALYSIS of Plasmodes
HARMAN'S Analysis of Psychology tests (1976 p 163)
Two Fleishman studies reanalysed in Chapter 6.

In the nine studies extraction of factors was "continued beyond the point where any meaningful factor variance was suspected to be present" (Fleishman and Hempel 1955, Fleishman 1960B, Fleishman and Ellison 1962) or "beyond the point where the product of the two highest centroid loadings became less than the standard error of the original correlation of the same two variables" (Fleishman 1954, 1958B). No justification was given for the use of either of these criteria. A comparison can now be made between the number of factors extracted and identified (labelled) using these two criteria in the original studies and the number accepted by the 'K-G' criterion and the Scree test as applied to the re-analysis carried out on the original data. Exhibit 6.1 shows the number of factors for each of the methods. It may be seen that the number of factors extracted and identified in the original studies is far in excess of those which would be accepted using the Scree test but in six of the eight cases the K-G criterion gives within one factor of the number which the investigators claimed they could identify. However, in the other two cases, the difference was four and five factors.

The alternative to these psychometric tests is to use statistical techniques, although they have their problems, and in studies such as those analysed here we are concerned with the meaningfulness of the decision. As Harman (1976, p. 185) says, "Statistical significance provides an upper limit of the number of factors that might be of practical significance." His suggestion of another practical approach, which agrees well with the Scree tests, to determine the percentage variance accounted for by each factor and if after say 75% of the variance is accounted for, any additional factor accounts for less than 5%, it would not be retained. The basis of this decision is that "any factor having such small impact on the total variance could hardly have any practical significance." Even if the factor was a mainly common factor and was not swamped by error variance of either sampling error or experimental error, the contribution it makes to the understanding of the presumed underlying factor pattern is negligible. The problem is deciding at what magnitude of percentage variance we draw the line. However, if we make explicit our decision, and this is probably deciding whether to accept 5% or 10% of total variance or thereabouts, it can then be left to further investigations to determine whether one too many or one too few factors has been accepted. There is no clear evidence for the implications of overfactoring or underfactoring. Kaiser (1963) concludes that overfactoring is invariably disastrous, whereas Cattell (1978) agrees with Thurstone when he says "that if one is to make an error, it is better to take out one too many factors than lose real information by taking one too few." Therefore for Kaiser, Cattell and Thurstone it is important to determine the number of common factors to within k - 1, where k is the actual number of factors. An extra "superfluous factor is likely to be squeezed out when demanded by rotation" (Cattell 1978). This may happen in two ways:

1. by giving up its variance to other factors, or

2. by it 'blending' with another factor - this collapse means that the two reference vectors are being forced to lie on one hyperplane.

However, problems arise when overfactoring or underfactoring by two or more factors occurs. These problems are evident when the next stage in a factor analysis is attempted, that of rotation. This will be discussed later.

If we return to Exhibit 6.1 and we base the number of factors to be extracted on the Scree test which Cattell claims "has had the most extensive theoretical analysis and practised testing" of any of the psychometric tests, then we can see that the K-G criterion overfactors by more than one factor in five of the studies. More importantly, the Centroid method has been, as stated earlier, described by Thurstone and Harman as a computational compromise and only approximated the Principal Factor method. Consequently, the factor pattern or solution obtained from that method will also be approximate and has implications for the determination of the real number and nature of the factors obtained in comparison with the principal factor method. From Exhibit 6.1 it may be seen that, in comparing the original studies with the principal factor re-analysis, the Centroid method in combination with the two criteria used by the investigators for determining the number of factors to be extracted (as stated earlier) resulted in overfactoring in all cases. The magnitude of the overfactoring ranges from two extra factors in one study to three times the number of factors obtained in the re-analysis of two studies. This magnitude of overfactoring seriously affects the subsequent rotations which were carried out and, consequently, the validity of the claims made for factor interpretations and 'ability' identification. As Cattell (1978) states:

> "Having determined the number of factors, and holding in his hands an unrotated matrix Vo with consistent communalities, the investigator stands at the most perilous phase of a factor analysis. However excellent the mark up to this point, the way in which the next step is carried out - that of finding the uniquely meaningful rotation - will decide whether a conclusion is drawn that is enlightening, or somewhat misleading, or positively absurd."

Rotation

The determination of the number of common factors is a necessary prerequisite to carrying out a rotation. This is because the rotation of an extra factor can "split the hyperplane of a legitimate factor (unless there are large error factors) creating two spurious factors" (Cattell 1978, p. 171). With gross underfactoring, Cattell claims the "distortion is devastating, for the massive variance in the early components has nowhere to go." This results in impressive, but possibly misleading, high loadings.

The necessity for rotation arises because "there is a basic indeterminacy in factor analysis - an infinitude of factorizations of a correlation matrix may account for the observed data equally well . . ., while the principal factor method leads to a unique solution, in the mathematical sense, . . . the search for a psychologically meaningful solution, which could be obtained by rotation from some arbitrary factorization of the correlation matrix, led Thurstone to formulate the concept of 'simple structure'" (Harman 1976).

The rotation which is of interest here is that of orthogonal rotation. In this the axes are kept at 90^{o} to one another and rotated. Originally, this was accomplished graphically. The problem arises to where should the axes be rotated? It was Thurstone who proposed the intuitive concept of simple structure (Thurstone 1935). He later extended the concepts to five criteria (Thurstone 1947). What is important is that it has been difficult to translate the intuitive concepts of simple structure into precise mathematical formulations. Many attempts were made up until the middle 1950's to make the process of rotating a number of factors to simple structure as easy as possible. One of these graphical methods was proposed by Zimmerman in 1946 and it was this method that Fleishman has used in eight out of the nine studies being re-analysed in this chapter. The other method used by Fleishman is not detailed other than that it was carried out on a computer. Zimmerman (1946) proposed a method which eliminated the calculation of the numerical values of the intermediate coordinates. It required only an ordinary drawing board, T-square and drawing triangle. This method was less laborious than other methods but at the cost of accuracy. As Harman (1976, p. 258) says about it:

> "As a result of many rotations, and the inaccuracies of plotting, the basic relationship - product of the factor matrix by its transpose - for the final rotated factors may not agree with that of the initial factors."

Earlier in this chapter the 'Centroid' method was discussed and it was noted that it provides an approximate solution compared with the principal factor method. Fleishman and his collaborators in nearly all their studies used the 'Centroid' method and in eight out of the nine studies which have been re-analysed in this chapter, the 'Centroid' method was used (Exhibit 6.1). This approximate factor pattern was then subjected to a rotation method devised by Zimmerman to ease the labour of computation, but it was recognized that it did so at the cost of accuracy.

There is a further and more fundamental difference between the results obtained from these nine original studies, and those results which are obtained from the more exact principal factor method followed by a rotation, such as 'Varimax', carried out on a computer. The original rotations were based on an intuitive notion of simple structure and it was recognized that the procedure was more of an art than a science. Consequently, the search for an objective basis to rotation led to a departure from the Thurstone criteria which were mainly stated in qualitative terms. It was Carrol in 1953 who produced the first wholly analytic rotation criteria for determining psychologically interpretable factors. Kaiser (1958, p. 188) saw that Carrol's work was "the first attempt to break away from an inflexible devotion to Thurstone's ambiguous, arbitrary, and mathematically unmanageable qualitative rules for his intuitively compelling notion of simple structure."

Consequently, with the development of analytic, mathematical techniques for obtaining a unique derived solution, there has been a move away from Thurstone's original notion of simple structure. Therefore, it would be expected that just on this basis, apart from the earlier comments on approximate methods, a difference would be found between the derived solutions obtained from the original studies and those obtained using the computerised analytic methods.

Comparison of Centroid with Principal Factor, and Zimmerman with Varimax solutions obtained in the nine studies - Exhibits 6.4 to 6.21

As was previously stated, in nine of the published studies carried out by Fleishman and his co-workers the intercorrelation matrix was included. This determination of the intercorrelations between the variables using the Pearson product-moment correlation is a common first step to almost all factor analysis methods. The availability of these nine intercorrelation

Exhibit 6.4 Comparison of Centroid factor pattern obtained in original study in Fleishman 1954 with the factor pattern obtained from a reanalysis of the original data using the Principal Factor method

	CENTROID METHOD FACTORS												PRINCIPAL FACTOR FACTORS										
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11
Steadiness - Precision 1	29	25	13	-19	-09	-16	-14	09	21	-10	-12	-13	25	27	03	24	-00	-23	04	08	-08	-02	03
Steadiness - Aiming	30	28	09	-20	-08	-22	-15	07	22	-16	14	09	27	29	-01	21	03	-28	09	20	-02	14	-03
Track Tracing	57	26	15	-21	-16	-08	-21	05	13	-22	06	06	55	33	16	26	-00	-40	21	17	-00	06	07
Two Plate Tapping	61	-14	06	-22	-05	08	13	-25	07	19	-09	-06	63	-06	-02	23	-25	03	-36	-04	05	-08	17
Key Tapping	37	03	11	-13	-08	-03	17	-10	-10	12	-10	-22	34	05	04	25	-18	10	-37	05	17	-27	25
Ten Target Aiming - errors	11	27	-21	23	-14	-28	23	12	11	12	23	-07	07	33	-17	-19	12	08	-08	39	08	-04	-04
Ten Target Aiming - corrects	49	-26	27	-22	20	17	-05	-06	09	08	-24	18	55	-25	18	22	-03	-08	-15	-34	-25	08	-10
Rotary Aiming	59	-28	09	-09	08	09	05	-13	09	05	13	10	66	-21	-04	01	-01	08	-20	03	-14	33	-00
Visual Reaction time	44	-19	24	08	-27	32	-13	19	-23	18	13	-03	46	-13	42	01	-37	39	33	08	04	08	02
Auditory Reaction time	30	-20	25	13	-27	15	-08	20	-25	23	14	-11	29	-15	33	01	-21	26	15	10	08	-00	04
Minnesota Rate of Manipulation - Placing	64	-12	19	11	03	09	09	-07	15	04	08	-06	64	-05	16	-07	05	-00	-10	05	-05	05	10
M R M - Turning	67	02	09	17	09	02	14	06	02	09	-05	07	70	01	12	-04	14	10	-19	-07	-10	08	-07
Purdue Pegboard RH	49	-10	33	28	-03	05	04	-07	06	-14	-04	-07	53	-06	39	-13	07	-21	04	11	-02	-07	12
Purdue Pegboard LH	48	09	16	21	20	03	05	-13	-11	-22	03	06	48	04	19	-14	25	-03	-01	-07	11	-04	-05
Purdue Pegboard both hands	54	10	26	31	16	05	-05	-09	11	-09	08	08	54	05	31	-16	24	-03	-02	-08	15	-01	-03
Purdue Pegboard Assembly	57	12	10	28	15	05	08	09	-12	-14	09	13	56	10	19	-17	28	11	08	02	05	-05	-06
O'Connor Finger Dexterity	57	07	26	22	15	01	07	-07	-06	-10	-08	-05	58	02	24	-14	21	-04	-05	-06	16	-12	02
Santa Ana Dexterity	48	-02	-06	08	22	-20	26	07	06	12	07	12	48	-02	-14	-04	26	12	-13	16	-00	01	-12
Hand Precision Aiming errors	31	41	-21	29	-39	12	05	-33	25	11	-04	14	29	61	02	-42	-33	-07	-20	05	-03	03	-10
Hand Precision Aiming corrects	26	-34	20	-29	33	-23	12	33	-12	-12	09	-11	28	-44	-07	42	41	05	13	15	-02	-08	06
Discrimination Reaction time	54	28	-24	-03	16	23	11	16	-07	-05	-08	-14	51	35	-15	01	16	25	13	-17	-04	-07	13
Complex Coordination	53	36	-11	-07	-04	17	03	09	-05	-13	-20	-09	48	44	-04	09	06	08	10	-18	-10	-18	03
Rudder Control	23	28	-16	-24	-13	-06	03	08	-20	09	-15	.06	18	31	-15	28	-06	10	07	-07	11	-16	-23
Rotary Pursuit	48	15	04	-19	-08	-07	10	05	-16	17	-21	22	46	16	00	24	-07	09	-08	-02	03	-11	-26
Dynamic Balance	20	20	-04	-10	-04	19	-08	04	-09	08	-06	22	18	23	04	11	-06	10	10	-23	01	02	-21
Postural Discrimination - vertical	24	21	-18	-09	15	07	-19	-11	-14	11	17	-11	20	20	-14	08	03	07	05	-14	35	25	13
Postural Discrimination - angular	15	23	-12	-17	22	10	-23	-12	-03	18	22	-10	11	20	-09	13	04	06	07	-19	26	31	10
Punch Board	62	-08	15	02	-18	-07	-04	-09	25	02	-08	-13	62	-01	15	05	-10	-15	-07	00	-10	-01	-04
Pin stick	52	03	06	-03	10	-14	06	-11	04	08	-08	08	53	02	-02	06	09	-05	-16	00	00	14	-20
Medium Tapping	67	-25	-14	-18	-10	-11	24	-06	-09	-12	22	11	69	-14	-14	09	-14	16	11	28	00	05	-14
Large Tapping	64	-25	-14	-19	-11	-13	19	-13	-13	-14	16	04	64	-13	-20	09	-09	03	00	19	02	-01	-11
Aiming	67	-40	-16	05	08	-16	-21	-16	-01	08	-12	06	70	-31	-22	-11	-13	-17	01	-07	13	02	-05
Pursuit Aiming I	65	-40	-17	12	05	-23	-15	-15	06	05	-10	-05	70	-33	-20	-18	-10	-16	-00	-04	25	-10	-01
Pursuit Aiming II	66	-35	-26	13	09	-22	-27	-07	-11	-04	-13	02	69	-29	-30	-17	-07	-16	15	-06	19	-06	-03
Square Marking	47	-20	-13	07	-13	05	-08	13	04	-11	-11	05	48	-10	-08	-10	-12	-02	20	01	-17	-19	-01
Tracing	45	-06	-15	-05	-15	16	-11	-09	11	-20	-03	04	46	08	-13	-06	-15	-13	16	-14	-17	00	09
Steadiness	34	10	06	-05	-18	-06	-18	02	10	10	10	-08	31	14	05	07	-13	-09	08	10	04	08	05
Printed D R T	50	19	-24	-03	07	08	15	19	17	05	-01	-13	47	29	-21	-00	10	17	03	02	-11	-00	14
Log Book Accuracy	58	-12	-29	11	11	13	14	21	26	02	03	-06	59	01	-25	-17	09	22	-05	09	-24	11	16
Marking Accuracy	60	-21	-26	08	10	11	-08	11	12	-17	-08	-04	61	-08	-23	-15	-01	-08	21	-17	-13	-06	09

Exhibit 6.5 Comparison of the factor pattern obtained from a Zimmerman Graphical Rotation in the original study in Fleishman 1954, with the factor pattern obtained from a reanalysis of the original data using the Varimax Rotation method.

	ZIMMERMAN ROTATION FACTORS												VARIMAX ROTATION FACTORS										
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11
Steadiness – Precision 1	-02	01	11	09	50	-02	03	-02	07	25	02	04	01	07	47	-05	12	-00	12	-02	01	11	02
Steadiness – Aiming	06	07	06	02	60	-05	03	11	07		15	01	04	06	54	-04	03	01	-03	10	10	10	09
Track Tracing	19	21	21	05	61	12	-05	13	16	15	13	-02	16	27	78	09	10	-01	05	-02	04	12	10
Two Plate Tapping	36	02	54	15	05	12	24	02	12	21	02	-10	31	14	16	13	11	02	63	-13	32	10	07
Key Tapping	23	03	19	03	06	15	24	-16	12	28	-03	01	09	11	09	09	08	-02	70	02	06	10	04
Ten Target Aiming errors	06	-03	-35	-10	06	-22	45	15	01	07	19	-04	-04	06	09	-07	11	13	01	56	05	03	-00
Ten Target Aiming corrects	06	15	66	24	07	07	05	11	15	00	-04	19	22	27	11	07	08	-09	15	-54	41	15	-07
Rotary Aiming	36	18	46	14	04	15	20	23	-03	-02	08	01	33	22	09	16	15	-04	12	-10	63	-07	10
Visual Reaction Time	11	12	19	09	-02	73	02	15	09	05	02	02	15	17	05	85	09	03	03	-10	09	10	03
Auditory Raction Time	10	04	05	09	-03	68	11	02	02	00	-02	05	08	17	-01	56	-01	-03	10	-04	04	01	-01
Minnesota Rate of Manipulation – Placing	22	31	36	15	12	22	32	20	-06	14	-01	-06	25	43	18	18	18	01	19	-04	31	-06	00
M R M – Turning	20	34	21	19	09	17	38	24	21	15	-01	02	20	49	09	10	24	02	15	-07	45	13	02
Purdue Pegboard RH	11	46	22	19	14	25	19	05	-09	10	-18	-05	19	54	30	22	04	02	09	-07	06	-16	-14
Purdue Pegboard LH	19	58	13	08	06	02	13	06	08	08	07	02	16	56	07	03	09	-01	02	01	09	08	06
Purdue Pegboard both hands	10	61	14	15	09	19	21	06	10	02	12	-02	13	66	10	11	06	02	04	-02	11	06	06
Purdue Pegboard – Assembly	17	55	03	07	08	15	21	25	18	07	06	07	14	59	08	15	23	-03	-04	12	13	12	03
O'Connor Finger Dexterity	15	53	19	16	10	13	25	02	10	18	-01	05	21	64	09	09	10	-01	15	-00	07	06	04
Santa Ana Dexterity	26	16	09	10	05	-09	47	25	15	-01	05	11	22	30	02	-04	17	-14	06	25	36	11	01
Hand Precision Aiming errors	02	13	01	02	17	01	15	15	26	13	00	-77	06	16	21	01	16	78	08	23	10	14	01
Hand Precision Aiming corrects	27	03	14	04	09	04	16	07	-14	01	-01	69	16	13	08	03	06	-77	06	-03	16	-00	-04
Discrimination Reaction time	16	21	05	01	00	02	10	32	28	53	05	18	12	25	09	04	58	-00	08	08	05	28	22
Complex Coordination	12	23	09	03	19	05	-01	17	36	51	07	-05	08	25	25	01	47	10	12	-01	-01	38	08
Rudder Control	16	-11	-03	-02	14	02	-01	-02	45	20	02	10	04	-03	14	-01	09	-01	10	09	-03	53	10
Rotary Pursuit	21	04	22	08	16	10	17	03	55	04	04	00	14	16	17	09	05	-01	20	01	22	47	-01
Dynamic Balance	-01	05	13	-04	03	10	-08	13	35	03	-07	13	-00	08	06	08	09	11	-06	-12	04	38	12
Postural Discrimination – Vertical	10	07	03	04	-01	03	02	00	00	18	48	-05	08	07	08	01	07	02	06	05	01	08	55
Postural Discrimination – Angular	-01	-02	11	-02	00	00	03	-01	05	12	55	-03	-01	01	09	-00	07	01	-01	-04	04	09	52
Punch Board	25	15	29	29	30	22	21	05	00	20	-07	-12	30	32	31	15	09	07	18	-14	26	10	-09
Pin Stick	23	19	25	19	16	-03	28	05	20	07	06	00	23	29	17	-02	03	-00	07	00	41	19	07
Medium Tapping	74	10	22	03	13	11	18	26	08	01	02	02	48	11	18	36	13	-15	10	19	39	19	-01
Large Tapping	74	10	21	08	12	09	11	16	05	06	03	03	50	12	18	17	10	-12	16	14	34	16	-01
Aiming	45	12	28	63	01	08	13	18	04	-02	11	00	75	23	07	07	04	-02	13	-08	24	02	09
Pursuit Aiming 1	50	14	16	63	00	09	18	11	-01	02	05	00	78	32	01	06	-00	-03	19	-00	13	-00	07
Pursuit Aiming 2	48	18	08	68	02	05	05	19	07	03	12	06	81	24	06	05	09	-07	05	00	11	04	10
Square Marking	29	12	07	30	07	19	-05	30	11	12	-10	01	44	13	11	18	27	-00	01	-05	04	09	-20
Tracing	28	14	21	16	15	07	-15	27	04	17	01	-18	37	08	23	06	32	13	00	-15	06	06	01
Steadiness	07	-01	10	13	31	22	10	06	02	10	15	-11	13	08	31	16	06	08	07	03	07	04	09
Printed D R T	14	04	07	05	13	-02	26	38	15	42	11	-02	14	14	17	02	50	03	10	17	17	14	13
Log Book Accuracy	23	08	12	20	00	03	28	59	-01	29	01	-01	30	16	03	08	53	00	08	15	41	-09	03
Marking Accuracy	29	20	15	37	02	03	01	46	-01	26	02	04	57	20	11	04	41	-01	-03	-12	09	04	02

Exhibit 6.6 Comparison of Centroid factor pattern obtained in original study in Fleishman & Hempel, 1954B with the factor pattern obtained from a reanalysis of the original data using the Principal Factor method

	CENTROID METHOD FACTORS										PRINCIPAL FACTOR FACTORS			
	1	2	3	4	5	6	7	8	9	10	1	2	3	4
Stage 1	79	04	20	-17	-09	-11	-13	13	07	10	80	02	-22	05
Stage 2	83	34	12	03	-07	-05	-16	08	14	-13	85	-27	-10	-02
Stage 3	85	33	07	01	-08	-07	-05	13	04	-05	87	-26	-04	03
Stage 4	83	43	13	13	02	04	-06	-04	-09	-12	86	-39	-03	-05
Stage 5	80	48	13	10	03	10	-05	-10	-01	01	84	-44	-01	-07
Stage 6	75	52	07	14	09	13	-02	-09	05	-02	78	-49	03	-11
Stage 7	77	48	09	15	06	08	05	05	-06	14	81	-44	02	-10
Stage 8	76	48	14	15	07	11	10	04	-02	02	79	-45	-00	-13
Numerical Operations	49	-35	-21	21	21	19	-11	19	09	-10	45	35	16	-15
Dial and Table Reading	71	-44	-08	07	22	10	-10	12	14	04	68	47	03	-12
Mechanical Principles	56	-29	33	-14	23	-04	-12	-10	07	05	55	30	-32	-09
General Mechanics	45	-20	13	-26	36	-15	-06	07	-22	-05	42	22	-31	09
Speed of Identification	68	-37	02	15	-17	-08	-03	-10	-05	-03	65	40	12	-07
Pattern Comprehension	65	-35	07	-17	-14	05	-10	-17	11	15	63	40	-06	07
Visual Pursuit	55	-11	12	10	-18	-08	14	-04	14	-13	54	13	-01	-04
Decoding	62	-41	06	-03	-17	27	-05	17	-12	14	59	46	-01	01
Instrument Comprehension	57	-25	-08	-17	-09	19	14	15	-04	-15	54	29	-02	17
Spatial Orientation	64	-31	14	07	-11	-08	20	08	-10	15	61	33	-03	-08
Speed of Marking	60	-23	-14	24	-13	-14	-08	-07	-05	19	58	25	28	-15
Log Book Accuracy	53	-21	-25	30	05	-22	-08	-18	-04	11	50	23	35	-11
Rotary Pursuit	60	17	-10	-13	04	-17	15	13	10	08	59	-10	-00	17
Plane Control	47	16	-07	-29	-03	-07	-09	-03	-13	-09	47	-11	-09	36
Discrimination Reaction Time	64	-22	-15	-12	-18	12	-16	03	-07	-10	62	29	08	23
Nut and Bolt	41	-07	10	-18	08	-10	15	-09	-03	-11	39	09	-15	11
Reaction Time	27	24	-39	03	-05	03	10	-11	-19	-04	27	-21	42	28
Rate of Movement	39	13	-31	-06	-08	06	08	-21	14	13	38	-07	28	16

Exhibit 6.7 *Comparison of the factor pattern obtained from a Zimmerman Graphical Rotation in the original study in Fleishman & Hempel, 1954B with the factor pattern obtained from a reanalysis of the original data using the Varimax Rotation method*

	Zimmerman Rotation Factors										Varimax Rotation Factors			
	1	2	3	4	5	6	7	8	9	10	1	2	3	4
Stage 1	24	48	10	39	20	38	28	03	22	02	55	39	48	01
Stage 2	45	62	26	24	26	17	21	04	15	-15	79	28	32	11
Stage 3	41	60	33	29	27	16	19	03	18	01	78	30	32	18
Stage 4	62	45	38	20	25	06	25	00	18	-03	87	24	22	15
Stage 5	65	46	40	11	16	13	22	00	15	01	89	20	19	16
Stage 6	63	47	43	02	15	12	20	06	09	-01	90	16	10	16
Stage 7	60	48	40	12	13	13	16	06	17	21	88	20	13	15
Stage 8	62	47	37	10	22	10	18	04	08	17	88	19	12	12
Numerical Operations	07	07	05	21	25	03	16	66	09	-05	10	60	07	04
Dial and Table Reading	07	13	03	26	32	30	30	60	21	00	18	77	30	-01
Mechanical Principles	17	06	-14	15	24	41	49	14	20	-02	23	46	43	-25
General Mechanics	-03	05	00	26	14	06	62	08	16	13	15	27	47	-13
Speed of Identification	12	01	10	35	47	29	08	21	37	-09	19	72	23	09
Pattern Comprehension	07	04	10	33	23	60	19	18	21	-11	16	59	43	05
Visual Pursuit	15	20	09	16	50	24	02	04	11	-06	30	41	22	04
Decoding	17	-03	01	59	22	36	06	35	10	11	11	65	36	03
Instrument Comprehension	02	09	20	46	35	20	16	24	-12	03	14	45	41	14
Spatial Orientation	10	07	04	35	45	32	09	12	27	26	23	60	29	-01
Speed of Marking	10	09	20	23	26	24	-03	26	50	00	25	65	02	16
Log Book Accuracy	03	05	27	04	27	12	07	31	55	-05	19	59	-03	23
Rotory Pursuit	03	48	34	12	21	18	18	06	10	17	43	21	32	23
Plane Control	07	25	33	29	04	09	29	-10	07	-09	32	05	44	26
D R Time	08	12	25	52	22	23	13	24	12	-18	18	50	41	27
Nut and Bolt	03	08	14	12	29	17	32	-07	03	03	20	20	34	01
Reaction Time	06	08	54	08	03	-11	-03	03	07	01	22	05	-03	57
Rate of Movement	03	17	48	-01	04	28	-03	12	07	-05	24	20	06	38

EXHIBIT 6.8 Comparison of Centroid factor pattern obtained in original study in Fleishman and Hempel, 1955, with the factor pattern obtained from a reanalysis of the original data using the Principal Factor method.

	CENTROID METHOD FACTORS											PRINCIPAL FACTOR FACTORS				
	1	2	3	4	5	6	7	8	9	10	11	1	2	3	4	5
Trial 1, DRT	67	29	20	-14	08	-24	-08	09	05	05	-12	71	-03	-29	02	08
Trial 3, DRT	77	23	25	-19	18	-15	-13	13	05	-06	10	81	06	-29	02	-00
Trial 5, DRT	79	26	28	-19	08	-12	-11	-09	-03	06	09	84	08	-32	00	01
Trial 7, DRT	78	20	36	-17	04	-04	-08	-02	11	05	01	82	18	-31	-03	03
Trial 9, DRT	78	16	35	-16	06	09	-02	-05	04	08	06	81	21	-28	-02	06
Trial 11, DRT	73	20	37	-14	-10	15	10	-05	01	-05	-03	77	19	-29	-06	03
Trial 13, DRT	75	17	30	-15	-03	13	13	05	-16	-12	-11	78	15	-24	-02	-01
Trial 15, DRT	76	13	35	-11	-17	19	18	-05	-07	-03	-01	78	23	-21	-04	07
Word Knowledge	54	27	-32	26	27	18	-13	-11	09	-10	-12	54	-38	17	-33	-23
Background Current Affairs	56	32	-26	28	33	16	-04	-15	06	-05	-07	57	-38	14	-42	-32
Mechanical Principles	60	28	-38	15	-18	-07	16	07	14	-12	04	60	-45	19	-04	16
General Mechanics	49	32	-44	29	-24	07	-20	19	-08	10	04	48	-52	26	-15	29
Tool Functions	43	25	-46	19	-29	-12	-08	16	-18	08	18	42	-52	25	01	40
Speed of Identification	62	-03	-23	-07	23	-03	16	-13	-12	-07	-03	61	-11	19	08	-28
Pattern Comprehension	59	21	-32	02	14	-11	14	-10	-04	-07	02	60	-36	12	-00	-15
Instrument Comprehension	64	16	-25	07	-03	-11	13	-06	06	08	-02	64	-26	15	01	05
Visual Pursuit	40	-14	-28	-14	-09	-16	11	-03	12	05	06	37	-11	25	31	02
Purdue Pegboard Assembly	49	-16	-19	-18	14	09	15	-04	-22	15	06	47	-01	19	22	-22
Santa Ana Dexterity	54	-20	-07	-22	17	08	-13	19	-12	-08	-08	52	12	13	22	-18
Rate of Movement	36	-14	-08	-08	08	19	-16	-02	20	-05	10	34	07	14	09	-03
Rotary Aiming	32	-45	-11	-21	-12	23	-09	-21	03	-04	06	27	25	31	26	-12
Visual Reaction Time	29	-48	41	31	-11	-12	-10	-12	-03	06	-20	23	62	26	-20	17
Auditory Reaction Time	24	-38	30	43	-10	-06	-11	-11	-17	-13	05	17	47	30	-31	19
Jump Vis. Reaction Time	50	-58	25	27	04	11	08	11	15	17	-03	42	58	43	-10	01
Jump Aud. Reaction Time	44	-56	26	26	12	10	13	09	07	-09	15	37	56	40	-12	-05
Complex Coordination	61	-07	-17	-18	-10	-23	09	13	10	06	-13	60	-05	14	32	09
Rotary Pursuit	44	-22	-12	-20	-16	-16	-13	10	03	-05	-07	41	05	18	31	12

EXHIBIT 6.9 Comparison of the factor pattern obtained from a Zimmerman Graphical Rotation in the original study in Fleishman ana Hempel, 1955, with the factor pattern obtained from a reanalysis of the original data using the Varimax Rotation method.

	ZIMMERMAN ROTATION FACTORS											VARIMAX ROTATION FACTORS				
	1	2	3	4	5	6	7	8	9	10	11	1	2	3	4	5
Trial 1, DRT	41	11	04	22	25	00	10	15	60	-03	01	-02	71	16	21	12
Trial 3, DRT	47	15	00	20	28	17	08	17	58	02	26	04	80	23	14	18
Trial 5, DRT	56	16	05	08	23	21	19	17	56	-14	13	06	84	21	14	18
Trial 7, DRT	52	22	00	12	21	29	09	07	58	-06	05	14	85	19	10	14
Trial 9, DRT	52	24	09	05	14	39	13	07	52	-04	01	18	83	20	11	11
Trial 11, DRT	60	23	10	11	14	37	15	01	39	08	-08	16	80	15	08	13
Trial 13, DRT	62	23	10	18	16	30	21	19	31	18	-07	14	76	22	09	17
Trial 15, DRT	59	30	15	10	07	41	23	04	33	10	-11	23	77	20	12	11
Word Knowledge	07	01	13	-02	78	15	13	10	15	04	-09	01	21	09	33	68
Background Current Affairs	13	04	10	-11	77	11	21	08	17	07	-06	03	25	05	28	79
Mechanical Principles	02	02	44	28	43	11	36	-11	27	14	-02	-05	26	24	63	32
General Mechanics	-09	00	70	04	44	09	08	18	25	04	-06	-02	13	09	75	30
Tool Functions	-10	-01	60	09	25	-02	26	17	20	00	08	-08	09	15	78	12
Speed of Identification	13	08	-05	13	37	18	51	23	16	04	00	05	29	48	14	43
Pattern Comprehension	13	-02	15	12	46	05	48	09	24	04	04	-11	29	32	35	46
Instrument Comprehension	05	11	23	13	36	11	41	03	37	00	-08	02	34	31	44	30
isual Pursuit	-15	02	07	25	07	18	37	02	25	-05	03	00	09	48	26	04
urdue Pegboard Assembly	03	06	-01	-03	08	27	46	35	18	06	00	05	20	50	06	22
anta Ana Dexterity	09	08	-07	24	17	31	10	46	20	12	07	12	31	49	02	16
ate of Movement	04	06	06	13	16	45	00	02	13	-06	06	14	17	28	09	09
otary Aiming	-09	10	-07	15	-04	57	17	15	-07	-18	-02	26	03	49	-05	00
isual Reaction Time	-05	72	-13	13	-06	07	-07	10	01	-24	-20	73	16	06	-07	-10
uditory Reaction Time	-08	68	05	06	04	05	-02	09	-20	-18	03	68	06	-04	04	-01
ump V Reaction Time	-15	73	-16	05	03	36	05	11	21	10	-09	75	17	33	-03	07
ump A Reaction Time	-05	70	-19	08	06	33	11	07	01	16	15	71	14	29	-09	10
omplex Coordination	-01	09	08	41	10	14	31	15	45	04	-07	04	35	52	31	02
otary Pursuit	-04	09	07	42	01	21	12	22	23	-10	02	11	21	45	22	-08

EXHIBIT 6.10 Comparison of Centroid factor pattern obtained in original study in Fleishman 1958B, with the factor pattern obtained from a reanalysis of the original data using the Principal Factor method.

CENTROID METHOD — FACTORS

	1	2	3	4	5	6	7	8	9	10
Two-Hand Coordination	45	-23	17	10	-13	15	05	12	-18	09
Rotary Pursuit	44	-13	23	05	12	-28	09	-29	18	-04
Complex Coordination	47	08	32	-09	14	-06	-13	-11	-06	03
Plane Control	42	-08	28	09	06	11	-26	12	09	-17
Pursuit Confusion TOT	34	-04	13	-14	-23	-11	12	13	02	-19
Pursuit Confusion Errors	31	-24	14	13	-06	-18	-21	06	08	-22
Disc. Reaction Time	58	04	-08	-20	-28	25	-14	-15	13	-16
Motor Judgment	42	-24	22	-08	-15	-15	18	07	03	08
Visual Coincidence	32	-09	-10	-14	-18	20	-07	05	06	09
Two-Hand Pursuit	50	-22	18	-15	11	09	-15	25	11	06
Single-Dimension Pursuit	40	09	11	-14	26	17	07	-15	13	13
Rate Control	40	-04	10	28	-16	-07	15	11	20	06
Dial Setting	49	-06	08	-36	-16	06	13	-03	12	10
Controls Adjustment	45	-15	27	-25	16	03	14	-06	06	14
Rotary Aiming	30	-14	-26	-05	19	-12	20	-20	05	-12
Visual Reaction Time	27	-24	-46	10	19	04	09	03	12	17
Auditory Reaction Time	31	-30	-43	12	13	09	-11	12	17	16
Jump V Reaction Time	39	-33	-51	10	23	08	13	-06	-13	-13
Jump A Reaction Time	46	-27	-53	25	15	09	07	09	-13	-15
Track Tracing	33	-21	05	-21	16	-27	-27	-14	-09	12
Steadiness-Precision	28	-19	-11	-15	-04	-17	-26	13	-23	14
Rudder Control - Single Target	54	-25	38	30	-14	19	05	-11	-21	06
Rudder Control - Triple Target	53	-26	37	36	-15	17	11	-12	-19	07
Printed Discrimination Reaction Time	46	-03	-14	-36	-06	10	-07	-23	12	-17
M.P. Bank	41	44	06	15	12	10	-09	-10	-03	-10
M.P. Heading	48	51	-11	17	-08	-08	-08	-15	03	16
M.P. Air Speed	49	48	-20	12	-21	-27	04	08	12	08
M.P. Bank & Altitude	64	39	08	-04	12	04	13	25	-13	-08
M.P. Bank & Air Speed	55	65	-09	-08	02	-04	13	16	-19	-04
M.P. Bank & Heading	69	54	-06	03	08	-09	-04	06	-05	11
M.P. Bank, Heading & Air Speed.	59	54	-03	08	-09	-10	09	10	06	-08

PRINCIPAL FACTOR — FACTORS

	1	2	3	4	5	6	7	8
Two-Hand Coordination	43	35	-20	08	28	02	08	-18
Rotary Pursuit	46	28	-01	-04	-65	22	09	09
Complex Coordination	50	10	-14	-22	-17	-14	-05	-07
Plane Control	41	21	-19	-08	03	-05	00	-08
Pursuit Confusion TOT	34	09	-06	-18	05	09	01	24
Pursuit Confusion Errors	27	28	-08	-04	02	11	15	07
Disc. Reaction Time	58	07	19	-16	25	10	-19	12
Motor Judgment	39	31	-07	-08	-01	10	00	17
Visual Coincidence	29	12	13	-03	26	07	01	02
Two-Hand Pursuit	47	30	06	-13	09	-16	01	00
Single-Dimension Pursuit	41	02	15	-08	-10	-13	-25	-17
Rate Control	39	10	-11	17	03	20	-06	15
Dial Setting	48	19	16	-24	06	-01	-15	19
Controls Adjustment	44	29	05	-20	-12	-11	-16	-05
Rotary Aiming	26	08	48	14	-12	24	12	-20
Visual Reaction Time	20	15	43	61	-07	-39	02	24
Auditory Reaction Time	18	15	18	19	07	01	01	06
Jump V Reaction Time	21	19	29	15	06	32	-17	-29
Jump A Reaction Time	30	05	07	06	18	17	29	-07
Track Tracing	28	26	19	-21	-17	-18	28	-12
Steadiness-Precision	22	14	07	-18	15	-18	46	02
Rudder Control - Single Target	53	42	-32	26	05	-01	-03	-10
Rudder Control - Triple Target	53	44	-35	36	-01	-04	-05	01
Printed Discrimination Reaction Time	42	08	34	-19	08	-05	-12	03
M.P. Bank	47	-32	-13	08	-09	-10	-01	-08
M.P. Heading	54	-43	-03	09	-06	09	08	01
M.P. Air Speed	55	-47	05	07	03	24	13	17
M.P. Bank & Altitude	69	-27	-08	00	02	-10	-00	-08
M.P. Bank & Air Speed	64	-58	-02	00	06	-13	-02	-05
M.P. Bank & Heading	74	-45	02	04	-02	-10	04	-14
M.P. Bank, Heading & Air Speed.	67	-47	-08	01	-03	05	-02	09

EXHIBIT 6.11 Comparison of the factor pattern obtained from a Zimmerman Graphical Rotation in the original study in Fleishman 1958B, with the factor pattern obtained from a re-analysis of the original data using the Varimax Rotation method

	ZIMMERMAN ROTATION FACTORS										VARIMAX ROTATION FACTORS							
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8
Two Hand Coordination	15	25	13	02	06	33	32	18	-12	-09	06	60	09	-03	14	-14	14	20
Rotary Pursuit	-09	50	-08	17	18	00	05	26	08	28	13	24	22	03	14	79	10	06
Complex Coordination	09	35	06	21	27	30	07	21	19	08	26	25	40	-09	-08	18	15	13
Plane Control	12	02	-01	11	25	41	19	21	03	25	13	39	22	-07	-01	05	15	13
Pursuit Confusion TOT	23	12	-04	01	11	-07	37	24	02	04	14	16	02	-06	-07	13	39	08
Pursuit Confusion Errors	-04	04	05	06	36	11	19	31	-07	18	-01	30	-01	-02	06	17	20	19
Discrimination Reaction Time	67	19	11	03	19	09	03	18	01	18	28	17	20	04	19	-08	58	03
Motor Judgment	07	40	03	01	11	03	40	15	06	06	02	34	08	01	02	21	35	09
Visual Coincidence	36	12	14	-03	08	12	12	15	-10	01	08	16	02	04	18	-13	30	13
Two-Hand Pursuit	18	13	07	18	26	32	37	00	-07	26	07	30	32	10	04	00	31	25
Single Dimension Pursuit	24	27	-02	23	05	25	-06	-09	14	26	23	08	46	07	15	02	14	-05
Rate Control	-03	30	29	-16	-02	17	30	06	14	08	20	35	-08	08	09	14	24	-10
Dial Setting	43	40	-03	05	08	-06	27	-08	-03	13	12	12	28	07	05	09	53	08
Control Adjustment	14	46	-12	24	06	18	22	-11	-04	17	05	24	46	01	06	16	27	08
Rotary Aiming	07	26	17	38	08	-22	-02	18	04	10	10	-05	07	18	58	18	05	15
Visual Reaction Time	01	15	56	24	02	-08	02	-08	-03	11	05	07	07	90	08	01	-02	04
Auditory Reaction Time	06	07	63	18	10	04	06	-06	-11	19	01	12	-00	26	18	00	13	04
Jump V Reaction Time	12	12	54	54	-01	-10	02	18	-09	-05	-01	15	11	03	59	-01	09	-11
Jump A Reaction Time	13	04	64	44	00	-02	13	27	00	-06	18	19	-15	-00	25	-02	12	29
Track Tracing	00	29	09	24	50	00	-03	-09	-02	00	-01	06	31	06	09	20	06	47
Steadiness Precision	06	10	19	09	43	00	17	-09	-05	-19	05	09	01	03	-05	-02	13	59
Rudder Control-single Target	08	44	06	01	03	52	19	44	-13	-09	11	76	15	10	07	08	08	03
Rudder Control-triple Target	04	48	08	-06	-03	48	20	46	-13	-09	11	79	11	22	-00	14	07	-03
Printed Discrimination Reaction Time	52	24	01	24	21	-08	-04	06	-02	19	15	-02	31	12	20	-02	41	13
MP Bank	24	07	10	12	02	21	-12	17	51	05	57	13	15	02	-04	03	-04	-01
MP Heading	24	27	20	-14	10	10	-10	11	61	02	69	05	-02	01	08	10	07	02
MP Air Speed	23	18	22	-19	13	-11	17	12	64	04	71	-01	-20	02	13	11	25	03
MP Bank & Altitude	32	15	02	24	00	26	37	09	56	-03	67	22	22	02	02	-01	14	09
MP Bank & Heading	41	11	02	13	-02	08	22	02	75	-15	85	00	15	01	-02	-11	10	03
MP Bank & Air Speed	31	24	15	09	15	19	14	09	72	04	83	10	22	05	11	-01	08	12
MP Bank, Heading & Air Speed	33	17	10	-01	05	05	23	21	66	08	79	08	04	-01	-01	08	21	03

EXHIBIT 6.12 Comparison of Centroid factor pattern obtained in original study in Fleishman, Roberts and Friedman, 1958, with the factor pattern obtained from a reanalysis of the original data using the Principal Factor method.

	CENTROID METHOD FACTORS						PRINCIPAL FACTOR FACTORS			
	1	2	3	4	5	6	1	2	3	4
Rhythm Discrimination	29	41	-22	-14	-19	12	24	39	10	11
Dot Perception	54	48	05	-04	-04	-19	53	54	-03	-07
Copying Behind	62	29	06	19	16	07	61	32	-01	-07
Hidden Tunes	46	34	-24	-24	-21	-04	43	34	12	07
Army Radio Code	46	28	10	05	28	-06	34	39	05	-24
Four Letter Words	46	-19	14	17	-34	05	45	-13	-16	36
Mutilated Words	58	-17	23	08	-31	16	60	-14	-30	33
Gestalt Completion	46	-43	-06	-15	-06	16	48	-39	03	03
Designs	53	-19	-23	18	-04	-23	52	-10	28	16
Concealed Figures	61	-21	-31	09	18	-11	63	-16	41	-04
Marking Accuracy	32	-20	-07	25	15	17	31	-16	11	02
Word Knowledge	63	-22	39	-30	04	-06	65	-23	-36	-17
Background Curr.Aff.	59	-33	30	-28	27	08	61	-36	-26	-35
Pattern Comprehension	58	-21	-38	-07	15	-13	58	-17	40	-05
Proficiency Criterion	39	39	32	16	-09	-05	37	40	-30	07

EXHIBIT 6.13 Comparison of the factor pattern obtained from a Zimmerman Graphical Rotation in the original study in Fleishman, Roberts, and Friedman, 1958, with the factor pattern obtained from a reanalysis of the original data using the Varimax Rotation method.

	ZIMMERMAN ROTATION FACTORS						VARIMAX ROTATION FACTORS			
	1	2	3	4	5	6	1	2	3	4
Rhythm Discrimination	14	-11	56	13	00	12	45	08	-15	07
Dot Perception	07	10	58	28	32	-19	75	10	10	08
Copying Behind	19	11	32	31	54	07	60	23	21	14
Hidden Tunes	28	04	62	15	-01	-04	50	22	-04	11
Army Radio Code	08	15	30	09	51	-06	53	08	13	-14
Four Letter Words	25	23	02	54	-02	05	09	22	12	55
Mutilated Words	25	38	07	55	03	16	17	21	28	65
Gestalt Completion	50	40	-06	12	-04	16	-07	45	33	26
Designs	54	05	02	27	16	-23	17	56	02	22
Concealed Figures	66	12	4	10	31	-11	20	72	15	05
Marking Accuracy	32	05	-17	15	28	17	03	33	13	11
Word Knowledge	20	76	14	19	16	-06	18	21	68	32
Background Curr.Aff.	28	74	00	01	28	08	06	30	77	14
Pattern Comprehension	69	15	12	-01	20	-13	16	69	14	04
Proficiency Criterion	-16	12	31	44	31	-05	53	-14	15	27

Exhibit 6.14 Comparison of Centroid factor pattern obtained in original study in Fleishman 1960B with the factor pattern obtained from a re-analysis of the original data using the Principal Factor method

	Centroid Method FACTORS 1	2	3	4	5	6	7	8	9	10	11	Principal Factor FACTORS 1	2	3	4	5
Trial 1, RP	70	33	-13	-18	-20	-18	-06	-06	-14	-02	02	74	-18	-07	19	30
Trial 3, RP	79	39	-06	-10	-21	-21	04	04	-16	-10	-04	84	-23	-11	13	28
Trial 5, RP	80	43	08	08	-19	-10	10	04	-10	02	-09	88	-29	-10	-00	12
Trial 7, RP	80	48	13	10	-09	-07	03	08	-03	08	-09	88	-34	-09	02	01
Trial 9, RP	79	46	18	16	-06	08	-07	04	-01	06	04	87	-33	-10	-04	-08
Trial 11, RP	77	46	20	17	-01	04	-07	-06	-02	-07	05	85	-33	-11	-08	-14
Trial 13, RP	76	42	22	24	07	07	-17	-02	08	-07	-02	84	-32	-05	-14	-21
Trial 15, RP	75	38	16	25	14	09	-08	-16	07	05	-08	81	-28	03	-10	-25
General Mechanics	42	-32	38	-38	-18	29	15	13	-07	-12	04	34	47	-49	11	-03
Tool Functions	38	-33	38	-48	-28	16	-03	09	09	-03	-06	31	51	-61	11	05
Speed of Identification	53	-38	06	10	12	-10	-13	23	02	07	17	47	45	12	-16	-06
Instrument Comprehension	49	-40	28	-14	11	-07	07	-09	-08	13	14	42	52	-14	-09	-13
Visual Pursuit	45	-21	-06	-17	06	-06	-22	-04	-16	-07	-06	40	29	02	07	11
Aiming	42	-11	-09	27	-20	-06	14	-09	10	-22	16	41	10	14	-20	11
Marking Accuracy	48	-10	-10	20	16	04	-09	10	-14	-26	08	46	12	22	-10	-00
Purdue Pegboard Assembly	43	-38	-12	08	-08	-16	-11	13	16	14	08	36	41	18	-14	15
Santa Ana Finger Dexterity	56	-21	-08	23	-04	-09	16	05	15	-04	-04	52	25	22	-15	02
Rate Control	32	11	-34	-40	28	16	13	12	19	-02	-07	28	09	16	64	-11
Single Dimension Pursuit meter	34	09	-32	-26	31	17	19	04	15	13	13	29	10	25	54	-20
Rate of movement	37	-14	-13	09	-09	18	16	-24	-05	13	03	32	15	13	-00	04
Rotary Aiming	43	-11	-36	20	-08	21	-15	-08	-09	15	03	40	10	35	-01	15
Jump Visual Reaction time	40	-14	-30	15	13	07	07	05	-19	12	-14	36	16	37	05	06
Track Tracing	51	-14	-05	-06	-05	-10	-22	-05	18	10	-08	48	22	06	02	10
Complex Coordination	60	-26	05	-13	20	-16	-06	-14	02	03	-15	55	38	05	03	-07
Discrimination Reaction time	55	-31	15	06	25	-23	29	-13	12	-09	-07	49	40	08	-14	-20

Exhibit 6.15 Comparison of the factor pattern obtained from a Zimmerman Graphical Rotation in the original study in Fleishman 1960B, with the factor pattern obtained from a re-analysis of the original data using the Varimax Rotation method

	Zimmerman Rotation FACTORS											Varimax Rotation FACTORS				
	1	2	3	4	5	6	7	8	9	10	11	1	2	3	4	5
Trial 1, RP	06	15	51	19	02	52	31	13	00	16	02	66	25	14	19	38
Trial 3, RP	14	32	60	16	07	48	31	19	02	24	-04	79	26	16	15	36
Trial 5, RP	12	50	58	25	07	38	25	10	07	16	-09	87	27	12	07	17
Trial 7, RP	08	61	51	22	04	39	27	12	13	06	-09	91	22	09	12	07
Trial 9, RP	12	65	36	24	-01	41	24	12	18	10	04	90	21	09	08	-03
Trial 11, RP	05	68	31	16	04	45	20	06	16	20	05	90	21	09	06	-09
Trial 13, RP	08	72	22	06	08	48	12	13	24	14	-02	88	24	05	04	-18
Trial 15, RP	-03	64	13	20	17	49	20	09	26	09	-08	82	28	01	11	-22
General Mechanics	81	14	03	-04	15	02	06	05	-05	12	04	10	12	75	06	01
Tool Functions	83	-01	08	-07	06	22	03	04	08	-02	-06	07	07	85	01	09
Speed of Identification	25	16	-01	14	32	02	00	45	33	02	17	11	59	28	02	-14
Instrument Comprehension	41	11	-04	14	50	25	-07	15	03	-06	14	08	43	53	03	-18
Visual Pursuit	20	-04	-06	10	22	36	11	28	02	16	-06	14	37	27	13	11
Aiming	11	08	25	12	23	10	-01	-03	35	36	16	24	42	03	-09	04
Marking Accuracy	02	23	09	11	37	23	19	-01	02	40	08	26	46	01	06	-04
Purdue Pegboard Assembly	12	-10	07	19	25	19	00	31	43	-05	08	02	58	18	-02	06
Santa Ana Finger Dexterity	12	13	20	18	39	09	06	13	42	17	-04	24	57	10	03	-05
Rate Control	01	-02	01	-05	17	01	72	06	10	-01	-07	11	08	09	71	07
Single Dimension Pursuit meter	03	03	-04	-10	18	02	64	-07	06	-09	13	11	16	02	67	-05
Rate of movement	15	05	04	40	21	09	13	00	20	13	03	14	33	07	09	03
Rotary Aiming	-01	00	-05	53	00	09	18	00	27	22	03	18	49	-11	14	12
Jump Visual Reaction time	-03	03	-01	40	28	06	20	24	11	12	-14	11	48	-08	21	05
Track tracing	16	01	04	11	15	42	12	15	35	-04	-08	23	41	21	11	09
Complex Coordination	20	09	-01	09	46	44	13	18	14	02	-15	21	50	34	18	-08
Discrimination Reaction time	15	17	11	-03	72	19	03	05	19	08	-07	17	53	30	07	-25

EXHIBIT 6.16 Comparison of Centroid factor pattern obtained in original study in Fleishman and Ornstein 1960, with the factor pattern obtained from a reanalysis of the original data using the Principal Factor method.

	Centroid Method Factors						Principal Factor Factors						
Maneuver	1	2	3	4	5	6	1	2	3	4	5	6	7
Straight and Level	59	-22	26	08	-17	-28	60	33	-54	10	22	25	-15
90° Climbing Turn	72	-17	-29	-20	-18	24	74	38	26	-14	35	11	27
Level off from Climbing Turn	64	15	-18	-32	32	-06	64	-06	31	-19	14	-11	-27
Gliding Turn	75	13	06	-17	29	05	75	-09	03	-17	18	-04	-16
Level off from Gliding Turn	61	15	25	13	-13	-03	60	-18	-19	02	06	17	-04
Take Off	62	-25	06	-31	-15	07	62	26	10	-19	-14	22	-04
Coordination Exercise	62	-19	26	-24	-17	14	62	17	-02	-27	-10	16	04
Straight and Level Gear Check	46	19	-19	-17	08	-28	46	-04	28	23	-03	-02	-35
Traffic Pattern at Auxiliary Field	54	18	-25	25	-19	-25	53	-10	04	40	34	03	-02
Rectangular Pattern	60	20	-14	17	-14	14	60	-22	09	11	23	-05	32
3-Point Landing	45	-25	-18	-15	-24	-23	45	42	21	39	-27	16	-02
Climbing Turn from Level	65	12	27	-09	06	10	65	-20	-05	-18	-26	12	-05
Land Characteristic Stall	74	-32	-27	11	13	14	74	23	09	08	-09	-25	15
Power-on Stall	67	10	26	08	18	-16	67	-13	-29	-09	13	-04	-16
Approach to Stall	74	-17	11	08	20	18	74	-03	-08	-10	-30	-24	18
Power-off Stall	76	-07	23	30	19	10	77	-08	-32	-02	-04	-08	07
Steep Turn (360°)	59	-29	-17	-08	12	-22	58	29	01	05	-05	-17	-08
Maximum Performance Climbing Turn	16	16	-06	25	-21	17	15	-21	-00	11	04	13	33
Spin	55	-14	-07	29	26	-21	55	04	-16	16	02	-46	-06
Rudder Control Stall	67	-05	-14	07	15	12	66	-03	05	-01	03	-16	01
Slow Flight Turn	68	-13	20	12	-05	04	67	01	-17	-07	-16	00	07
Slow Flight Recovery	77	21	-07	05	-09	16	76	-18	10	05	-07	10	08
Forced Landing	69	31	-05	-24	14	27	70	-25	30	-19	07	09	-06
Traffic Pattern at Home Field	69	33	10	08	-15	-13	68	-33	03	32	-25	21	-03

EXHIBIT 6.17 Comparison of the factor pattern obtained from a rotation carried out by an "analytical procedure programmed for an IBM 650" in original study in Fleishman and Ornstein 1960, with the factor pattern obtained from a re-analysis of the original data using the Varimax Rotation method

Maneuver	COMPUTER PROGRAMME ROTATION FACTORS 1	2	3	4	5	6	VARIMAX ROTATION FACTORS 1	2	3	4	5	6	7
Straight and Level	23	-08	38	42	41	07	22	01	21	86	19	02	20
90^{o} Climbing Turn	68	41	29	21	-01	06	17	24	83	21	23	26	20
Level off from Climbing Turn	25	52	39	-16	22	32	29	64	30	05	24	-02	02
Gliding Turn	24	38	51	05	17	46	38	51	28	28	30	11	-04
Level off from Gliding Turn	08	16	42	48	06	24	39	26	04	39	14	28	03
Take Off	54	11	50	13	11	00	49	18	40	17	09	-02	30
Coordination Exercise	41	00	60	23	01	07	53	11	38	20	14	03	14
Straight and Level Gear Check	07	47	23	02	34	07	11	56	-02	07	15	00	33
Traffic Pattern at Auxiliary Field	09	46	00	49	31	06	-09	42	08	35	22	41	19
Rectangular Pattern	20	43	15	45	-03	22	15	27	24	11	30	57	-01
3-Point Landing	42	17	18	18	35	-18	13	10	18	08	15	04	76
Climbing Turn from Level	15	16	56	23	04	33	67	25	04	12	17	15	08
Land Characteristic Stall	68	23	07	24	19	38	28	18	34	07	60	16	32
Power-on Stall	05	14	45	29	33	43	39	31	07	46	33	11	-10
Approach to Stall	45	09	34	25	12	51	58	10	14	02	58	19	13
Power-off Stall	27	05	33	43	16	61	49	14	09	40	48	25	03
Steep Turn (360^{o})	47	15	19	09	46	16	21	20	26	19	44	-06	29
Maximum Performance Climbing Turn	01	15	-05	37	-17	05	09	-04	02	00	-01	45	-00
Spin	22	13	02	24	43	43	10	21	00	20	68	05	07
Rudder Control Stall	41	31	19	21	12	40	30	32	21	13	42	18	09
Slow Flight Turn	31	03	37	41	16	30	51	10	14	25	35	16	13
Slow Flight Recovery	26	47	36	41	-02	27	47	36	15	14	24	39	20
Forced Landing	23	53	49	06	-11	37	45	57	27	01	11	26	00
Traffic Pattern at Home Field	-01	39	43	48	17	18	46	37	-19	18	15	45	37

Exhibit 6.18 Comparison of Centroid factor pattern obtained in original study in Parker and Fleishman 1960, with the factor pattern obtained from a reanalysis of the original data using the Principal Factor method

CENTROID METHOD FACTORS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Aerial Orientation	60	-25	04	-06	-15	-01	-04	08	10	21	-17	-05	09	05	05
Complex Movements	55	-04	03	13	14	05	02	-02	06	-09	11	09	22	-08	-03
Coordinate Movements	57	-18	18	13	05	13	02	-05	16	16	05	05	01	01	05
Directional Control	50	-03	03	21	09	13	11	-04	23	16	02	-17	-14	06	06
Discrimination Reaction Time	50	11	07	24	-13	10	17	03	13	-16	15	-01	17	-05	00
Following Directions	40	-31	21	11	-05	07	06	-06	-19	10	12	02	-04	-03	15
Forced Landings	54	-03	12	12	09	09	07	01	15	-08	-02	-09	-36	07	00
Formation Visualization	66	-37	09	-03	15	-08	-21	13	-09	-11	02	-08	08	03	-09
General Mechanics	64	-19	-13	-19	00	-28	-10	-05	-10	-08	-06	04	-13	-15	13
Instrument Comprehension	70	-25	05	06	-01	00	09	03	-01	-10	-12	-08	07	09	01
Mechanical Comprehension	60	-33	06	-15	-01	-18	-18	05	04	00	-02	-03	-17	-15	07
Pattern Comprehension	65	-25	-04	05	18	-12	-27	18	06	-06	10	08	00	-10	-06
Planning a Course	51	-17	19	07	04	17	15	04	-11	03	-12	27	03	-16	05
Signal Interpretation	49	-22	08	01	09	27	22	-07	02	07	-14	16	-11	04	-12
Spatial Orientation	45	09	10	15	00	09	-13	-06	-28	-04	-14	05	06	15	-03
Speed of Identification	41	13	23	36	-09	-07	18	01	-24	-02	17	-17	-11	-03	04
Stick and Rudder Orientation	64	-35	-02	-19	00	07	-22	-01	12	08	-13	08	09	07	-02
Vocabulary	22	-35	31	07	-34	-38	01	-19	14	07	-06	-10	-06	-04	-13
Visual Pursuit	61	-05	-01	10	02	12	02	-10	-22	16	12	02	-01	-06	-15
Visualisation of Maneuvers	63	-29	01	01	-12	12	-22	00	-07	-07	-02	-14	05	16	03
Finger Dexterity	25	30	-09	19	18	-19	-16	-01	-03	10	18	-01	-08	-12	-27
Purdue Pegboard	37	40	-11	35	15	-06	-18	-03	-02	07	-06	10	-02	16	-03
Rate of Manipulation - placing	14	51	-05	37	05	-12	-18	01	07	-07	-15	01	-04	-02	04
Rate of Manipulation - turning	28	45	-11	26	-04	-06	-13	-08	-04	-03	-27	11	01	-12	00
Two plate Tapping	25	45	-08	16	-12	-01	-03	12	08	02	-24	-01	-01	06	06
Precision Steadiness - errors	40	20	04	-08	08	-11	08	20	-13	23	15	05	-07	03	14

PRINCIPAL FACTOR FACTORS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Aerial Orientation	59	-25	05	07	-13	-02	-06	-00	-00	16	03	-18	04	04	-15
Complex Movements	55	-05	04	-09	12	-06	-01	-08	09	00	02	15	04	09	17
Coordinate Movements	57	-18	19	-09	06	-15	-02	-02	12	08	19	-01	02	-06	-04
Directional Control	50	-03	05	-17	14	-06	03	-05	03	06	23	-16	-19	-09	-12
Discrimination Reaction Time	54	14	10	-56	-28	-15	15	-40	20	01	-22	15	02	03	-03
Following Directions	33	-24	31	-23	-01	-25	15	49	03	17	07	15	-30	11	07
Forced Landings	54	-03	12	-05	14	-01	-00	-04	-08	-09	23	-06	-27	-14	-03
Formation Visualization	66	-37	07	12	16	00	-16	-02	-05	06	-22	11	-04	09	04
General Mechanics	63	-18	-22	25	-03	32	-10	-15	-05	-06	-21	-01	07	-20	-20
Instrument Comprehension	70	-24	01	-00	04	08	01	-26	-09	-12	-08	-14	-01	11	-19
Mechanical Comprehension	58	-31	02	20	-03	13	-13	-04	01	02	-07	-02	-06	-16	04
Pattern Comprehension	64	-25	-05	06	15	06	-27	-11	01	13	-08	17	-03	-08	11
Planning a Course	51	-16	17	-00	06	-11	05	-15	-19	-08	13	-06	27	-05	19
Signal Interpretation	48	-22	06	01	09	-18	17	-09	-06	-11	26	-17	10	-00	10
Spatial Orientation	46	10	10	-09	12	-14	-14	14	-17	-17	-15	-05	24	12	-18
Speed of Identification	42	11	33	-45	19	21	21	21	-26	-02	-23	-04	-14	-19	-08
Stick and Rudder Orientation	65	-37	-04	24	-09	-17	-20	00	15	06	09	-04	09	17	-04
Vocabulary	22	-39	39	-07	-33	47	-08	09	19	07	04	-22	-11	03	14
Visual Pursuit	61	-05	02	-11	07	-14	06	19	-02	05	-05	-04	15	-20	10
Visualisation of Maneuvers	63	-30	02	01	-06	-15	-17	15	-04	-05	-14	-04	-15	12	-06
Finger Dexterity	25	29	-07	-09	18	14	-17	08	09	13	-03	09	03	-18	15
Purdue Pegboard	38	40	-10	-22	23	05	-30	08	02	01	11	-01	10	04	-07
Rate of Manipulation - placing	15	51	-04	-24	17	14	-32	-00	-02	-04	07	-06	-06	07	05
Rate of Manipulation - turning	29	45	-10	-18	04	10	-24	04	-02	-12	06	-15	14	10	14
Two plate Tapping	26	44	-08	-12	-06	04	-13	-04	-08	05	10	-17	-06	16	01
Precision Steadiness - errors	40	19	03	09	05	04	10	10	-10	27	02	08	05	-05	-02

.....continued

Exhibit 6.18 (Continued)

CENTROID METHOD FACTORS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Direction Control	57	-10	-09	07	05	09	00	08	13	-07	-03	-15	18	-15	-04
Control Sensitivity	39	35	08	-11	-18	02	11	-02	-12	-31	-11	-04	-04	-15	14
Ten Target Aiming - errors	-03	25	34	-09	-49	25	-25	04	13	03	09	06	-13	05	-12
Ten Target Aiming - correct	18	46	20	-11	-35	17	-23	28	-03	09	12	16	02	-05	-01
Bimanual Matching	51	15	-23	-10	-01	11	15	08	-07	08	-02	-03	-06	08	06
Track Tracing - errors	46	20	-06	-08	11	-22	15	21	-05	07	09	08	03	18	-07
Two Hand Coordination	51	15	-20	-21	-07	09	08	-16	08	07	01	-13	-01	-08	-13
Choice Reaction Time	21	24	23	-02	-05	-05	21	19	04	-21	-07	-09	00	14	-16
Complex Coordinator	59	24	-01	-19	09	04	16	02	-17	-10	-05	-12	02	-09	-08
Pursuit Confusion - errors	50	-02	-33	-02	01	02	04	-16	11	-09	16	15	-04	13	04
Pursuit Confusion - corrects	48	15	-29	-10	-06	03	07	-23	08	-18	10	17	-15	-05	-04
Motor Judgement	17	12	-22	-02	-12	-21	20	-14	15	10	-04	13	05	05	-03
D R T	52	18	10	-03	14	09	-03	-03	15	-24	14	03	04	07	05
Rotary Pursuit	43	24	-34	-04	-16	-09	-05	06	16	09	11	-09	09	02	24
Visual Reaction Time	-03	28	44	-14	17	-02	17	12	21	04	01	00	15	-09	01
Auditory Reaction Time	09	26	35	-17	29	03	03	-08	11	12	-13	05	-07	-18	01
Jump V Reaction Time	11	38	36	-14	12	03	-18	-28	00	-04	16	00	04	07	15
Jump A Reaction Time	22	33	31	-32	24	-12	-15	-23	-03	-01	-05	-08	-01	13	05
Steadiness Aiming	14	12	10	-31	07	-20	06	22	05	-12	02	08	-08	11	-11
Single Dimension Pursuit	24	14	-04	-09	-14	-01	-13	-32	-04	00	05	-08	12	-05	-08
Rate Control	45	21	05	-27	00	-02	09	-15	-17	12	-08	-01	09	12	-04
Rotary Aiming	07	41	11	14	03	-13	06	00	02	21	-01	-13	09	-07	00
Rudder Control	55	23	-25	-25	-15	-09	11	03	-03	13	02	01	02	-06	-03
Current Affairs	09	-29	33	21	-25	-41	15	-12	02	-05	04	23	08	09	06

PRINCIPAL FACTOR FACTORS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Direction Control	57	-11	-08	-06	05	-09	-02	-12	04	06	-04	-01	-12	11	15
Control Sensitivity	39	34	06	06	-15	04	12	-01	-15	-23	-10	-01	-08	07	17
Ten Target Aiming - errors	03	-25	-35	-07	48	17	24	-04	11	10	-07	04	14	18	06
Ten Target Aiming - correct	18	49	15	20	-44	-29	-31	-04	-20	16	03	12	10	-14	-01
Bimanual Matching	52	14	-23	03	-03	-09	18	06	-09	08	05	-08	-02	-00	-06
Track Tracing - errors	46	20	-06	08	06	18	13	00	-10	25	06	06	17	09	09
Two Hand Coordination	51	14	-19	10	-12	-06	17	09	14	-05	05	-10	-07	-05	08
Choice Reaction Time	21	25	22	04	-03	10	13	-18	-23	-02	03	04	-14	20	-02
Complex Coordinator	59	23	-02	13	-10	-02	23	02	-14	-09	-14	-06	01	01	09
Pursuit Confusion - errors	50	-03	-32	-05	-03	01	07	04	12	-18	12	21	02	-14	-25
Pursuit Confusion - corrects	48	08	-28	-06	-14	10	09	05	03	-29	19	18	02	-10	05
Motor Judgement	17	11	-20	-04	-13	24	12	03	11	01	20	-04	09	04	-01
D R T	53	19	10	06	11	-09	00	-09	07	-18	08	30	-20	08	02
Rotary Pursuit	43	23	-32	-02	-16	07	-02	09	10	16	02	04	-18	05	-10
Visual Reaction Time	-03	30	41	18	07	00	16	-29	11	15	08	07	00	04	01
Auditory Reaction Time	09	26	32	23	20	-03	07	-19	18	02	02	-13	12	-18	-02
Jump V Reaction Time	10	37	33	17	07	-07	-04	07	24	-14	-08	10	-03	-04	-03
Jump A Reaction Time	21	34	29	49	25	10	-01	23	23	-16	-03	-04	-04	08	-04
Steadiness Aiming	12	11	05	44	05	22	06	03	-23	08	12	14	-06	05	-03
Single Dimension Pursuit	24	13	-01	-01	-17	-03	-02	12	28	-14	-19	-04	03	03	03
Rate Control	45	20	04	19	-06	-01	21	08	09	-05	-12	-10	17	03	-13
Rotary Aiming	08	43	14	-18	02	11	03	-10	16	24	-09	-10	08	-02	-09
Rudder Control	56	23	-24	13	-22	07	20	10	02	18	-03	-06	01	04	15
Current Affairs	10	-29	40	-19	-25	45	-04	06	-02	-12	18	24	25	07	-07

Exhibit 6.19 Comparison of the factor pattern obtained from a Zimmerman Graphical Rotation in the original study in Parker and Fleishman 1960, with the factor pattern obtained from a reanalysis of the original data using the Varimax Rotation method

ZIMMERMAN ROTATION — FACTORS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Aerial Orientation	52	05	-01	08	-12	25	05	05	-02	20	26	-11	13	-07	17
Complex Movements	16	10	-15	04	19	13	20	01	10	34	30	13	04	04	19
Coordinate Movements	36	00	-05	11	15	24	19	-01	03	18	40	06	14	04	-03
Directional Control	34	13	-16	05	08	13	27	-07	01	04	30	-11	17	20	-12
Discrimination Reaction Time	07	30	-10	15	14	20	38	-06	14	13	25	04	02	-04	17
Following Directions	27	-10	-01	02	05	23	06	04	31	09	27	06	20	-16	-08
Forced Landings	29	12	-03	09	07	11	36	08	04	13	10	-03	35	20	-15
Formation Visualisation	33	-11	-03	-03	-05	18	15	15	20	61	19	-06	18	04	12
General Mechanics	29	18	-04	-12	-04	19	-11	19	11	38	07	02	47	01	21
Instrument Comprehension	47	09	-16	02	-01	24	28	08	15	33	14	00	16	-05	13
Mechanical Comprehension	32	-03	07	-06	-05	21	-02	11	04	38	17	-06	47	03	12
Pattern Comprehension	16	01	-08	05	-05	16	06	17	07	58	32	00	27	16	14
Planning a Course	31	-10	-13	25	17	11	14	13	10	12	23	22	24	-16	-16
Signal Interpretation	45	-10	-12	10	06	01	30	05	-01	03	18	25	19	01	05
Spatial Orientation	34	10	02	27	10	01	06	05	30	24	-01	10	-03	06	04
Speed of Identification	09	17	-05	15	16	20	23	08	53	06	13	-10	14	10	00
Stick and Rudder Orientation	53	-04	05	02	-11	16	03	01	-12	57	25	07	17	-03	14
Vocabulary	-18	-18	13	-04	-12	67	05	-03	08	15	-02	-06	11	13	02
Visual Pursuit	35	03	00	07	04	-01	13	-02	35	14	33	14	16	16	18
Visualisation of Maneuvers	46	08	07	05	-16	16	16	-08	21	47	16	-04	13	-07	01
Finger Dexterity	-08	07	-03	04	05	-01	-02	05	18	13	17	00	05	49	16
Purdue Pegboard	14	33	-13	33	15	-04	-02	07	14	16	09	06	-10	43	-02
Rate of Manipulation – placing	-10	35	-13	38	20	00	-05	-02	03	06	-10	-09	-06	36	00
Rate of Manipulation – turning	08	33	-13	40	18	-02	-10	-07	05	06	-10	06	04	27	19
Two Plate Tapping	14	41	-05	35	08	-04	04	04	-04	-05	-07	-13	-02	17	12
Precision Steadiness – errors	20	22	06	-01	13	-06	-05	34	16	-01	28	-08	14	08	08

VARIMAX ROTATION — FACTORS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Aerial Orientation	56	24	-04	04	15	-03	08	04	-04	-09	24	05	-03	12	21
Complex Movements	45	14	09	17	01	16	-10	18	12	16	-00	17	-00	06	-07
Coordinate Movements	49	08	11	15	10	04	03	22	-04	09	31	20	01	08	03
Directional Control	34	13	05	11	00	16	-05	09	02	07	51	07	10	03	-01
Discrimination Reaction Time	27	23	-01	88	07	14	09	06	20	15	05	05	12	00	02
Following Directions	23	08	-02	06	14	-10	02	76	-05	-00	09	08	17	06	07
Forced Landings	39	11	08	-06	01	13	05	05	17	18	42	13	19	-01	-07
Formation Visualisation	81	04	02	-02	02	-02	-10	10	08	03	-06	02	11	07	07
General Mechanics	63	34	-01	-07	12	02	-05	-40	-05	15	-10	02	14	11	03
Instrument Comprehension	65	19	-03	13	10	02	-11	-17	22	07	21	11	08	01	27
Mechanical Comprehension	67	17	03	-09	14	-07	04	-11	-06	06	06	05	10	03	-06
Pattern Comprehension	76	04	-02	02	01	14	-03	-01	-03	13	-03	05	05	16	-13
Planning a Course	41	09	02	05	07	03	03	04	10	04	05	56	06	07	07
Signal Interpretation	35	17	01	01	01	-05	-08	10	07	07	28	47	-03	-04	07
Spatial Orientation	31	08	08	03	-06	27	07	13	05	08	-06	15	16	00	45
Speed of Identification	15	08	04	15	15	19	-07	18	17	00	16	04	79	09	11
Stick and Rudder Orientation	74	21	02	-04	08	-06	05	13	-08	04	11	09	-31	00	15
Vocabulary	31	06	-01	-00	76	-10	03	05	-00	-25	12	-06	08	-16	-16
Visual Pursuit	42	31	04	08	-03	12	03	22	-17	08	06	27	26	08	06
Visualisation of Maneuvers	68	18	-10	01	01	-00	09	21	05	04	09	-06	08	-13	19
Finger Dexterity	12	11	13	03	-04	42	-02	01	-13	08	-06	-03	16	15	-20
Purdue Pegboard	14	08	08	04	-06	67	-00	05	-05	14	10	01	04	13	12
Rate of Manipulation – placing	-05	-00	07	02	-03	69	05	-05	11	02	05	-07	07	-01	-03
Rate of Manipulation – turning	-01	21	04	03	02	64	05	-04	06	02	-04	12	00	-07	08
Two Plate Tapping	-01	24	-01	05	-04	49	13	-03	20	-08	12	-02	-04	04	05
Precision Steadiness – errors	19	27	11	-03	-04	13	05	11	05	-01	04	04	13	38	-00

Exhibit 6.19 (Continued)

ZIMMERMAN ROTATION — FACTORS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Direction Control	24	11	-19	03	04	08	23	-10	02	34	25	-12	14	00	26
Control Sensitivity	13	38	10	13	29	00	17	01	14	06	-19	01	26	-11	24
Ten Target Aiming - errors	-06	07	63	35	-05	04	15	-13	-09	14	03	-03	-01	-05	02
Ten Target Aiming - correct	-06	26	50	42	07	-13	01	10	00	-04	18	-07	01	-07	18
Bimanual Matching	33	37	-17	08	-04	-13	14	05	14	04	20	01	14	09	10
Track Tracing - errors	21	29	-03	-06	04	-01	10	42	09	10	16	00	-02	18	20
Two Hand Coordination	37	25	07	-13	04	-07	15	-16	-02	06	14	04	16	17	30
Choice Reaction Time	06	15	07	09	12	06	39	25	02	-02	-15	-11	-07	02	15
Complex Coordinator	34	28	09	00	17	-08	23	07	21	10	00	-03	20	02	38
Pursuit Confusion - errors	23	37	-08	-15	-08	02	11	-04	00	24	21	30	14	11	03
Pursuit Confusion - correct	17	38	-01	-11	05	01	13	-08	-01	15	05	35	28	18	16
Motor Judgement	14	28	-11	-11	-06	15	-04	02	-11	-14	04	17	-04	13	20
D R T	14	28	07	01	29	04	29	07	-01	34	15	08	08	09	01
Rotary Pursuit	17	60	-02	-06	-04	01	00	-05	-04	12	27	-14	08	04	12
Visual Reaction Time	-08	-07	13	03	48	05	15	21	-22	-16	07	-16	-13	-02	09
Auditory Reaction Time	12	-14	11	07	51	-04	-01	12	-20	-09	01	-05	10	16	05
Jump V. Reaction Time	03	13	36	01	52	01	-04	-02	05	07	00	04	-11	10	-14
Jump A. Reaction Time	26	07	31	-12	48	-01	-06	13	-02	14	-16	-04	-06	20	-01
Steadiness Aiming	02	07	18	-12	04	-02	11	40	-13	08	-10	-03	05	05	14
Single Dimension Pursuit	15	15	19	-06	10	07	-05	-26	12	11	-01	08	-03	10	20
Rate Control	47	19	15	-08	21	01	01	11	15	03	01	07	-02	07	25
Rotary Aiming	-03	-01	02	12	26	09	-09	03	08	-21	11	-21	-14	17	07
Rudder Control	34	40	08	-08	00	-08	00	09	03	03	18	03	19	08	40
Current Affairs	-02	07	-02	01	-03	67	-04	19	15	-05	-01	19	-08	-12	01

VARIMAX ROTATION — FACTORS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Direction Control	52	23	-05	15	-08	12	-08	09	14	02	10	08	-01	-01	-08
Control Sensitivity	10	39	13	00	-00	18	16	-01	37	09	-10	12	16	-10	02
Ten Target Aiming - errors	10	01	-12	-00	-12	-02	-72	-02	-09	01	-07	05	-04	15	-01
Ten Target Aiming - correct	02	15	13	05	-13	21	80	00	07	-01	-12	04	-11	22	03
Bimanual Matching	23	48	-06	02	-16	12	01	04	07	08	17	08	05	16	10
Track Tracing - errors	21	30	07	-00	04	18	-07	03	16	09	01	-00	03	48	06
Two Hand Coordination	24	56	09	01	-06	08	02	04	00	13	13	06	-00	-04	-04
Choice Reaction Time	03	09	12	03	05	09	08	-03	51	-03	06	04	07	13	.04
Complex Coordinator	27	54	13	03	-07	09	08	-00	25	05	-03	16	19	05	09
Pursuit Confusion - errors	28	33	-06	09	-01	06	-06	-04	-11	54	16	-03	01	09	13
Pursuit Confusion - correct	18	41	-09	01	09	16	01	-03	04	51	04	13	02	-03	-03
Motor Judgement	-05	32	-07	01	21	14	-11	-08	-02	12	09	02	-11	10	-02
D R T	35	14	27	06	-09	17	04	14	32	38	09	00	01	03	-06
Rotary Pursuit	20	46	-09	07	-05	25	06	02	03	13	12	-27	-04	15	-04
Visual Reaction Time	-12	-08	48	14	02	-03	08	-03	27	-12	06	08	-08	23	-12
Auditory Reaction Time	-01	-00	56	04	-05	04	04	-14	-02	-09	12	18	03	10	-02
Jump V. Reaction Time	-03	03	56	02	-02	13	16	10	06	09	-06	-08	05	-06	03
Jump A. Reaction Time	09	17	70	-34	01	13	-02	06	10	02	-03	-10	00	-03	10
Steadiness Aiming	08	11	14	-39	04	-05	05	-09	25	05	-04	-03	-03	32	-03
Single Dimension Pursuit	12	30	17	16	07	10	06	07	-07	06	-12	-11	00	-20	07
Rate Control	18	46	29	05	01	03	01	00	04	02	-00	07	06	09	27
Rotary Aiming	-14	12	25	31	04	30	03	-05	-00	-18	07	-09	09	21	02
Rudder Control	23	69	-00	03	-01	13	04	04	08	-01	-02	02	-00	11	-07
Current Affairs	09	-18	-05	05	77	-07	03	10	07	19	-08	10	06	11	11

EXHIBIT 6.20 Comparison of Centroid factor pattern obtained in original study in Fleishman and Ellison, 1962, with the factor pattern obtained from a reanalysis of the original data using the Principal Factor method.

	CENTROID METHOD FACTORS 1	2	3	4	5	6	7	PRINCIPAL FACTOR FACTORS 1	2	3	4	5	6
Medium Tapping	67	40	20	-24	-19	-21	-08	70	-28	21	21	37	-06
Large Tapping	68	42	16	-26	-15	-23	-04	72	-30	19	18	39	-08
Aiming	72	35	12	19	14	07	-08	76	-22	08	17	-23	-01
Pursuit Aiming I	72	39	14	20	20	10	-08	77	-26	11	19	-30	-02
Pursuit Aiming II	71	41	14	22	06	-06	80	77	-29	11	18	-33	-05
Square Marking	57	26	08	11	05	-09	16	57	-13	05	13	-05	-03
Tracing	32	-03	05	-15	-06	14	-11	29	06	05	04	05	16
Steadiness	16	-12	-02	-06	-10	15	-16	12	11	01	-04	-02	19
Discrimination Reaction Time-Printed	32	05	09	-14	-12	-10	23	30	02	08	09	17	05
Precision Steadiness - Counter	28	-18	12	04	-12	19	-04	22	30	05	08	-06	28
10 Target Aiming - Errors	01	-45	52	21	-21	06	11	-11	35	-39	79	02	08
10 Target Aiming - Corrects	47	31	-44	-26	19	15	-14	59	-27	-12	-44	04	13
Hand Precision - Aiming Errors	05	-44	63	-23	18	-05	-17	-06	33	93	-15	-06	05
Hand Precision - Aiming Corrects	33	35	-54	15	-32	28	07	42	-32	-53	-33	01	11
Minnesota Rate of Manipulation - Placing Test	69	-13	-14	-17	17	08	20	66	23	-00	-06	06	13
Minnesota Rate of Manipulation - Turning Test	68	-15	-14	-17	08	13	19	65	25	-02	-08	07	19
Pin Stick	49	-15	05	04	05	08	08	45	22	03	07	-02	15
Purdue Pegboard Right Hand	56	-28	-24	08	06	-10	-09	52	36	-11	-11	-02	-11
Purdue Pegboard Left Hand	53	-25	-23	11	-07	-07	-14	49	33	-13	-11	-03	-11
Purdue Pegboard Both Hands	58	-28	-23	10	05	-23	-04	56	41	-09	-09	-00	-24
Purdue Pegboard Assembly	56	-26	-24	08	-04	-19	13	53	38	-12	-10	05	-11
O'Connor Finger Dexterity	59	-17	-22	10	02	-14	-03	58	27	-10	-11	-02	-09

EXHIBIT 6.21 Comparison of the factor pattern obtained from a Zimmerman Graphical Rotation in the original study in Fleishman and Ellison, 1962, with the factor pattern obtained from a reanalysis of the original data using the Varimax Rotation method.

	ZIMMERMAN ROTATION FACTORS							VARIMAX ROTATION FACTORS					
	1	2	3	4	5	6	7	1	2	3	4	5	6
Medium Tapping	77	10	28	22	14	10	21	15	40	04	78	07	05
Large Tapping	75	10	31	25	15	06	19	17	40	07	79	10	02
Aiming	52	30	20	01	57	13	-01	23	73	09	28	06	16
Pursuit Aiming I	52	27	19	-01	63	11	-02	21	81	08	25	06	15
Pursuit Aiming II	54	28	18	-01	63	05	-04	20	84	08	23	09	12
Square Marking	46	26	10	20	31	00	-11	22	46	08	29	03	10
Tracing	12	05	11	13	15	25	19	12	12	00	18	01	24
Steadiness	-03	06	08	01	04	27	13	07	00	00	-00	02	24
Discrimination Reaction Time-Printed	30	07	03	34	00	05	-02	12	10	-02	30	-18	13
Precision Steadiness	05	17	-00	10	13	34	09	12	08	-06	04	-07	39
10 Target Aiming - Errors	03	08	-70	09	-04	27	08	02	-06	09	-01	-94	12
10 Target Aiming - Corrects	-04	14	72	13	31	07	06	22	25	40	22	52	19
Hand Precision - Aiming Errors	-02	-04	-51	15	13	00	64	-00	-04	-93	03	32	20
Hand Precision - Aiming Corrects	15	14	56	-00	05	40	-50	17	17	73	07	29	08
Minnesota Rate of Manipulation - Placing Test	10	37	24	53	34	14	09	49	22	06	28	08	37
Minnesota Rate of Manipulation - Turning Test	09	34	23	52	30	23	08	48	18	08	26	09	43
Pin Stick	08	34	07	25	24	20	03	32	20	-02	16	-05	34
Purdue Pegboard - Right Hand	01	60	18	17	12	16	14	62	13	04	08	03	16
Purdue Pegboard - Left Hand	05	55	18	10	05	26	11	59	13	07	06	02	14
Purdue Pegboard - Both Hands	08	66	16	20	06	10	13	72	14	-01	11	-01	08
Purdue Pegboard - Assembly	09	59	14	32	00	12	-01	64	08	05	13	00	17
O'Connor Finger Dexterity	13	59	20	19	11	14	07	59	20	08	13	06	17

matrices allowed a re-analysis of the original data in the nine studies to be made using the modern Principal Factor method and the more modern rotation method, namely, Varimax. The resulting Factor patterns from the Principal Factor method are compared with those obtained in the original studies where the Centroid (in eight studies) and Principal Axes (one study) were used; also the rotated factor solutions from the Varimax are compared with the Zimmerman rotation factor solutions (in one study a computer programme for rotations was used by Fleishman).

The results of such a comparison are important because it was recognised when the original analysis was carried out that both the Centroid method and the Zimmerman method of rotation are approximate methods. Harman (1976) compares Thurstone's application of the Centroid method to a twenty variable plasmode with a Principal Factor solution of the same problem. He concludes that it is "remarkable how closely Thurstone was able to approximate the computer produced principal-factor solution by his hand methods almost forty years earlier." However, Harman does not compare the factor loadings produced by the various methods, but only compares the total variance. The latter comparison is important with the studies under consideration here because it is the identification of psychomotor abilities from the factor loadings which is crucial to Fleishman's studies. If those factor loadings are spurious or unreliable in any way then his claim to have identified eleven or so "basic" psychomotor abilities would be in question. However, this would not mean that it is not possible to do this using factor analysis but merely that the approximate methods employed by Fleishman and his co-workers did not produce reliable or valid results.

The use of the Kaiser-Guttman method of determining the number of factors when using the Principal Factor method results in there being far fewer factors than in the original analysis and, consequently, a thorough statistical comparison cannot be made. This difference in number of factors has greater significance when a rotation is attempted, as extra factors will take some of the variance of the other more major factors. Nevertheless it is possible to assess the factor congruence between the original factor pattern and that obtained from a re-analysis of the original data.

A number of methods for measuring factor congruence statistically have been suggested and the one which is supported by a number of sources is that developed from Burt's (1941) "congruence coefficient", by Tucker (1951) and particularly Wrigley and Newhaus (1955). It was realised that ordinary correlation coefficients were inadequate for two reasons. Firstly, the ordinary r takes its deviations from the mean of each data group, therefore as factor loadings can be negative or positive, if large positive loadings predominate, the smaller positives become negative deviations. As Cattell (1978, p. 252) says "it is important in a good index to give credit to similar signs in the loading from the two experiments."

The second problem with using an ordinary correlation coefficient is that if the loadings rank on the same factor, but their means or variances are very different, then the ordinary correlation coefficients will not discriminate between this situation and the situation where they are of the same magnitude. The following formula is not completely adequate for this latter case but is an excellent index (Harman 1976, Cattell 1978) where there is only a moderate sample discrepancy of loading sizes.

Thus the congruence coefficient suggested by Wrigley and Newhaus (1955) will be used to measure factor similarity and this is:

$$r_c = \frac{\sum_{j=n} b_{j1} \, b_{j2}}{\left(\sum_{j=n} b^2_{j1} \quad \sum_{j=n} b^2_{j2} \right)^{1/2}}$$

where b_{j1} and b_{j2} are the loadings of variable a_j on the factors F1 and F2 which are being compared. However, as with any measures of correlation or congruence we require a means of determining whether the value obtained is significant and at what level. Fortunately, although there are no clear tests of statistical significance derived from first principles, Schneewind and Cattell (1970) generated distributions, using the Monte Carlo procedure, of congruence coefficients from typical loading patterns over many real psychological experiments. Though this method is by no means exact, they produced tables of significance levels which are useful guidelines (Exhibit 6.22). A rather more thorough statistically based method was used, but using simulated data by Korth (1978) to produce a table of significance values which relate the congruence coefficient to both the number of variables and the number of factors (Exhibit 6.23). The tables are difficult to compare as Schneewind and Cattell do not include number of factors but, unlike Korth, relate values to a number of significance levels. However, in general, Korth requires higher values of the congruence coefficient for significance at $P \leqslant .05$. The latter, together with the stronger statistical base and the constraint of number of factors, suggests that it is safer to use Korth's table.

The values are derived from many actual factor analyses by Monte Carlo methods, as described in Schneewind and Cattell (1970), where the full distributions are given. The values in the regular r_c column were calculated in the ordinary way, and those in the r_{cs} (s = symmetrized) by entering both the loadings and the reflected sign loadings, i.e., they are literally on twice the number of variables, whereupon they converge on one value. Probably most users will employ simply r_c. The values are very significantly different from correlation coefficients between factors.

X = number of variables common to the two factor analyses, and used for comparison; p is the usual significance value for resemblance of the two factors. The r_c and r_{cs} values are the required lower bound for that value.

X	p	r_c	r_{cs}
10	.001	−.87 through +.91	±.90
	.01	−.75 through +.78	±.77
	.025	−.67 through +.70	±.69
	.05	−.59 through +.63	±.62
	.10	−.50 through +.53	±.52
20	.001	−.76 through +.82	±.78
	.01	−.63 through +.68	±.64
	.025	−.53 through +.57	±.54
	.05	−.47 through +.50	±.48
	.10	−.38 through +.41	±.39
30	.001	−.68 through +.73	±.70
	.01	−.55 through +.58	±.57
	.025	−.48 through +.51	±.49
	.05	−.38 through +.43	±.41
	.10	−.31 through +.36	±.33
40	.001	−.51 through +.65	±.60
	.01	−.38 through +.46	±.42
	.025	−.33 through +.39	±.35
	.05	−.27 through +.32	±.28
	.10	−.20 through +.24	±.22
50	.001	−.42 through +.54	±.52
	.01	−.34 through +.39	±.38
	.025	−.28 through +.32	±.29
	.05	−.23 through +.27	±.24
	.10	−.17 through +.19	±.18

Exhibit 6.23 Significance Values for Congruence Coefficients by the Korth and Tucker Method[a]

Number of variables in common[b]	Number of factors in each study	Critical $p < .05$ value of r_c	Number of variables in common	Number of factors in each study	Critical $p < .05$ value of r_c
10	4	.93	50	10	.41
30	4	.46	60	10	.38
50	4	.34	70	10	.36
70	4	.32			
28	8	.58	28	11	.61
30	8	.52	30	11	.55
32	8	.53	32	11	.55
28	9	.55	28	12	.58
30	9	.54	30	12	.58
32	9	.55	32	12	.56
			30	15	.56
28	10	.60	50	15	.42
30	10	.55	60	15	.43
32	10	.51	70	15	.38
			54	23	.46
			50	25	.58

[a]From Bruce Korth, "A significance test for

Statistical comparison of original and modern factor solutions

A computer programme was written which obtained the congruence coefficient for all possible pairs of factors between, firstly, the Centroid factor patterns and the Principal Factor patterns and, secondly, between the factor patterns obtained by the Zimmerman rotation method and that obtained by the Varimax method. This comparison was carried out for all the nine studies. However, in one study it was a Principal axes method used not Centroid (Parker and Fleishman, 1960), and in another study (Fleishman and Ornstein, 1960) the rotation was carried out by an "analytical procedure programmed for an IBM 650", but there is no description of the nature of the "analytical procedure". These two differences in method are noted and will be discussed later.

The number of pairs of factors which have been calculated in each instance is the product of the number extracted in the original study and the number extracted by the Principal Factor method using K-G criterion as a cut off. Thus from Exhibit 6.1 the minimum number of pairs calculated is 24 and the maximum is 225. Most of these are of no interest as they are of very low congruence and, consequently, only those which are statistically significant at $p \leqslant .05$ will be included and also those which are close to significance. These are detailed in Exhibit 6.24 to 6.32.

There are a number of ways in which the comparisons may be made. However, we were interested in firstly comparing the Centroid method for producing the initial factor pattern with the Principal Factor method. It has been described earlier how the Centroid method is an approximate

Exhibit 6.24

Congruence coefficients of comparison between Centroid and Principal Factor analysis of the Fleishman 1954 study.
From Exhibit 6.23 for 40 variables and 12 factors congruence coefficients > 0.5 are significant at $p < .05$. Only significant coefficients are given.

		PRINCIPAL FACTOR										
		1	2	3	4	5	6	7	8	9	10	11
	1	.998										
	2		.945									
	3			.890								
CENTROID	4				.898							
	5					.776						
	6								.541			
	7											
	8							.524				
	9											
	10											
	11								.567		.548	
	12											.676

Congruence coefficients of comparison between Zimmerman and Varimax method of rotation applied to the Fleishman 1954 study.

		VARIMAX ROTATION OF PRINCIPAL FACTOR SOLUTION										
		1	2	3	4	5	6	7	8	9	10	11
	1	.915	.619			.553		.581		.767		
	2	.549	.966			.527				.531		
	3	.668	.654	.544	.500			.670	.510	.810		
	4	.927	.624							.565		
ZIMMERMAN	5			.965								
ROTATION	6		.518		.947							
OF CENTROID	7	.517	.731			.508		.595		.769		
SOLUTION	8	.694	.582			.888				.674		
	9					.528					.948	
	10		.519	.575		.885		.538			.579	
	11											.901
	12						.931					

EXHIBIT 6.25

Congruence coefficients of comparison between Centroid and Principal Factor analysis of the Fleishman & Hempel 1954 B study.
From Exhibit 6.23 for 26 variables and 10 factors, congruence coefficients >0.6 are significant at P < .05. Only significant coefficients are given.

		PRINCIPAL FACTOR			
		1	2	3	4
	1	.999			
	2		.991		
	3.			.846	
	4			.605	.740
CENTROID	5				
	6				
	7				
	8				
	9				
	10				

Congruence coefficients of comparison between Zimmerman and Varimax method of rotation applied to the Fleishman and Hempel 1954B study.

		VARIMAX ROTATION OF PRINCIPAL FACTOR SOLUTION			
		1	2	3	4
	1	.961			
ZIMMERMAN	2	.962		.633	
ROTATION	3	.842			.901
OF CENTROID	4		.870	.898	
SOLUTION	5	.669	.923	.797	
	6		.877	.844	
	7	.659	.635	.872	
	8		.841		
	9		.836		
	10				

Congruence coefficients of comparison between Centroid and Principal Factor analysis of the Fleishman and Hempel 1955 study.
From Exhibit 6.23 for 27 variables and 11 factors congruence coefficients > 0.61 are significant at $p < .05$. Only significant coefficients are given.

		PRINCIPAL FACTOR				
		1	2	3	4	5
CENTROID	1	.998				
	2		.735			
	3		.834			
	4				.771	
	5					.848
	6					
	7					
	8					
	9					
	10					
	11					

Congruence coefficients of comparison between Zimmerman and Varimax method of rotation applied to the Fleishman and Hempel 1955 study.

		VARIMAX ROTATION OF PRINCIPAL FACTOR SOLUTIO[N]				
		1	2	3	4	5
ZIMMERMAN ROTATION OF CENTROID SOLUTION	1		.91			
	2	.973				
	3				.914	
	4		.619	.819		
	5				.767	.972
	6		.723	.816		
	7			.838	.689	.710
	8			.785		
	9		.933	.693	.614	
	10					
	11					

Congruence coefficients of comparison between Centroid and Principal Factor analysis of the Fleishman, Roberts, & Friedman, 1958 study. From Exhibit 6.23 for 15 variables and 5 factors congruence coefficients > 0.7 are significant at p < .05. Only significant coefficients are given.

		PRINCIPAL FACTOR 1	2	3	4
CENTROID	1	.974			
	2		.987		
	3			.954	
	4				
	5				.865
	6				

Congruence coefficients of comparison between Zimmerman and Varimax method of rotation applied to the Fleishman, Roberts, & Friedman 1958 study

		VARIMAX ROTATION OF PRINCIPAL FACTOR SOLUTION 1	2	3	4
	1		.995		
ZIMMERMAN	2			.981	
ROTATION	3	.921			
OF CENTROID	4				.900
SOLUTION	5	.772			
	6				

EXHIBIT 6.28

Congruence coefficients of comparison between Centroid and Principal Factor analysis of the Fleishman 1958B study.
From Exhibit 6.23 for 31 variables and 10 factors, congruence coefficients > 0.55 are significant at $p < .05$. Only significant coefficients are given.

		PRINCIPAL FACTOR							
		1	2	3	4	5	6	7	8
	1	.99							
	2		.926						
	3			.705					
	4				.748				
CENTROID	5								.569
	6							.547	
	7								
	8								
	9								
	10								

Congruence coefficients of comparison between Zimmerman and Varimax method of rotation applied to the Fleishman 1958B study.

		VARIMAX ROTATION OF PRINCIPAL FACTOR SOLUTION							
		1	2	3	4	5	6	7	8
	1	.725		.573				.819	
	2		.752	.709			.623	.701	
ZIMMERMAN	3				.580	.635			
ROTATION OF	4			.596		.693			
CENTROID	5			.555				.593	.843
SOLUTION	6		.839	.558					
	7		.720					.720	
	8		.773						
	9	.940							
	10			.577				.550	

EXHIBIT 6.29

Congruence coefficients of comparison between Centroid and Principal Factor analysis of the Fleishman 1960B study.
From Exhibit 6.23 for 25 variables and 11 factors, congruence coefficients > 0.61 are significant at $p < .05$. Only significant coefficients are given.

		PRINCIPAL FACTOR				
		1	2	3	4	5
CENTROID	1	.995				
	2		.932			
	3			.823		
	4				.714	
	5					.694
	6					
	7					
	8					
	9					
	10					
	11					

Congruence coefficients of comparison between Zimmerman and Varimax method of rotation applied to the Fleishman 1960B study.

		VARIMAX ROTATION OF PRINCIPAL FACTOR SOLUTION				
		1	2	3	4	5
ZIMMERMAN ROTATION OF CENTROID SOLUTION	1			.973		
	2	.948				
	3	.886				
	4	.619	.756			
	5		.863			
	6	.899	.705			
	7	.620			.938	
	8		.781			
	9		.852			
	10	.641	.641			
	11					

EXHIBIT 6.30

Congruence coefficients of comparison between Principal Axes and Principal Factor analysis of the Parker and Fleishman 1960 study.
From Exhibit 6.23 for 50 variables and 15 factors, congruence coefficients >0.42 are significant at $p < .05$. Only significant coefficients are given.

Principal Axes	PRINCIPAL FACTOR 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	.999														
2		.962													
3			.855												
4				.877											
5					.514										
6						.846									
7							.763								
8									.620	.604					
9								.486	.487		.519				
10										.663		.423			
11												.711			
12											.452		.683		
13														.486	
14														.427	.532
15															

Congruence coefficients of comparison between Zimmerman and Varimax method of rotation applied to the Parker and Fleishman 1960 study.

ZIMMERMAN ROTATION OF CENTROID SOLUTION	VARIMAX ROTATION OF PRINCIPAL FACTOR SOLUTION 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	.849	.763								.429	.564	.529			.566
2		.792				.724			.450	.585					
3															
4						.653									
5			.907			.462			.499						
6	.541				.891										
7	.588	.442							.664		.611	.524			
8									.479					.786	
9	.468							.492					.830		.459
10	.923	.445								.480					
11	.764	.520		.440				.459			.566	.424		.470	
12										.668		.486			
13	.794	.604								.445	.432	.490			
14						.794									
15	.491	.821													

EXHIBIT 6.31

Congruence coefficients of comparison between Centroid and Principal Factor analysis of the Fleishman and Ornstein 1960 study.
From Exhibit 6.23 for 24 variables and 7 factors, congruence coefficients > 0.56 are significant at $p < .05$. Only significant coefficients are given.

		PRINCIPAL FACTOR						
		1	2	3	4	5	6	7
CENTROID	1	1.000						
	2		.884					
	3			.728				
	4			.590				
	5						.740	
	6				.613			.644

Congruence coefficients of comparison between 'IBM 650' and Varimax method of rotation applied to the Fleishman and Ornstein 1960 study.

		VARIMAX ROTATION OF PRINCIPAL FACTOR SOLUTION						
		1	2	3	4	5	6	7
'IBM 650' ROTATION OF CENTROID SOLUTION	1	.744	.607	.894		.814		.690
	2	.616	.948	.597		.625	.742	
	3	.952	.780	.651	.709	.654		
	4	.725			.781	.712	.865	
	5		.583		.717	.740		.651
	6	.823	.730		.590	.884	.608	

EXHIBIT 6.32

Congruence coefficients of comparison between Centroid and Principal Factor analysis of the Fleishman and Ellison 1962 study.
From Exhibit 6.23 for 22 variables and 7 factors, congruence coefficients > 0.58 are significant at $p < .05$. Only significant coefficients are given.

		PRINCIPAL FACTOR					
		1	2	3	4	5	6
CENTROID	1	.994					
	2		.941				
	3			.634	.715		
	4					.703	
	6						.812
	7						

Congruence coefficients of comparison between Zimmerman and Varimax method of rotation applied to the Fleishman and Ellison 1962 study.

		VARIMAX ROTATION OF PRINCIPAL FACTOR SOLUTION					
		1	2	3	4	5	6
ZIMMERMAN ROTATION OF CENTROID SOLUTION	1		.871		.909		
	2	.986	.588				.697
	3			.676		.670	
	4				.679		.798
	5		.943		.626		.663
	6	.657					.815
	7			.744			

method and it is consequently important to know how similar it is to the Principal Factor method calculated on a computer.

Secondly, it was important to know how approximate were the methods of rotation (usually Zimmerman) used in conjunction with the Centroid method, when compared with the more modern 'Varimax' rotation when used in conjunction with the Principal Factor method. The comparison is not made between Zimmerman and Varimax rotations as this would require starting off with the same method of factor analysis. Instead the assessment is of the adequacy of the approximate methods as used by Fleishman et al in their studies, i.e. Centroid factor analysis in conjunction with the Zimmerman rotation. Consequently, if the Centroid method produces a different factor pattern to the Principal Factor method then this difference will be carried over to the rotation.

The adequacy of these approximate methods is important, as it is from the results of such an analysis that the psychometric interpretations are made regarding the identity of the factors and any changes in variance contributions during practice.

The number of factors extracted and rotated was determined using the Kaiser-Guttman criterion, even though it is argued elsewhere that this overestimates the number of factors when the number of variables is greater than about twenty. The reasons for using the K-G criterion were, firstly, that this is a method which is often used in studies in the literature and is a reputable method for determining the number of factors and, indeed, is the standard method in the S.P.S.S. computer programme which is widely used; secondly, that the K-G criterion allowed for a large number of factors to be extracted, and in four cases within one of the number extracted in the original studies and within two in another two of the studies. In the remaining three studies the K-G criterion gave less than half the number of factors. Therefore in most of the cases a similar number of factors was extracted and this is important as overfactoring may cause later factors to split previous factors, as discussed earlier. The use of similar number of factors meant that any differences found could be ascribed to the difference in methods rather than overfactoring or underfactoring.

The congruence coefficients were calculated for all possible pairs of factors between the factor patterns, and the Exhibits 6.24 to 6.32 show only those values of which were significant at $p \leqslant .05$ level of significance. The significance level of values of the congruence coefficients was calculated for each case using Exhibit 6.23. These levels are more exacting than those of Schneewind and Cattell (1970), as shown in Exhibit 6.22, and take into consideration the number of factors and the number of variables in each case. Where the number of factors is different in the factor patterns being compared, then whichever is the greatest number of factors is used in the computation.

Comparison of the Centroid and Principal Factor Analysis

The study of Parker and Fleishman (1960) (Exhibit 6.30) will not be included here but will be discussed later because they used a Principal Axes method of factor analysis.

In the remaining eight cases the following range of congruence coefficients was obtained for each of the first four factors extracted:

	Factor 1	Factor 2	Factor 3	Factor 4
Highest	1.00	.991	.954	.898
Lowest	.974	.834	Non-significant congruence	.613

It may be seen that there is extremely high congruence between the first factors and high congruence between the second, but the third and fourth factors show great variation. Also no one case exhibits consistently the highest nor the lowest congruence for each of these four factors. The trend is for congruence to decrease from the initial high congruence of the first factor, to the next factor and so on. This trend of decreasing congruence occurs in all the cases.

Not all the factors are congruent with their respective numbered factor. For example, in Exhibit 6.27 factor 4 of the Principal Factor method is congruent with factor 5 in the Centroid method, and in Exhibit 6.31 factor 4 in the Principal Factor method is congruent with factor 6 in the Centroid method. Further, some factors are congruent with more than one other factor and some are not congruent with any factors.

It would seem reasonable to have expected that there would be greater congruence between the factors when a similar number of factors has been extracted, and that there would be fewer cases where a factor was congruent with more than one factor. However, this is not evident as may be seen by comparing Exhibits 6.24, 6.27, 6.28, 6.31 and 6.32 with

Exhibits 6.25, 6.26 and 6.29. Exhibit 6.29 has a very dissimilar number of factors extracted and yet it shows as high and straightforward a pattern of congruence coefficients as those of the former group of Exhibits where a similar number of factors has been extracted.

Where the Centroid method and the Principal Factor method has produced a large number of factors, such as in Exhibit 6.24 and 6.28, then the first four or five factors are similar but after that they are either of marginal congruence or of no congruence at all.

To ascertain the effect of having exactly the same number of factors extracted by both methods, the Principal Factor analysis of Exhibits 6.25 and 6.27 was re-run but forcing the programme to extract the same number of factors which the Centroid method produced. The congruence coefficients were then recomputed and are shown in Exhibits 6.33 and 6.34. It may be seen from these latter Exhibits that forcing the Principal Factor analysis to extract the same number of factors as were extracted in the original study, produces congruence coefficients which are almost identical with those in Exhibits 6.25 and 6.27. It would appear that extracting more factors had very little effect on the earlier factors. This in itself is not important here, what is important is that where fewer factors have been extracted by the application of the K-G criterion when applying the Principal Factor analysis then it would have made no difference to force the extraction of the same number of factors as in the original study. Of course the later factors extracted may well have been found to be significantly congruent with some factors in the original study but it is the methods which are being compared and an integral part of modern factor analysis is to limit the number of factors extracted.

Exhibit 6.33

Congruence coefficients of comparison between Centroid and Principal Factor analysis of the Fleishman and Hempel 1954B study where the Principal Factor analysis has been forced to extract the same number of factors as was extracted in the original study. From Exhibit 6.23 for 26 variables and 10 factors, congruence coefficients > 0.6 are significant at $P < 0.05$. Only significant coefficients are given.

		Principal Factor									
		1	2	3	4	5	6	7	8	9	10
Centroid	1	.999									
	2		.992								
	3			.836							
	4			.627	.730						
	5					.713					
	6						.850				
	7							.663			
	8										
	9										
	10										

		Varimax Rotation of Principal Factor Solution									
		1	2	3	4	5	6	7	8	9	10
Zimmerman Rotation of Centroid Solution	1	.959									
	2	.964						.654			
	3	.843					.782		.723		
	4		.960	.706		.634				.611	
	5	.675	.892	.685	.620	.826				.781	
	6		.918	.716		.735					
	7	.664	.633	.958							
	8		.728		.945	.718					
	9	.701			.965						
	10										.792

Exhibit 6.34

Congruence coefficients of comparison between Centroid and Principal Factor analysis of the Fleishman, Roberts and Friedman 1958 study, where the Principal Factor analysis has been forced to extract the same number of factors as was extracted in the original study. From Exhibit 6.23 for 15 variables and 6 factors, congruence coefficients > 0.9 are significant at $P < 0.05$. Only significant coefficients are given.

		Principal Factor					
		1	2	3	4	5	6
Centroid	1	.998					
	2		.988				
	3			.960			
	4					.90	
	5				.919		
	6						

		Varimax Rotation of Princiapl Factor Solution					
		1	2	3	4	5	6
Zimmerman Rotation of Centroid Solution	1		.975				
	2	.982					
	3					.953	
	4				.935		
	5			.900			
	6						

It would seem that the Centroid method in these eight studies produced almost identical first factors and highly similar second factors when compared with the Principal Factor method; but from there on there is a rapid decrease in similarity. This is to be expected when using an approximate method such as the Centroid Method as the error which is incurred in the calculation is cumulative.

Also when overfactoring occurs, which it is suggested occurred in all the studies analysed here, by more than one or two factors (in some cases by eight factors) then the later factors may be spurious and more affected by the approximations inherent in the method.

As regards Exhibit 6.30, which shows the comparisons between the Principal Axes method and the Principal Factor method, the same trends are found but six out of the first seven factors are highly similar. The same multiple congruency occurs in the latter half of the factors.

The Centroid method in conjunction with the Zimmerman method of rotation in comparison to the Principal Factor method in conjunction with the Varimax method of rotation

In the study by Fleishman and Ornstein (1960) the rotation was carried out by an IBM 650, although they do not state the procedure by which this rotation was accomplished. Consequently the results in Exhibit 6.31 will be discussed later.

The first characteristic to notice of the rotation congruence coefficients is that there are far more multiple congruencies than with the comparison of Centroid with Principal Factor methods. Only in Exhibit 6.27 do we find a relatively simple relationship in which four factors of each method are almost identical and one of the remaining two factors of the Zimmerman rotation is very similar (rc = .772) to one of these four factors mentioned above.

From the other exhibits it can be seen that many of the Zimmerman rotation factors are similar to many of the Varimax rotation factors and vice versa. This is to be expected when overfactoring takes place. However, if the two processes of factor analysis and rotation were identical then we would expect congruence coefficients of 1.00 between one factor and one other factor. This is because the methods used here produce orthogonal factor solutions.

If the Zimmerman method is approximate then it will increase the error in the analysis which is already produced by the Centroid method, which is itself an approximate method. This will be seen in a spreading of variance accounted for between factors and, consequently, a lowering of what should be high congruences and a raising of what should be low congruences. This will be further exacerbated by the inability of the subjective Zimmerman method to maximise the rotation to simple structure. That is, the 'Varimax' method should make more extreme the loadings of the variables on the factors, whereas the Zimmerman method is less successful at this.

However, it may be seen from the exhibits that there are many congruence coefficients greater than 0.9 which means there is a very high similarity. In the three cases where the Principal Factor method extracted a far smaller number of factors than in the original studies, it may be seen that the small number of factors is congruent to almost all of the larger number of factors. These cases are seen in Exhibits 6.25, 6.26 and 6.29. In Exhibit 6.25 four factors are highly congruent with nine factors of the Centroid/Zimmerman solution and indeed three factors would probably suffice. Exhibit 6.26 shows that five factors of the Principal Factor/Varimax method are highly congruent with the nine factors of the Centroid/Zimmerman method. Exhibit 6.29 also shows that four factors of the Principal Factor/Varimax method are highly congruent with the nine factors of the Centroid/Zimmerman method. These three cases further support the conclusion that overfactoring took place and together with the Centroid/Zimmerman method produced a number of related factors which were not separate and distinct.

When overfactoring is not large, such as in Exhibit 6.27, it can be seen that there is a very high similarity between the two methods. However, when this is not the case and when there are a similar number of factors in each study, such as Exhibit 6.24, 6.28 and 6.30, then many factors are congruent with many others.

Cattell (1978) suggests that if one can rearrange the order of one factor pattern such that the diagonal of the congruence coefficient matrix is a maximum then this is evidence of strong similarity. This can only be attempted when a similar number of factors is being compared, such as in Exhibits 6.24, 6.28 and 6.30. The rearrangement of these latter Exhibits is shown in Exhibits 6.35, 6.36 and 6.37. The highest congruence coefficient is taken for each of the Centroid/Zimmerman method factors in turn. The

Exhibit 6.35

Centroid / Zimmerman factors	Principal Factor/Varimax Factors 1	2	9	-	3	4	7	5	10	-	11	6
1	.915											
2		.966										
3			.810									
4				-								
5					.965							
6						.947						
7							.595					
8								.888				
9									.948			
10										-		
11											.901	
12												.931

Reordering by maximising the diagonal of the congruence coefficient matrix from Exhibit 6.24.

Exhibit 6.36

Centroid/Zimmerman factors	Principal Factor/Varimax Factors 7	3	4	5	8	2	-	-	
1	.819								
2		.709							
3			.580						
4				.693					
5					.843				
6						.839			
7							-		
8								-	
9									.940
10									

Reordering by maximising the diagonal of the congruence coefficient matrix from Exhibit 6.28.

Exhibit 6.37

	Principal Factor/Varimax Factors														
Principal Axes / Zimmerman Factors	15	6	-	-	3	5	9	14	13	1	8	10	11	-	2
1	.566														
2		.724													
3			-												
4				-											
5					.907										
6						.891									
7							.664								
8								.786							
9									.830						
10										.923					
11											.459				
12												.668			
13													.432		
14														-	
15															.821

Reordering by maximising the diagonal of the congruence coefficient matrix from Exhibit 6.30.

object is to maximise the congruence coefficients in the diagonal and this has been done in Exhibits 6.35, 6.36 and 6.37. From these exhibits it may be seen that some factors have no unique counterpart, but these are highly related to other factors as mentioned before. Exhibit 6.35, which refers to the Fleishman 1954 study, has a very high overall congruence whereas Exhibit 6.36 (Fleishman 1958) and Exhibit 6.37 (Parker and Fleishman 1960) show only a moderate overall congruence, with about half the factors having no congruence or having marginal congruence. It should be remembered that Exhibit 6.23 gives values at $p \leqslant .05$ and that if the more stringent level of significance at $p \leqslant .01$ was used then according to Exhibit 6.22 the congruence coefficient would have to be far larger to be considered significant.

Exhibit 6.31 has been left out of this analysis because the rotation was carried out on an IBM 650, but it is not reported in the article (Fleishman and Ornstein 1960) what method was used for the rotation. Presumably it was not the Zimmerman rotation.

The pattern of congruencies in Exhibit 6.31 are similar to those obtained from the other studies; however, if they are reordered (Exhibit 6.38) to give a maximum along the diagonal it may be seen that there are no non-significant congruencies and that most are very high. This suggests that given the approximate Centroid method which was used to obtain the initial factor structure, then the Varimax rotation is very similar to the method of rotation used on the IBM 650 in this study by Fleishman and Ornstein (1960).

As before, to assess the effect on the congruence coefficients when the

Exhibit 6.38

		Princiapl Factor/ Varimax Factors					
		3	2	1	6	4	5
Centroid /IBM 650 Rotation	1	.894					
	2		.948				
	3			.952			
	4				.865		
	5					.717	
	6						.884

Reordering by maximising the diagonal of the congruence coefficient matrix from Exhibit 6.31.

same number of factors is extracted, the comparison of rotations in Exhibits 6.33 and 6.34 may be compared with the congruence coefficients of the rotations in Exhibits 6.25 and 6.27 respectively.

In both cases there is an overall similarity of the congruence coefficients but some important differences. A comparison of the congruence coefficients of the rotated factors of the Fleishman, Roberts and Friedman (1958) study in Exhibit 6.27 and 6.34 shows that the factor numbers are now different, the extraction of two extra factors has made little difference except that it has separated out one of the factors. That is, in Exhibit 6.27, factors 3 and 7 of the Zimmerman rotation are both congruent with factor 1 of the Varimax rotation, whereas in Exhibit 6.34, factor 5 of the Zimmerman rotation is now uniquely congruent with factor 3 of the Varimax rotation and with a greater magnitude of congruence than before.

A comparison of Exhibits 6.25 and 6.33 produces similar conclusions though the pattern of congruence coefficients is far more complex. Factor 1 of the Varimax rotation has almost identical coefficient values when extracting four or ten factors. Factor 2 is very similar for four or ten factors and factor 3 is also very similar except that it loses a marginal congruence coefficient of 0.633 with factor 2 of the Zimmerman rotation. Factor 4 of the Varimax rotation in Exhibit 6.25 could be either factor 6 or factor 8 in Exhibit 6.33 or even have been split into both factors 6 and 8.

It would appear that extracting more factors has little effect when only one or two more are extracted as in Exhibit 6.34 but more than this has some effect. In both the cases analysed here (Exhibits 6.33 and 6.34) a 'splitting' of a factor was found, this is labelled by Cattell (1978, p. 171) as 'factor fission'. However, the overall pattern of congruence coefficients remains highly similar and this allows the comparisons we have made between differing numbers of factors in the patterns.

Conclusions

From the sixteen studies in Fleishman's programme of research, nine studies were chosen for re-analysis from the intercorrelation matrix. The object was to assess the adequacy of the methods used and the decisions taken (such as the number of factors to be extracted) in the original studies, and compare them with modern techniques and recent developments in the understanding of Factor Analysis. The method chosen was the Principal Factor method.

All but one of the studies used the Centroid method which was seen by Thurstone as a 'computational compromise' but recognised by Harman 1976 and Cattell 1978 as a very close approximation. However, from this re-analysis of the eight studies it would seem, when comparing the factors obtained from the Centroid method with those from the Principal Factor method, that the first two factors extracted are very similar, though not identical; but there is a decrease in congruence as more factors are extracted and also a large increase in the variation in congruence coefficients throughout the eight studies. Therefore, it would appear that the Centroid method and the Principal Factor method produce almost identical first and second factors, but there is great variation in the factor congruence from the third factor onwards, and as yet it is not possible to identify the conditions under which congruence will be greatest or least. This conclusion is not important just for assessing the programme of research carried out by Fleishman and his colleagues, but suggests that in many areas of psychological research, such as intelligence, specific abilities and personality, a re-analysis of the data which was originally analysed using the Centroid method may be necessary to ensure that the later factors are not artifacts of the method.

In almost all the studies by Fleishman et al the factor analysis extracted a large number of factors. This is not so important when comparing the initial factor analysis methods such as Centroid and Principal Factor when the same number of factors is extracted by each method. However, determining the number of factors to be extracted by any method is vitally important for two reasons. Firstly, only the common factors are important in factor analysis and further factor extraction will produce spurious factors. Secondly, any rotation of more than one spurious factor probably will lead to the splitting of common factors into two or more spurious factors. The problem is to decide when factor extraction should cease. The Kaiser-Guttman method of determining the number of factors is used in many studies, but there is a growing number of studies which indicate that it overestimates the number of factors, especially when the number of variables is in excess of twenty. Certainly in the comparison with the Scree test carried out here (Exhibit 6.3) the K-G method accepted more factors, and this difference increased with an increase in the number of variables. The Scree test is becoming more accepted as a psychometric aid for determining the number of common factors (Cattell 1978, Harman 1976). It is interesting to note that it agrees well with Harman (1976) when he suggests that factors which contribute less than 5% of the total variance should not be included. The nine studies which are listed in Exhibit 6.1 were further analysed by determining the amount of variance accounted for by each successive factor in the Principal Factor analysis. It was found that the Scree test in all cases accepted only factors contributing more than about 4.6% of the variance. For the present, then, the Scree test is very probably the best method for deciding on the number of factors to accept.

The Zimmerman graphical rotation method which is used by Fleishman and his co-workers in nearly all their studies is less laborious than other methods but at the cost of accuracy. It was important to assess how reliable and accurate was the combination of the two approximate methods of Centroid factor analysis followed by a Zimmerman rotation. The comparison was made with the rotational method 'Varimax' which is used in combination with the Principal Factor method. In some cases the number of factors extracted and rotated was different from the number extracted and rotated in the original studies. This was shown to have little effect on the first few factors but may affect later factors. However, the general pattern of congruence coefficients was found to be very similar.

The pattern of congruence coefficients tended to be different depending on the number of factors rotated. The tendency was for more multiple congruences the greater the number of factors rotated. This may be indicative of overfactoring which Cattell suggests leads to factor fission, that is, a splitting up of a factor into two or more factors. Also as more factors are extracted, common variance decreases and error variance becomes dominant. This error variance may be found in many factors in the form of systematic error variance which may be caused by experimenter bias, uncontrolled variables, etc . . . . Consequently, this would mean that some later factors would be correlated and account for the multiple congruencies.

The Centroid/Zimmerman method is in general a good approximation to the Principal Factor/Varimax method, but when considering a particular factor there may be significant discrepancies. After rotation it is not possible to identify which factors are reliable or accurate. This is possible with the Centroid analysis alone because the first two factors have been found to be accurate in all the comparisons, but further factors may or may not be the same as the Principal Factor factors. However, when rotation is carried out then the number of the factor does not relate to anything but is merely a label. Consequently, the factors obtained from the use of the approximate methods, namely, the Centroid and Zimmerman methods, are often significantly different from those obtained from the more exact Principal Factor and Varimax methods of analysis.

SECTION 4

SECTION 4

With the realisation that the approximate factor analytic and rotation techniques used in the original studies led to different factor patterns from those obtained by more modern computerised methods, it was concluded that the original studies could be re-analysed using current techniques for deciding on the number of factors to be extracted, the determination of factor invariance between studies and other decision procedures, together with current factor analytic and rotation methods. This was carried out for both the development of an ability taxonomy and the investigation of changes in abilities required during learning. An assessment of the orthogonality assumption was also made by re-analysing all the original studies using an oblique rotation method.

From all the re-analyses it was concluded that there was no change in the pattern of abilities during learning. This was similar to the findings in the study of trainee typists over 10 months. Six factors were found to be highly similar across studies. From the oblique rotations and the tabulation of the correlations, between the six factors it was concluded that some abilities could be treated as orthogonal whilst others may be partly correlated, though the orthogonality assumption may be justified in general.

The final chapter discusses the implication of the research, both methodological and empirical findings, for the development of an abilities taxonomy and a model of the learning of psychomotor tasks.

CHAPTER 7

RE-ANALYSIS OF FLEISHMAN'S STUDIES

It has been shown that the approximate methods used by Fleishman et al in their studies led to conclusions which differ substantially from the results obtained by more modern computerised factor analytic and rotation methods. Progress has also been made with the determination of the number of extractable factors, and the importance of extracting only common factors is now widely recognized.

The object here is to re-analyse by more modern methods all of the eleven studies which were published by Fleishman et al which included the intercorrelation matrix as an Exhibit, and to interpret from the rotated factor pattern the abilities defined by the factors. The procedure for carrying out this analysis is based on the recommendations of Child 1970, Harman 1976, Cattell 1978, and Mardia, Kent and Bibby 1979. The analysis has been restricted mainly to an orthogonal model, though an oblique rotation was carried out as a check on the orthogonality of the factors, as suggested by Cattell (1978, p. 127, 128). The procedure was to carry out a Principal Component analysis on the published intercorrelation matrices. This produced a listing of the eigenvalues for each factor with the communalities as unity. These eigenvalues were plotted and the Scree test applied to determine the number of factors. If there was some doubt then one more factor was accepted. The intercorrelation matrix was then subjected to a Principal Factor analysis with the number of factors to be extracted set by the 'Scree Test'. The resulting factor pattern was rotated by the orthogonal method 'Varimax' to maximise on the criteria of 'simple structure'. An oblique rotation was also carried out to assess whether the assumption of orthogonality was reasonable. However, the rotated orthogonal factor pattern was the basis for the interpretation of the factors underlying the data.

The eleven studies may be separated into two types. Firstly, three studies whose object was to examine the changes in abilities during learning (Fleishman and Hempel 1954B; Fleishman and Hempel 1955; Fleishman 1960B) and secondly eight studies (Fleishman 1954; Fleishman and Hempel 1954A; Fleishman 1958A; Fleishman 1958B; Fleishman, Roberts and Friedman 1958; Fleishman and Ornstein 1960; Parker and Fleishman 1960; Fleishman and Ellison 1962) whose object was to determine a basic ability taxonomy. Actually all eleven studies provide data for achieving the latter object and will be used for this end.

Firstly, the studies which examined the changes in factor contribution during learning and the interpretation of these factors as abilities will be re-analysed.

Factor contribution during learning

The study by Fleishman and Hempel (1954B) is one of the first in their programme of research. The study was an attempt to identify the factors involved at different stages of performance on a criterion psychomotor task. The criterion task used was the Complex Coordination Test which required the subject to make complex motor adjustments of an airplane-type stick and rudder in response to successively presented patterns of visual signals. The subjects were 197 basic airmen who completed 64 two-minute trials over a period of two days. These trials were sampled by grouping blocks of five trials into eight stage scores. Thus 40 of the 64 trials were included in the analysis. The full list of variables in the analysis is given in Exhibit 6.6, Chapter 6.

The intercorrelation matrix is shown in Exhibit 7.1 and the plot of the eigenvalues for each factor is shown in Exhibit 7.2. The application of the Scree test suggests that there are only three common factors. Exhibit 7.3 shows the Principal Factor analysis and the 'Varimax' rotation solution. In the original Centroid analysis (Exhibit 6.6) ten factors were extracted, of which nine were interpreted and labelled. A critical assessment of their analysis and conclusions was made in Chapter 5 and it was found that even using their results there was little or no evidence for the conclusions drawn by Fleishman and Hempel (1954B).

The re-analysis of the data using the more exact computer methods and procedures produces a different factor pattern from that obtained in the original study (Exhibits 6.6 and 6.7). Firstly, there are only three common factors not nine. Secondly, from the 'Varimax' rotation shown in Exhibit 7.3 it may be seen that if we accept as significant, loadings of 0.3 or greater, that is at least 9% of the variance of that variable is accounted for by that factor, then only two of the variables significantly contribute to the criterion task. The percentage variance accounted for by these two factors is:

CØRRELATIØN CØEFFICIENTS.. obtained from Fleishman and Hempel 1954B

Exhibit 7.I

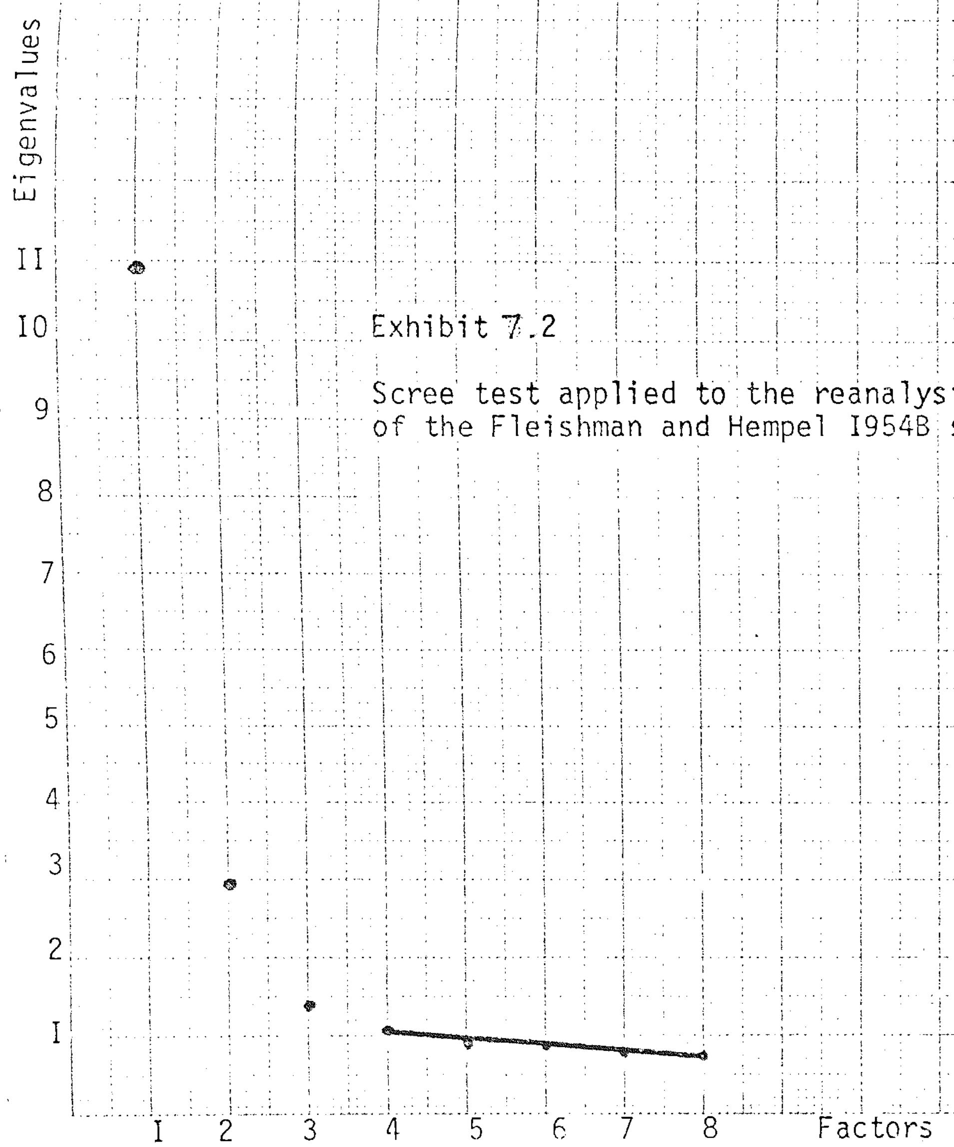
	STAGE1	STAGE2	STAGE3	STAGE4	STAGE5	STAGE6	STAGE7	STAGE8	NUMOP
	DTR								
STAGE1	1.00000	.75000	.73000	.66000	.64000	.57000	.63000	.59000	.280
00	.51000								
STAGE2	.75000	1.00000	.85000	.85000	.84000	.79000	.77000	.79000	.300
00	.46000								
STAGE3	.73000	.85000	1.00000	.85000	.83000	.79000	.81000	.79000	.300
00	.45000								
STAGE4	.66000	.85000	.85000	1.00000	.90000	.88000	.86000	.85000	.260
00	.40000								
STAGE5	.64000	.84000	.83000	.90000	1.00000	.90000	.87000	.86000	.220
00	.37000								
STAGE6	.57000	.79000	.79000	.88000	.90000	1.00000	.85000	.86000	.230
00	.34000								
STAGE7	.63000	.77000	.81000	.86000	.87000	.85000	1.00000	.90000	.230
00	.36000								
STAGE8	.59000	.79000	.79000	.85000	.86000	.86000	.90000	1.00000	.240
00	.34000								
NUMOP	.28000	.30000	.30000	.26000	.22000	.23000	.23000	.24000	1.000
00	.63000								
DTR	.51000	.46000	.45000	.40000	.37000	.34000	.36000	.34000	.630
00	1.00000								
MP	.49000	.40000	.39000	.36000	.36000	.29000	.33000	.30000	.320
00	.54000								
GM	.38000	.31000	.29000	.27000	.25000	.20000	.25000	.24000	.230
00	.43000								
SØI	.50000	.45000	.46000	.41000	.37000	.31000	.32000	.35000	.440
00	.61000								
PC	.55000	.41000	.44000	.38000	.37000	.27000	.33000	.29000	.340
00	.59000								
VP	.43000	.47000	.45000	.42000	.39000	.34000	.36000	.38000	.230
00	.40000								
DEC	.50000	.38000	.39000	.34000	.32000	.24000	.29000	.29000	.450
00	.61000								
IC	.44000	.38000	.42000	.35000	.31000	.27000	.28000	.30000	.420
00	.51000								
SØ	.47000	.39000	.46000	.40000	.38000	.31000	.39000	.35000	.310
00	.54000								
SØM	.46000	.41000	.44000	.40000	.36000	.33000	.39000	.34000	.370
00	.49000								
LBA	.33000	.32000	.35000	.34000	.33000	.28000	.31000	.28000	.400
00	.50000								
RP	.51000	.51000	.59000	.51000	.50000	.47000	.50000	.49000	.220
00	.38000								
PLCØM	.40000	.45000	.44000	.44000	.42000	.39000	.39000	.36000	.080
00	.22000								
CRT	.50000	.44000	.48000	.42000	.38000	.33000	.35000	.33000	.390
00	.54000								
NUT	.35000	.30000	.31000	.32000	.28000	.25000	.24000	.26000	.130
00	.28000								
RT	.08000	.22000	.27000	.30000	.30000	.30000	.27000	.33000	.270
00	.09000								
RØM	.25000	.32000	.31000	.28000	.34000	.37000	.30000	.32000	.120
00	.24000								

Exhibit 7.I continued

	MP	GM	SØI	PC	VP	DEC	IC	SØ	SØM	LBA
STAGE1 00	.49000	.38000	.50000	.55000	.43000	.50000	.44000	.47000	.460	.33000
STAGE2 00	.40000	.31000	.45000	.41000	.47000	.38000	.38000	.39000	.410	.32000
STAGE3 00	.39000	.29000	.46000	.44000	.45000	.39000	.42000	.46000	.440	.35000
STAGE4 00	.36000	.27000	.41000	.38000	.42000	.34000	.35000	.40000	.400	.34000
STAGE5 00	.36000	.25000	.37000	.37000	.39000	.32000	.31000	.38000	.360	.33000
STAGE6 00	.29000	.20000	.31000	.27000	.34000	.24000	.27000	.31000	.330	.28000
STAGE7 00	.33000	.25000	.32000	.33000	.36000	.29000	.28000	.39000	.390	.31000
STAGE8 00	.30000	.24000	.35000	.29000	.38000	.29000	.30000	.35000	.340	.28000
NUMBP 00	.32000	.23000	.44000	.34000	.23000	.45000	.42000	.31000	.370	.40000
DTR 00	.54000	.43000	.61000	.59000	.40000	.61000	.51000	.54000	.490	.50000
MP 00	1.00000	.52000	.46000	.52000	.34000	.43000	.30000	.44000	.330	.26000
GM 00	.52000	1.00000	.29000	.30000	.17000	.32000	.30000	.32000	.170	.23000
SØI 00	.46000	.29000	1.00000	.57000	.44000	.58000	.40000	.58000	.550	.48000
PC 00	.52000	.30000	.57000	1.00000	.43000	.60000	.44000	.49000	.450	.39000
VP 00	.34000	.17000	.44000	.43000	1.00000	.33000	.35000	.46000	.320	.32000
DEC 00	.43000	.32000	.58000	.60000	.33000	1.00000	.53000	.59000	.410	.32000
IC 00	.30000	.30000	.40000	.44000	.35000	.53000	1.00000	.46000	.340	.22000
SØ 00	.44000	.32000	.58000	.49000	.46000	.59000	.46000	1.00000	.490	.37000
SØM 00	.33000	.17000	.55000	.45000	.32000	.41000	.34000	.49000	1.000	.55000
LBA 00	.27000	.23000	.48000	.39000	.32000	.32000	.22000	.37000	.550	1.00000
RP 00	.27000	.26000	.31000	.32000	.29000	.24000	.28000	.40000	.260	.27000
PLCØM 00	.22000	.29000	.23000	.31000	.20000	.19000	.29000	.21000	.180	.19000
CRT 00	.37000	.30000	.52000	.54000	.38000	.55000	.47000	.41000	.430	.33000
AUT 00	.27000	.30000	.31000	.30000	.24000	.22000	.31000	.26000	.200	.18000
RT 00	.05000	-.05000	.02000	.15000	.03000	.10000	.08000	.11000	.060	.14000
RØM 00	.12000	.04000	.22000	.26000	.16000	.18000	.24000	.15000	.280	.26000

Exhibit 7.2

Scree test applied to the reanalysis of the Fleishman and Hempel 1954B study.



FACTOR MATRIX USING PRINCIPAL FACTOR WITH ITERATIONS Obtained from a reanalysis of the Fleishman and Hempel 1954B study.

Exhibit 7.3

	FACTOR 1	FACTOR 2	FACTOR 3
STAGE1	.79551	.01915	-.21669
STAGE2	.85407	-.27551	-.09343
STAGE3	.87293	-.26325	-.03532
STAGE4	.85561	-.35933	-.02117
STAGE5	.83702	-.43607	-.00863
STAGE6	.77792	-.49482	.03945
STAGE7	.80559	-.41094	.02459
STAGE8	.78950	-.45308	.05745
NUMOP	.45357	.34925	.16292
DTR	.58391	.47235	.03065
MP	.55225	.34365	-.32575
GM	.42123	.21695	-.32880
SOI	.65276	.44487	.13092
PC	.52663	.43422	-.06289
VP	.53927	.12715	-.00399
DEC	.59533	.45766	-.01515
IC	.54317	.28944	-.02954
SO	.61050	.32766	-.02064
SOM	[illegible]	.25354	.29253
LBA	.50297	.23432	.35309
RP	.53031	-.10030	-.02994
PLCOM	.46512	-.14433	-.09499
DRT	.61796	.28045	.06080
NUT	.39125	.08795	-.15938
RT	.20671	-.19690	.35563
ROM	.37460	-.55887	.26298

VARIMAX ROTATED FACTOR MATRIX
AFTER ROTATION WITH KAISER NORMALIZATION obtained from a reanalysis of the Fleishman and Hempel 1954B study.

Exhibit 7.3

	FACTOR 1	FACTOR 2	FACTOR 3
STAGE1	.05240	.55288	−.06330
STAGE2	.82387	.35874	.08435
STAGE3	.31242	.37469	.14421
STAGE4	.38742	.26312	.16174
STAGE5	[illegible]	.21841	.17289
STAGE6	.38785	.13258	.21191
STAGE7	.87596	.19187	.19975
STAGE8	.87325	.17599	.18042
NUMOP	.37475	.54520	.22675
DTR	.18641	.79943	.13397
MP	.25358	.61658	−.23135
GM	.22488	.46614	−.25446
SOI	.19130	.71986	.23081
PC	.20273	.71697	.03566
VP	.31291	[illegible]	.09112
DEC	.13417	.73443	.17312
IC	.21532	.57496	.05814
SO	[illegible]	.65096	.07870
SOM	.25739	.54483	−.38283
LBA	.15277	.47181	−.42669
RP	[illegible]	[illegible]	−.13639
PLCUM	[illegible]	.23313	[illegible]
DRT	.25753	.62386	.15728
NUT	.25412	.33442	−.08693
RT	.25192	.84424	−.43956
ROM	.27348	.17042	−.33219

	Factor 1	Factor 2
Stage 1	37%	30%
Stage 2	68%	13%
Stage 3	67%	14%
Stage 4	79%	7%
Stage 5	81%	5%
Stage 6	79%	-
Stage 7	77%	-
Stage 8	76%	-

It would appear that, except for stage 1, one factor contributes the vast majority of the variance and that this contribution remains fairly constant throughout. However, stage 1 has two factors contributing with Factor 2 rapidly decreasing 'its' contribution and of no importance from stage 5 onwards.

Therefore apart from the initial stage there is no strong evidence of changes in factor contribution during practice. No factor specific to the task is evident in the factor pattern. Exhibit 7.4 shows those variables with loadings greater than or equal to 0.3. The factors for the present will not be labelled but will be compared with those found in the other ten studies to determine their mutual similarities and thereby give greater confidence in interpreting and labelling them.

The second study which was concerned with the "organization of abilities at different stages of practice in a complex psychomotor learning" is Fleishman and Hempel 1955. The criterion task used was the Discrimination Reaction Time Test. 264 basic trainee airmen were given 16 trials with

Exhibit 7.4 Variables with loadings greater than or equal to 0.3 in the reanalysis of the study by Fleishman and Hempel 1954 B

Factor 1

Rotary Pursuit	.50
Plane Control	.43
Visual Pursuit	.31

Factor 2

Dial and Table reading	.80
Speed of Identification	.72
Pattern Comprehension	.72
Decoding	.73
Spatial Orientation	.65
Mechanical Principles	.62
Discrimination Reaction time	.61
Instrument Comprehension	.57
Numerical Operations	.55
Speed of Marking	.54
General Mechanics	.47
Visual Pursuit	.45
Log Book Accuracy	.47
Nut and Bolt	.33
Rotary Pursuit	.31

Factor 3

Log Book Accuracy	43
Reaction Time	41
Speed of Marking	38
Rate of Movement	33

each trial consisting of 20 stimulus settings. Eight stages of practice, representing every other trial, were selected for inclusion in the analysis together with the 19 reference tests administered to the subjects. The intercorrelation matrix is shown in Exhibit 7.5. Applying the 'Scree Test' to the plot of the eigenvalues suggested that there were four common factors at the most, as shown in Exhibit 7.6. Therefore, the Principal Factor analysis and the Varimax rotation were carried out for four factors being extracted and the resultant factor patterns are shown in Exhibit 7.7. The list of reference tests may be seen in Exhibit 6.5 and 6.6 and also that eleven factors were extracted and rotated in the original study.

From the factor patterns produced in the re-analysis it may be seen (Exhibit 7.7) that, after rotation, one factor accounts for the vast majority of the criterion task variance. Indeed the highest loading of any of the other factors on the criterion tasks is only 0.26. The following is the percentage variance accounted for by Factor 2 for each stage of practice.

	Factor 2
Trial 1	49%
Trial 3	62%
Trial 5	71%
Trial 7	72%
Trial 9	67%
Trial 11	64%
Trial 13	58%
Trial 15	59%

From this analysis there would appear to be no evidence for the claim

CORRELATION COEFFICIENTS, obtained from Fleishman and Hempel 1955.

Exhibit 7.5

K	TRL1	TRL3	TRL5	TRL7	TRL9	TRL11	TRL13	TRL15	WDKNC	CURAFF
TRL1 00	1.00000	.74000	.71000	.69000	.62000	.59000	.57000	.56000	.330	.34000
TRL3 00	.74000	1.00000	.82000	.78000	.74000	.68000	.66000	.64000	.360	.40000
TRL5 00	.71000	.82000	1.00000	.83000	.79000	.72000	.72000	.71000	.380	.40000
TRL7 00	.69000	.78000	.83000	1.00000	.80000	.74000	.72000	.74000	.350	.38000
TRL9 00	.62000	.74000	.79000	.80000	1.00000	.77000	.73000	.77000	.300	.36000
TRL11 00	.59000	.68000	.72000	.74000	.77000	1.00000	.74000	.80000	.300	.33000
TRL13 00	.57000	.66000	.72000	.72000	.73000	.74000	1.00000	.79000	.310	.37000
TRL15 00	.56000	.64000	.71000	.74000	.77000	.80000	.79000	1.00000	.280	.30000
WDKNOW 00	.33000	.36000	.38000	.35000	.30000	.30000	.31000	.28000	1.000	.71000
CURAFF 00	.34000	.40000	.40000	.38000	.36000	.33000	.37000	.38000	.710	1.00000
MECPRI 00	.37000	.39000	.37000	.37000	.35000	.34000	.39000	.38000	.500	.50000
GENMEC 00	.30000	.27000	.29000	.22000	.24000	.23000	.24000	.26000	.530	.48000
TOOLF 00	.24000	.25000	.24000	.18000	.20000	.17000	.19000	.18000	.330	.34000
SPIDEN 00	.38000	.44000	.44000	.39000	.37000	.39000	.43000	.40000	.422	.48000
PATCOM 00	.41000	.44000	.46000	.36000	.37000	.34000	.40000	.34000	.500	.55000
INSCOM 00	.45000	.42000	.47000	.44000	.42000	.40000	.38000	.43000	.440	.45000
VISPUR 00	.21000	.23000	.25000	.21000	.22000	.16000	.17000	.22000	.172	.16000
PPEGAS 00	.23000	.28000	.32000	.31000	.34000	.30000	.34000	.32000	.240	.24000
SADEXT 00	.34000	.47000	.41000	.38000	.36000	.32000	.42000	.36000	.260	.25000
RMOVE 00	.18000	.24000	.20000	.28000	.30000	.23000	.23000	.25000	.192	.18000
ROTAIM 00	0.00000	.11000	.16000	.14000	.19000	.19000	.15000	.23000	.050	.03000
VISRT 00	.12000	.14000	.17000	.24000	.26000	.21000	.20000	.25000	-.040	-.02000
AUDRT 00	.04000	.09000	.12000	.13000	.14000	.14000	.14000	.20000	.022	.02000
JVISRT 00	.19000	.26000	.24000	.32000	.35000	.30000	.31000	.37000	.110	.14000
JAUDRT 00	.09000	.24000	.22000	.29000	.30000	.28000	.27000	.33000	.090	.10000
COMCOR 00	.44000	.48000	.45000	.44000	.41000	.37000	.43000	.38000	.232	.24000
ROTPUR 00	.29000	.28000	.30000	.31000	.31000	.25000	.27000	.24000	.150	.06000

T	MECPRI	GENMEC	TOOLF	SPIDEN	PATCOM	INSCOM	VISPUR	PPEGAS	SADEX	RMOVE
TRL1 00	.37000	.30000	.24000	.38000	.41000	.45000	.21000	.23000	.342	.18000
TRL3 00	.39000	.27000	.25000	.44000	.44000	.42000	.23000	.28000	.470	.24000
TRL5 00	.37000	.29000	.24000	.44000	.46000	.47000	.25000	.32000	.410	.20000
TRL7 00	.37000	.22000	.18000	.39000	.36000	.44000	.21000	.31000	.382	.28000
TRL9 00	.35000	.24000	.20000	.37000	.37000	.42000	.20000	.34000	.360	.30000
TRL11 00	.34000	.23000	.17000	.39000	.34000	.40000	.16000	.30000	.320	.23000
TRL13 00	.39000	.24000	.19000	.43000	.40000	.36000	.17000	.34000	.420	.23000
TRL15 00	.38000	.26000	.18000	.40000	.34000	.43000	.22000	.32000	.360	.25000
WDKNOW 00	.50000	.53000	.33000	.42000	.50000	.44000	.17000	.24000	.260	.19000
CURAFF 00	.50000	.48000	.34000	.46000	.55000	.45000	.16000	.24000	.250	.16000
MECPRI 00	1.00000	.60000	.58000	.41000	.54000	.58000	.33000	.25000	.200	.20000

Exhibit 7.5 continued.

T	MECPRI	GENMEC	TOOLF	SPIDEN	PATCOM	INSCOM	VISPUR	PPEGAS	SADEX	RMOVE
GENMEC	.60000	1.00000	.71000	.27000	.41000	.47000	.23000	.19000	.190	.16000
TOOLF	.58000	.71000	1.00000	.28000	.42000	.42000	.27000	.21000	.150	.14000
SPIDEN	.41000	.27000	.28000	1.00000	.52000	.45000	.32000	.46000	.380	.16000
PATCOM	.54000	.41000	.42000	.52000	1.00000	.51000	.31000	.36000	.270	.19000
INSCOM	.58000	.47000	.42000	.45000	.51000	1.00000	.32000	.33000	.290	.20000
VISPUR	.33000	.23000	.27000	.32000	.31000	.32000	1.00000	.27000	.200	.17000
PPEGAS	.25000	.19000	.21000	.46000	.36000	.33000	.27000	1.00000	.400	.16000
SADEXT	.24000	.19000	.15000	.38000	.27000	.29000	.20000	.40000	1.000	.24000
RMOVE	.20000	.16000	.14000	.16000	.19000	.20000	.17000	.16000	.240	1.00000
ROTAIM	.07000	.06000	-.01000	.25000	.07000	.13000	.23000	.27000	.310	.32000
VISRT	-.49000	-.10000	-.11000	.08000	-.06000	.04000	.03000	.04000	.140	.10000
AUDRT	-.31000	0.00000	0.00000	.06000	-.04000	.05000	-.03000	.05000	.080	.06000
JVISRT	.09000	.04000	-.03000	.23000	.08000	.19000	.19000	.20000	.300	.24000
JAUDRT	.07000	-.04000	-.07000	.25000	.08000	.14000	.15000	.21000	.300	.28000
COMCOR	.46000	.29000	.33000	.39000	.40000	.47000	.38000	.34000	.380	.20000
ROTPUR	.25000	.21000	.23000	.27000	.23000	.24000	.32000	.22000	.350	.28000

	ROTAIM	VISRT	AUDRT	JVISRT	JAUDRT	COMCOR	ROTPUR
TRL1	3.30300	.12000	.04000	.19000	.09000	.44000	.29000
TRL3	.11000	.14000	.09000	.26000	.24000	.48000	.28000
TRL5	.16000	.17000	.12000	.24000	.22000	.45000	.30000
TRL7	.14000	.24000	.13000	.32000	.29000	.44000	.31000
TRL9	.19000	.26000	.14000	.35000	.30000	.41000	.31000
TRL11	.19000	.21000	.14000	.30000	.26000	.37000	.25000
TRL13	.15000	.23000	.14000	.31000	.27000	.43000	.27000
TRL15	.23000	.25000	.20000	.37000	.33000	.38000	.24000
ADRNCR	.35000	-.04000	.02000	.11000	.09000	.23000	.15000
CURAFF	.03000	-.02000	.02000	.14000	.10000	.24000	.06000
MECPRI	.07000	-.29000	-.01000	.09000	.07000	.46000	.25000
GENMEC	.36000	-.10000	0.00000	.04000	-.01000	.29000	.21000
TOOLF	-.01000	-.11000	0.20000	-.03000	-.07000	.33000	.23000
SPIDEN	.25000	.08000	.06000	.23000	.25000	.39000	.27000
PATCOM	.37000	-.06000	-.24000	.08000	.08000	.40000	.23000
INSCOM	.13000	.04000	.05000	.19000	.14000	.47000	.24000
VISPUR	.23000	.03000	-.03000	.19000	.15000	.38000	.32000
PPEGAS	.27000	.04000	.05000	.26000	.21000	.34000	.22000
SADEXT	.31000	.14000	.08000	.30000	.30000	.38000	.35000
RMOVE	.32000	.10000	.06000	.24000	.20000	.20000	.20000
ROTAIM	1.00000	.21000	.17000	.34000	.30000	.24000	.24000
VISRT	.21000	1.00000	.57000	.61000	.49000	.16000	.15000
AUDRT	.17000	.57000	1.00000	.44000	.49000	0.00000	.10000
JVISRT	.34000	.61000	.44000	1.00000	.73000	.28000	.23000
JAUDRT	.30000	.49000	.49000	.73000	1.00000	.19000	.20000

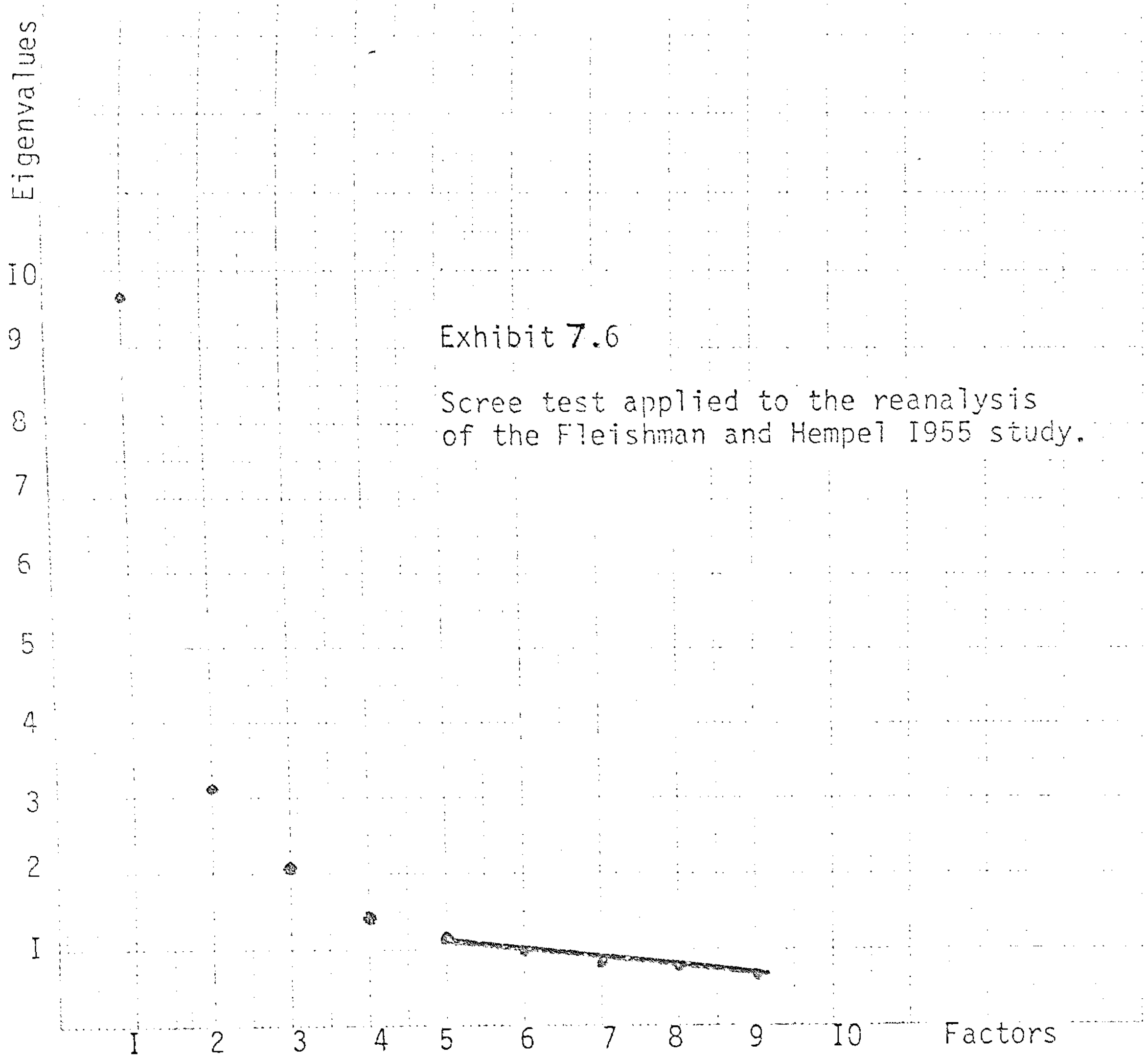


Exhibit 7.6

Scree test applied to the reanalysis of the Fleishman and Hempel 1955 study.

Exhibit 7.7

FACTOR MATRIX USING [illegible] FACTOR WITH ITERATIONS obtained
from a reanalysis of the Fleishman and Hempel 1955 study

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
TRL1	.7[illegible]	-.23917	-.28638	-.01477
TRL3	.81[illegible]	.[illegible]5153	-.28514	-.02593
TRL5	.81[illegible]	.04755	-.31024	-.00567
TRL7	[illegible]	.17[illegible]2	-.31032	.02596
TRL9	.81[illegible]	.13931	-.27093	.01741
TRL11	.7[illegible]	.1[illegible]112	-.29011	.05140
TRL13	.78[illegible]3	.14347	-.24015	.02925
TRL15	.78[illegible]	.21923	-.21082	.24158
[illegible]	.53[illegible]	-.37295	.17124	.31592
[illegible]	.5[illegible]	-.[illegible]5906	.13597	.36417
[illegible]	.[illegible]176	-.41651	.27338	.06338
GEN[illegible]EC	.47[illegible]	-.[illegible]9068	.25210	.17123
TOOLF	.4[illegible]	-.48776	.23[illegible]	.02756
[illegible]	[illegible]	-.11050	.19457	-.07909
[illegible]	[illegible]	-.36783	.12058	.31110
[illegible]	[illegible]	-.20158	.16[illegible]21	.04640
VIS[illegible]	.37[illegible]	-.11061	.25[illegible]	-.39703
[illegible]	[illegible]	-.[illegible]1320	.19138	-.21582
[illegible]	[illegible]	.10275	.13337	-.22174
[illegible]	.337[illegible]	.[illegible]0663	.14[illegible]	-.09294
[illegible]	[illegible]	.05323	.31257	-.26767
VIS[illegible]T	.23[illegible]	.[illegible]2419	.23352	.19399
[illegible]	.17[illegible]	.47372	.2776[illegible]	.31114
JV[illegible]	.1[illegible]	.59139	.4240[illegible]	.10396
JA[illegible]	.3[illegible]	.[illegible]7257	.39160	.12473
CO[illegible]	.5[illegible]	-.[illegible]5011	.15[illegible]86	-.31032
ROT[illegible]	.31[illegible]	.[illegible]5277	.18[illegible]23	-.30194

VARIMAX ROTATED FACTOR MATRIX
AFTER ROTATION WITH KAISER NORMALIZATION obtained from a reanalysis of the Fleishman and Hempel 1955 study

Exhibit 7.7

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
TRL1	.25850	.69889	.17803	-.02875
TRL3	.24311	.79641	.23325	.05333
TRL5	.24321	.83868	.21525	.06294
TRL7	.15302	.84872	.19025	.14873
TRL9	.16311	.82137	.20979	.18196
TRL11	.15591	.79762	.15292	.16556
TRL13	.20383	.76201	.20773	.15482
TRL15	.17418	.76516	.20712	.23202
KDKNOW	.79704	.22023	.03156	.06678
CURAFF	.71918	.26824	-.00992	.08603
MECPRI	.79230	.22390	.27057	-.06510
GENMEC	.72953	.09251	.15176	-.05812
TOOLF	.02056	.05411	.22908	-.13705
SPIDCH	.41555	.29602	.39667	.10579
FATCOM	.58988	.28616	.28231	-.06864
INSCOM	.54594	.31265	.31598	.02863
VISPUR	.22035	.07458	.50848	-.00439
PREGAS	.21476	.28946	.44968	.09077
SADEXT	.14095	.31121	.45563	.15448
RMOVF	.13322	.16857	.27956	.14910
ROTAIM	-.13560	.03761	.47302	.27871
VISPT	-.13034	.15739	.37441	.69856
AUDRT	.11751	.05414	-.33004	.65061
JVISRT	.01983	.16811	.31046	.77264
JAUDRT	.00152	.14392	.25442	.73938
COMCOR	.25619	.32448	.56141	.02638
ROTPUR	.10408	.18772	.49321	.08421

that there are changes in the factors which contribute to performance during practice. Exhibit 7.8 shows those reference test variables which have loadings greater than 0.3 and which will be used later to identify the factors.

The third study of changes in factor contribution during learning was carried out by Fleishman (1960B). The criterion practice task was the Rotary Pursuit test which required the subjects to keep the tip of a stylus in contact with a metal target button which rotated on a disc at 60 r.p.m. Each of the 224 basic trainee airmen was tested on 15 trials, with each trial consisting of five 20 second test periods, and given the 17 selected reference tests listed in Exhibit 6.11, Chapter 6. The intercorrelation matrix was subjected to a Principal components analysis. The plot of the eigenvalues for each factor and the application of the 'Scree Test' is shown in Exhibit 7.9. The number of factors to be extracted was determined as four and the subsequent Principal Factor analysis and Varimax rotation is shown in Exhibits 7.10 and 7.11. It can be seen from Exhibits 6.11 and 6.12 in Chapter 6 that eleven factors were extracted and rotated in the original study.

The rotated factor pattern shown in Exhibit 7.11 produced one factor which had high loadings on all the stages of practice. Only one other factor contributed significantly and that occurred in the final two trials. The following is the percentage of variance, for each stage of practice, accounted for by these two factors:

Exhibit 7.8 Variables with loadings greater than or equal to 0.3 in the reanalysis of the study by Fleishman and Hempel 1955.

Factor 1

Current Affairs	.72
Word knowledge	.71
General Mechanics	.73
Mechanical Principles	.69
Tool Functions	.62
Pattern Comprehension	.59
Instrument Comprehension	.55
Speed of Identification	.41

Factor 2

Complex Coordination	.32
Instrument Comprehension	.31
Santa Ana Dexterity	.31
Speed of Identification	.30

Factor 3

Complex Coordination	.56
Visual Pursuit	.51
Rotary Pursuit	.49
Santa Ana Dexterity	.46
Purdue Peg Board Assembly	.45
Speed of Identification	.40
Instrument Comprehension	.32
Jump Visual R.T.	.31

Factor 4

Jump Visual R.T.	.77
Jump Auditory R.T.	.74
Visual R.T.	.70
Auditory R.T.	.65

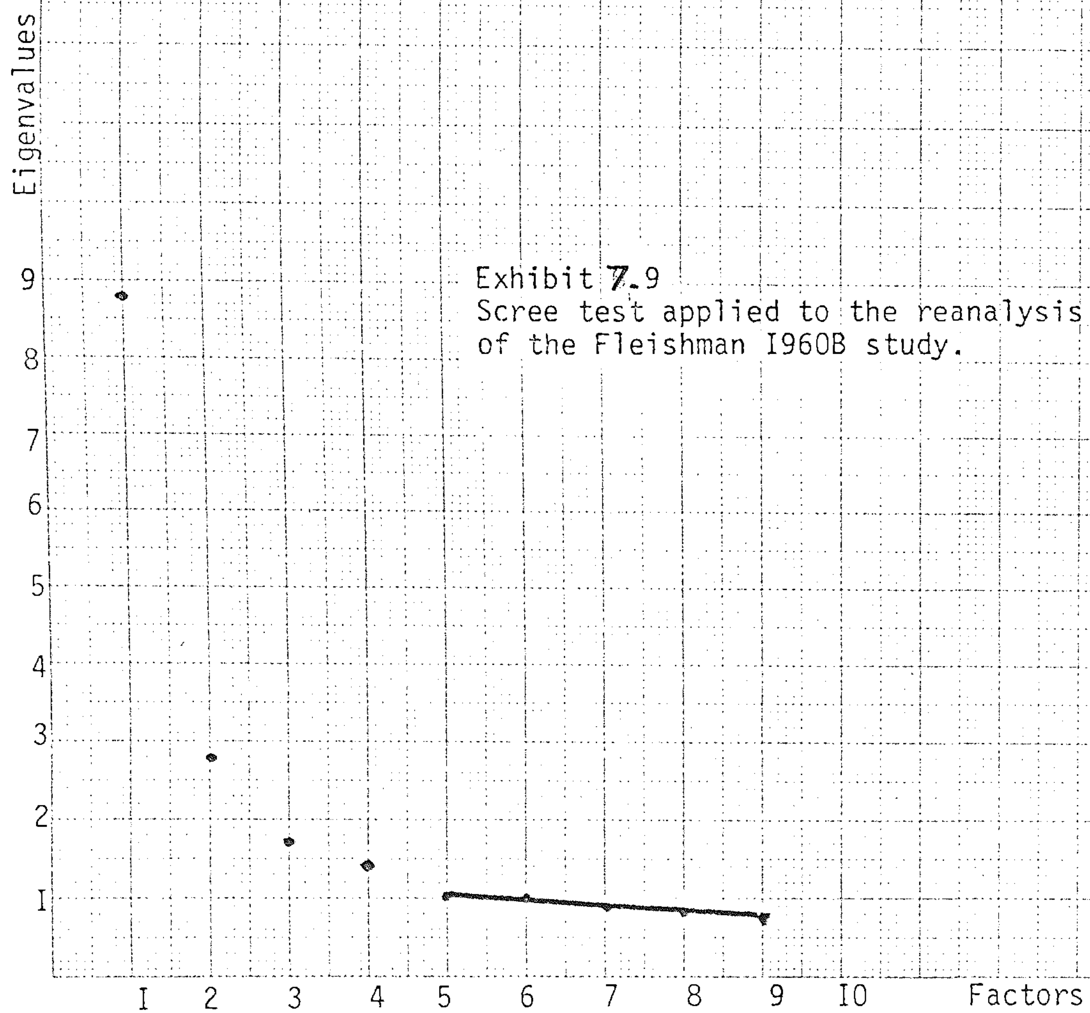


Exhibit 7.9
Scree test applied to the reanalysis of the Fleishman I960B study.

FACTOR MATRIX USING PRINCIPAL FACTOR WITH ITERATIONS obtained from a reanalysis of the Fleishman 1960b study

Exhibit 7.10

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
TRIAL1	.72675	-.17871	-.06332	.16465
TRIAL3	.83453	-.22015	-.11338	.11364
TRIAL5	.87717	-.29281	-.09919	-.00481
TRIAL7	.88102	-.34447	-.09783	.01722
TRIAL9	.86669	-.33464	-.10499	-.04144
TRIA11	.85435	-.33483	-.10705	-.07662
TRIA13	.83283	-.31719	-.05523	-.12625
TRIA15	.80501	-.27364	.03023	-.08402
GENMEC	.33992	.46548	-.49195	.09797
TFUNC	.31351	.51242	-.63704	.09852
SPIDFN	.46775	.44579	.12279	-.16339
INSC	.42153	.52055	-.13732	-.09083
VISPUR	.39804	.28855	.01935	.05792
AIMING	.48624	.09529	.14075	-.19909
MARKAC	.45617	.11378	.22598	-.09614
PEGASS	.30437	.44360	.18407	-.13786
SANTA	.52072	.24430	.22013	-.14674
RATEC	.28221	.18537	.11432	.65636
SDPURM	.28940	.09220	.22518	.51748
RMOV	.32444	.14646	.13276	-.00079
TORAIM	.47063	.09938	.34946	.08336
JVISRT	.35025	.15041	.37112	.06301
TTRAC	.47577	.21974	.05925	.02475
COMCORD	.54858	.38293	.04862	.02920
DISCRT	.49128	.38993	.38214	-.12771

VARIMAX ROTATED FACTOR MATRIX
AFTER ROTATION WITH KAISER NORMALIZATION obtained from a reanalysis of the Fleishman 1960B study.

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
TRIAL1	.05163	.19579	.13976	.25662
TRIAL3	.81622	.21756	.16021	.21337
TRIAL5	.86019	.23752	.10939	.10596
TRIAL7	.71744	.20323	.08175	.12271
TRIAL9	.90473	.21578	.08208	.06376
TRIA11	.89715	.21888	.07622	.02781
TRIA13	.86231	.20154	.03544	-.08717
TRIA15	.79852	.30571	-.00567	.05440
GENMEC	.10635	.14788	.74286	.05687
TFUNC	.07482	.09626	.55865	.02451
SPIDEN	.10564	.01894	.25591	.00119
INSC	.07383	.47385	.49651	-.00436
VISPUR	.14841	.30414	.25589	.16522
AIMING	.25308	.40589	.01735	-.06581
MARKAC	.26067	.45733	-.01226	.06402
PEGASS	.03337	.56638	.16243	.01969
SANTA	.24569	.57973	.07764	.03744
RATEC	.11626	.07284	.08945	.71544
SDPURM	.10917	.16722	.01539	.60884
RMOV	.15543	.32674	.05969	.10570
TORAI1	.19526	.45674	-.11552	.18020
JVISRT	.12278	.46125	-.15581	.23926
TTRAC	.24375	.39938	.19752	.14409
CONCORD	.21579	.52459	.31869	.17173
DISCRT	.16223	.56578	.26358	.02342

Exhibit 7.II

	Factor 1	Factor 2
Trial 1	46%	-
Trial 3	64%	-
Trial 5	78%	-
Trial 7	84%	-
Trial 9	82%	-
Trial 11	80%	-
Trial 13	74%	7%
Trial 15	64%	10%

It is not obvious whether the small increase in the contribution of Factor 2 is a trend or merely a brief contribution. Again, there is no evidence for a change in the factors contributing to performance during practice. However, none of the reference tests had loadings greater than 0.26 which is a marginally significant loading. This factor may be specific to the task or the choice of reference tests did not include ones which involved this factor. Exhibit 7.12 shows the reference tests which have loadings greater than 0.2 on Factor 1 which, if Harman's Standard Error formula is used (Harman 1976, p. 441), would be considered statistically significant.

Conclusion

All three studies, when re-analysed, produced very similar results. One factor was dominant (58 - 84% of variance) throughout learning with virtually no other factor contributing except for the first stage, where in all three studies the dominant factor contributed between 37% and 49% of

Exhibit 7.12 Reanalysis of Fleishman 1960B showing variables with loadings greater than or equal to 0.2 for Factor 1 and 0.3 for the remaining factors

Factor 1

Marking accuracy	.26
Aiming	.25
Santa Ana Finger Dexterity	.24
Track Tracing	.24
Complex Coordination	.21

The following are the three other factors and the reference tests with loadings greater or equal to 0.3.

Factor 2

Speed of Identification	.62
Santa Ana Finger Dexterity	.58
Purdue Pegboard Assembly	.57
Discrimination Reaction Time	.57
Complex Coordination	.52
Instrument Comprehension	.47
Jump Visual Reaction Time	.46
Marking Accuracy	.46
Rotary Aiming	.46
Aiming	.41
Track Tracing	.40
Visual Pursuit	.36
Rate of Movement	.33

Factor 3

Tool Functions	.85
General Mechanics	.74
Instrument Comprehension	.50
Complex Coordination	.32

Factor 4

Rate Control	.72
Single Dimension Pursuit	.61

the variance. However, only in one of the studies (Fleishman and Hempel 1954B) was another factor found to contribute significantly in the first stage.

Re-analysis of reference test studies

The other eight studies have all been re-analysed using the same methods and procedures as those used in the re-analysis of the three previous studies. That is, the intercorrelation matrix was subjected to a Principal Components analysis from which the eigenvalues, with communalities as unities, were obtained. These were plotted and the Scree test applied. The intercorrelation matrix was then subjected to a Principal Factor analysis with a defined number of factors to be extracted. The resulting factor pattern was rotated using the 'Varimax' method and it was the rotated solution which was used to define the factors.

From the Varimax factor solution, obtained by re-analysing all the eleven studies, each factor was extracted and those variables whose loadings were greater than or equal to 0.3 were listed for that factor. It is realised that the significance or otherwise of a loading is dependent on a number of factors which differed with each of the eleven studies which were re-analysed, but the aim was to identify those factors which were the same. The prominent loadings of a factor provide a pattern of "salient variables" (Cattell 1978, p. 485) which is the first step in identifying which factors may be representing the same variance. These lists of prominent loadings (Exhibits 7.13 to 7.19 inclusive) were then examined and grouped together in terms of similarity of salient variables (Cattell 1978, p. 484).

Exhibit 7.13 Variables with loadings greater than or equal to 0.3 in the reanalysis of the study by Fleishman, Roberts and Friedman 1958

Factor 1

Word knowledge	76
Background Current Affairs	67
Mutilated Words	60
Gestalt Completion	45
Four letter Words	42

Factor 2

Dot Perception	75
Copying Behind	59
Hidden Tunes	51
Army Radio Code	49
Rythm Discrimination	46

Factor 3

Concealed Figures	72
Pattern Comprehension	69
Designs	53
Gestalt Completion	43
Marking Accuracy	32

Exhibit 7.14 Variables with loadings greater than or equal to 0.3 in the reanalysis of the study by Fleishman 1958B

Factor 1	
M.P. - Bank and Heading	.86
M.P. - Bank and Air Speed	.83
M.P. - Bank, Heading and Air Speed	.81
M.P. - Air Speed	.70
M.P. - Heading	.69
M.P. - Bank and Altitude	.67
M.P. - Bank	.57
Discrimination Reaction Time	.31
Factor 2	
Rudder Control - Triple Target	.82
Rudder Control - Single Target	.79
Two hand Coordination	.52
Plane Control	.41
Motor Judgement	.39
Rate Control	.36
Rotary Pursuit	.34
Pursuit Confusion - Errors	.33
Two hand Pursuit	.33
Complex Coordination	.31
Control Adjustment	.30
Factor 3	
Printed Discrimination Reaction Time	.57
Dial Setting	.53
Discrimination Reaction Time	.52
Two hand Pursuit	.47
Ctonrol Adjustment	.45
Track Tracing	.41
Rotary Aiming	.37
Single Dimension Pursuit	.35
Motor Judgement	.32
Visual Coincidence	.30
Rotary Pursuit	.30

Exhibit 7.15 Variables with loadings greater than or equal to 0.3 in the reanalysis of the study by Fleishman and Ellison 1962

Factor 1

Pursuit Aiming - 2	.78
Pursuit Aiming - 1	.77
Large Tapping	.75
Medium Tapping	.74
Aiming	.74
Square Marking	.54
Ten target Aiming - correct	.44
Minnesota Rate of Manip-placing	.35
Minnesota Rate of Manip - turning	.32

Factor 2

Purdue Pegboard - Both hands	.69
Purdue Pegboard - Assembly	.66
Purdue Pegboard - Right hand	.63
O'Connor Finger Dexterity	.61
Minnesota Rate of Manip-turning	.61
Minnesota Rate of Manip-placing	.60
Purdue Pegboard - Left hand	.59
Pin Stick	.44

Factor 3

Hand Precision Aiming - Errors	.92
Hand Precision Aiming - Correct	.71
Ten Target Aiming - Correct	.34

Exhibit 7.16 Variables with loadings greater than or equal to 0.3 in the reanalysis of the study by Parker and Fleishman 1960

Factor 1

Formation Visualisation	.78
Stick and Rudder Orientation	.70
Instrument Comprehension	.69
Pattern Comprehension	.69
Visualisation of Maneuvres	.66
Mechanical Comprehension	.65
Coordinate Movements	.61
Aerial Orientation	.60
General Mechanics	.55
Planning a Course	.53
Visual Pursuit	.53
Direction Control	.51
Complex Movements	.51
Signal Interpretation	.50
Forced Landings	.50
Directional Control	.45
Following Directions	.41
Discrimination Reaction Time	.39
Vocabulary	.37
Spatial Orientation	.37
Speed of Identification	.36
Pursuit Confusion (errors)	.34
Discrimination Reaction Time - printed	.33
Complex Coordinator	.32

Factor 2

Rudder Control	.67
Rotary Pursuit	.53
Two Hand Coordination	.53
Complex Coordination	.53
Bimanual Matching	.51
Pursuit Confusion - correct	.48
Pursuit Confusion - errors	.42
Control Sensitivity	.40
Rate Control	.39
General Mechanics	.36
Discrimination Reaction Time - printed	.34
Track Tracing - errors	.33
Ten Target Aiming (correct)	.31
Two plate tapping	.31
Motor Judgement	.30

Factor 3

Jump Auditory Reaction Time	.58
Visual Reaction Time	.51
Jump Visual Reaction Time	.51
Auditory Reaction Time	.46
Ten Target Aiming - correct	.41
Ten Target Aiming - errors	- .36
Choice Reaction Time	.33
Control Sensitivity	.32
Rate Control	.30

Factor 4

Purdue Pegboard (summ of all scores)	.67
Minnesota Rate of Manip - placing	.64
Minnesota Rate of Manip - turning	.51
Finger Dexterity	.44
Two Plate Tapping	.39
Rotary Aiming	.33
Speed of Identification	.30

Factor 5

Discrimination Reaction Time - printed	.58
Speed of Identification	.37
Steadiness Aiming	- .35
Jump Auditory Reaction Time	- .34
Following Directions	.32

Exhibit 7.17 Variables with loadings greater than or equal to 0.3 in the reanalysis of the study by Fleishman 1954

Factor 1

Two Plate Tapping	.49
Rotary Aiming	.58
Medium Tapping	.64
Large Tapping	.63
Aiming	.77
Pursuit Aiming I	.75
Pursuit Aiming II	.78
Minnesota Rate of Manip - placing	.40
Minnesota Rate of Manip - turning	.43
Santa Ana Dexterity	.40
Hand Precision Aiming - correct	.35
Punch Board	.38
Pin Stick	.36
Square Marking	.44
Tracing	.37
Printed Disc. React. Time	.30
Log book Accuracy	.53
Marking Accuracy	.59

Factor 2

Minnesota Rate of Manip - placing	.50
Minnesota Rate of Manip - turning	.52
Purdue Peg board - right hand	.62
Purdue Peg board - left hand	.52
Purdue Peg board - both hands	.65
Purdue Peg board - assembly	.57
O'Connor Finger Dexterity	.60
Track Tracing	.33
Ten Target Aiming - correct	.34
Rotary Aiming	.32
Visual Reaction Time	.36
Punch Board	.40

Factor 3

Steadiness Precision	.44
Steadiness Aiming	.41
Track Tracing	.57
Punch Board	.34
Steadiness	.31
Two Plate Tapping	.40
Key Tapping	.32
Hand Precision Aim - errors	.37
Discrimination Reaction Time	.39
Complex Coordination	.53
Rudder Control	.43
Rotary Pursuit	.44
Printed Disc. Reaction Time	.36

Factor 4

Ten Target Aiming - errors	.39
Ten Target Aiming - correct	.32
Hand Precision Aiming - errors	.38
Discrimination Reaction Time	.39
Printed Discrimination Reaction Time	.37

Exhibit 7.18 Variables with loadings greater than or equal to 0.3 in the reanalysis of the study by Fleishman 1958A

Factor 1

Track tracing	.65
Steadiness Precision	.63
Steadiness Tremor	.62
Arm Tremor	.33

Factor 2

Control Movement E	.57
Rotary Positioning E	.41
Knobs Positioning E	.38
Target Aiming	.32

Factor 3

Control movement R	.58
Direction Tracing	.36
Knob Positioning R	.30

Factor 4

Arm Drift	.54

Exhibit 7.19 Variables with loadings greater than or equal to 0.3 in the reanalysis of the study by Fleishman and Hempel 1954 A

Factor 1

Purdue Peg Board - Both hands	.67
O'Connor Finger Dexterity	.62
Purdue Peg Board Assembly	.58
Purdue Peg Board - left hand	.57
Purdue Peg Board - right hand	.57
Minnesota Rate of Manip - turning	.50
Minnesota Rate of Manip - placing	.46
Punch Board	.34

Factor 2

Tapping - small	.61
Square marking	.57
Marking accuracy	.57
Tapping - large	.48
Tracing	.47
Puch Board	.45
Minnesota Rate of Manip - placing	.37
Minnesota Rate of Manip - turning	.30
Purdue Pegboard - right hand	.30

Factor 3

Santa Ana Dexterity	.54
Tapping - large	.44
Pin stick	.40
Minnesota Rate of Manip - turning	.39
Tapping - small	.38

The Varimax rotated factor patterns were then re-examined for each of the factors included in a group, and all the variables which were common to the factors in that group and their loadings on each of the factors were listed (Exhibits 7.20 to 7.25). The study by Fleishman and Ornstein 1960 was not used, as none of the variables in the study was used in any of the other studies. From the ten studies 35 factors were obtained and grouped by prominent loadings.

Although Cattell (1978, p. 526) states that he would "venture to speak of a definitely replicated factor only when significant matches have been shown among at least three studies", those groups which only include two factors, that is, involving only two studies, have been included as they are an extremely important step in identifying a set of invariant factors. Four of the six groupings involved three or four studies (Exhibits 7.20 to 7.23 inclusive) and two groups involved two studies (Exhibits 7.24, 7.25). However, if similarity of factors is to be measured by the Wrigley and Newhaus congruence coefficient as used in Chapter 6, it is necessary to use the Korth table as shown in Exhibit 6.23 to determine the significance values for the congruence coefficients, and the values are only calculated for a minimum of ten variables in common between the two factors. This means that only some of the congruence coefficients may be assessed for their statistical significance.

It is important, when assessing the similarity of factors, to include not just the salient variables, that is those with large loadings, but also those variables whose loadings are not of a significant size. The former inform us of what the factor represents and the latter of what the factor does not represent. The inclusion of non-significant variables allows for the limitation of the factor to be assessed.

Exhibit 7.20

Factor A

	Fleishman & Ellison 1962	Parker & Fleishman 1960	Fleishman 1954	Fleishman & Hempel 1954 A
Purdue Pegboard Right hand	63	-	.62	57
Purdue Pebgoard Left hand	59	-	.52	.57
Purdue Pegboard both hands	69	-	.65	.67
Purdue Pegboard Assembly	66	-	.57	.58
Purdue Pegboard (Summation)	-	67	-	-
Minnesota Rate of Manip. - Turning	61	51	52	50
Minnesota Rate of Manip - Placing	60	64	50	46
O'Connor Finger Dexterity	61	44	60	62
Tracing	21	-	13	16
Medium Tapping	21	-	.20	.19
Large Tapping	21	-	.15	15
Aiming	29	-	21	19
Square Marking	25	-	18	15
Discrimination Reaction Time (printed)	18	22	13	-
Ten Target Aiming - Errors	06	10	01	-
Ten Target Aiming - Correct	25	08	34	-
Precision Steadiness	26	16	09	-

$r_c = .92$ (Fleishman & Ellison 1962, Parker & Fleishman 1960, Fleishman 1954)

$r_c = 1.00$ (Fleishman 1954, Fleishman & Hempel 1954 A)

$r_c = 0.97$ (all four studies)

All values of congruence coefficient r_c are significant at $p < .05$

Exhibit 7.21

Factor B			
	Fleishman & Ellison 1962	Fleishman 1954	Fleishman & Hempel 1954 A
Pursuit Aiming I	77	75	-
Pursuit Aiming II	78	78	-
Medium Tapping	74	64	61
Large Tapping	75	63	48
Aiming	74	77	-
Square Marking	54	44	57
Minnesota Rate of Manip - placing	35	40	37
Minnesota Rate of Manip - turning	32	43	30
Marking Accuracy	-	59	57
Punch Board	-	38	45
Tracing	21	37	47
O'Connor Finger Dexterity	21	27	18
Purdue Pegboard Right Hand	12	21	30
Purdue Pegboard Left Hand	11	21	12
Purdue Pegboard Both Hands	13	18	17
Purdue Pegboard Assembly	10	24	20

Fleishman & Ellison 1962 – Fleishman 1954: $r_c = .98$

Fleishman 1954 – Fleishman & Hempel 1954 A: $r_c = .98$

Fleishman & Ellison 1962 – Fleishman & Hempel 1954 A: $r_c = .94$

All values of congruence coefficient r_c are significant at $p \leq .05$

Exhibit 7.22

Factor C			
	Parker & Fleishman 1960	Fleishman & Hempel 1954	Fleishman 1960
Speed of Identification	36	72	26
Pattern Comprehension	69	72	-
Spatial Orientation	37	65	-
General Mechanics	55	47	-
Mechanical Comprehension/Principles	65	62	-
Discrimination Reaction Time	39	61	26
Instrument Comprehension	69	57	50
Visual Pursuit	53	45	26
Rotary Pursuit	14	31	-

$r_c = 0.95$

Significant at $p \leq .05$

Exhibit 7.23

Factor D				
	Fleishman 1958 B	Fleishman 1960 B	Fleishman & Hempel 1955	Fleishman 1954
Discrimination Reaction Time	52	57	-	39
Discrimination Reaction Time Printed	57	-	-	36
Rotary Aiming	37	46	47	15
Rotary Pursuit	30	-	49	44
Complex Coordination	29	52	56	53
Track Tracing	41	40	-	57
Visual Reaction Time	17	-	07	17
Audition Reaction Time	20	-	03	07
Jump Visual Reaction Time	26	46	31	-
Purdue Pegboard Assembly	-	57	45	13

$r_c = .89$

Exhibit 7.24

Factor E		
	Fleishman 1958 B	Parker & Fleishman 1960
Rudder Control	82	67
Two hand Coordination	52	53
Motor Judgement	39	30
Rate Control	36	39
Rotary Pursuit	34	53
Complex Coordination	31	53
Pursuit Confusion - Errors	33	53
Pursuit Confusion - T.O.T.	20	48
Discrimination Reaction Time - Printed	00	34
Track Tracing - Errors	13	33
Jump Visual Reaction Time	11	00
Jump Auditory Reaction Time	16	04
Steadiness - Precision	11	26
Visual Reaction Time	10	12
Auditory Reaction Time	07	13
Rotary Aiming	01	10
Single Dimension Pursuit	12	26

$r_c = 0.90$

Significant at $p \leq .05$

Exhibit 7.25

Factor F		
	Fleishman & Hempel 1955	Parker & Fleishman 1960
Jump Visual R.T.	77	51
Jump Auditory R.T.	74	58
Visual R.T.	70	52
Auditory R.T.	65	46
Rotary Pursuit	08	05
Mechanical Principles/Comprehension	07	00
General Mechanics	06	06
Speed of Identification	11	15
Pattern Comprehension	07	09
Instrument Comprehension	03	03
Visual Pursuit	00	03
Rotary Aiming	28	26

$r_c = 0.99$

Significant at $p \leq .05$

The congruence coefficients were calculated where appropriate and their values are given, with their significance levels, in Exhibits 7.20 to 7.25. They have been labelled Factors A to F in accordance with Cattell's advice to avoid premature interpretation (Cattell 1978, p. 529, p. 535 and p. 545). However, it is an important step to interpret the factors and identify the ability which is common to those tests with prominent loadings, but which is not involved in the successful completion of those reference tests which have very low or non-significant loadings.

Interpretation and Identification of Ability Factors

The application of factor analysis to the data gathered in these studies implies that there is an underlying structure which determines the scores and, consequently, the variance on each of the tests. The tests used in these studies are psychomotor tests as opposed to personality tests or attitude tests. Consequently, if the assumption of an underlying structure is valid then it is a structure of basic psychomotor abilities and, as the analysis was orthogonal, they are independent abilities. The assumption of orthogonality will be discussed later.

Factor A (Exhibit 7.20) is defined by seven tests all found to have prominent loadings in three studies and four tests in another study. The common feature of the Purdue Peg Board test in all its forms, the Minnesota Rate of Manipulation test (both turning and placing), and the O'Connor Finger Dexterity test, is that of finger movements or finger dexterity. That this is the ability identified by this factor is further borne out by inspecting the other tests which had very low or non-significant loadings. None of these tests involve the use of finger movements, but do involve arm movements, eye-hand coordination, spatial and other abilities.

In the reassessment of Fleishman's evidence in Chapter 5 it was concluded that there was some evidence for a factor which measured Finger Dexterity. From this re-analysis it now appears that there is strong evidence for a basic ability of Finger Dexterity, defined as the ability to make fast, controlled manipulations of very small objects with the fingers.

Factor B (Exhibit 7.21) is predominantly defined by Pursuit Aiming, Aiming, Medium and Large Tapping, and Square Marking, all of which require accurate aiming movements. Even the Square Marking test requires the subject to place a series of X marks precisely inside a series of small (1/8") squares (Fleishman 1954). The aiming of all of these tests require small accurate movements of the hand. This is also seen in Medium and Large Tapping, where in the former the subject is required to make three dots in a series of 3/8" diameter circles, and in the latter the subject is required to do the same in a series of 1/2" circles.

That the Minnesota rate of Manipulation test loaded moderately on this test may be because the subject is required to move the cylindrical blocks and position them accurately and quickly and, consequently, there is an element of aiming involved. In two studies the Marking Accuracy test was used and loaded highly in both cases. This requires subjects to place a mark as rapidly as possible under a series of circles which are placed over one of two items.

The Punch Board test, which loaded moderately on this factor, was also used in two of the studies. This test required the subject to punch through a series of holes in a metal plate with a small pin. Again aiming is important in the execution of this test. However, the Punch Board and especially the O'Connor Finger Dexterity and Purdue Peg Board tests mainly require accurate finger movements and the latter two tests do not load significantly on this factor. This suggests that this factor does not involve aiming by finger movements but by movements of the whole hand where the fingers are kept in a relatively fixed position. The label of Aiming appears appropriate for this factor.

Factor C (Exhibit 7.22) is based mainly on two studies with some evidence from a third. The prominent variables are:

Speed of Identification
Pattern Comprehension
Spatial Orientation
Mechanical Comprehension
Discrimination Reaction Time
Instrument Comprehension

All of these tests have a common requirement - that of identifying a pattern. Only some, such as Discrimination Reaction Time and Instrument Comprehension, also require the subject to make a judgement regarding the orientation of the stimulus. Consequently, the ability should be limited to pattern identification. However, it does not appear to be limited to visual information, as General Mechanics loads highly on this factor. This suggests that it is more the ability to visualise patterns and it is the same as that ability as Perceptual Speed (Theologus, Romashko and Fleishman 1970, p. 80). As we have only two studies on which to base this interpretation (the third having only a few common variables) and some of the loadings, though significant, show wide differences in loadings, this must be treated as a tentative interpretation.

Factor D (Exhibit 7.23) is based on four studies, but only two of the studies have eight tests in common, the other two having six and five tests in common. There appears to be a strong similarity of many loadings on the tests, but there are some inconsistencies and this is borne out in the congruence coefficient for the two studies, with eight tests in common being marginally significant (at $p \leqslant .05$) with a value of 0.89. With fewer than ten variables involved and with large differences in significance levels given by Korth and by Schneewind and Cattell (Exhibits 6.23 and 6.22), it is difficult to be confident of the statistical significance levels. Nevertheless the congruence coefficient is high and the general pattern of loadings suggests that the factor is defined predominantly by the following tests:

Discrimination Reaction Time - Printed/Apparatus

Rotary Pursuit

Track Tracing

Complex Coordination

and possibly by

Rotary Aiming

Purdue Peg Board Assembly

Discrimination Reaction Time (Apparatus), Rotary Pursuit, Track Tracing and Complex Coordination all require the continual adjustment of responses to new stimulus patterns. However, the loading in two studies of the printed version of the Discrimination Reaction Time test, which requires no movements other than placing a tick on a line, suggests that this factor may be more decision-making orientated than motor orientated. Therefore, it would be more concerned with the recognition of the stimulus pattern, and especially with the orientation of the pattern in deciding which directional response is appropriate. This would be very similar to Fleishman's label of Response Orientation which he describes as having "been found general to visual discrimination reaction tasks involving rapid directional discrimination and orientation of movement. It appears to involve the ability to select the correct movement in relation to a given stimulus especially under highly speeded conditions." (Theologus, Romashko and Fleishman 1970, p. 82.) That it does not load significantly on the Visual Reaction Time and Auditory Reaction Time tests, which require no directional discrimination nor orientation of movement, corroborates the interpretation of this factor. However, the Jump Visual Reaction Time test marginally loaded on this factor and this may be because the subject is required to move his hand a distance of 6 inches to the button when the stimulus light comes on. Consequently, some directional control is required. Similarly, the Purdue Peg Board Assembly requires the subject to make rapid movements of both hands, but not simultaneously, a distance varying between 2 and 16 inches.

Factor E (Exhibit 7.24) has loadings on seventeen tests but common to only two studies. The loadings are very similar and, indeed, the congruence coefficient is 0.9, which is statistically significant at $p \leqslant 0.05$ (Korth, Exhibit 6.23). The prominent loading is for the Rudder Control test which requires the subject to line up a mock airplane cockpit, by means of foot pedals, to one of three lights which is on. The next most prominent loading is the Two-Hand Coordination test which requires the subject to follow a target by the movement of a handle in each hand. One handle moves the target follower to the right and left, and the other handle moves the target follower to and from the subject. The Complex Coordination test requires the subject to use both hands and feet to achieve the required response. However, the Rotary Pursuit test only requires one-handed movements. This is also the case for Pursuit Confusion, Motor Judgement and Rate Control. Consequently, what is common to all of these tasks is the control of a rudder, stick or knob, with precision. Therefore it is not multi-limb coordination, but rather control precision.The latter is defined as "the ability to make fine, highly controlled, but not over-controlled, muscular adjustments, primarily where larger muscle groups are involved. Most critical where adjustments must be rapid but precise. Adjustments are made to visual stimuli and can involve arm-hand or leg." (Theologus, Romashko and Fleishman 1970, p. 81.) However, because the Single Dimension Pursuit test was not loaded, it may not extend to control by the use of a wheel which is used in that test. None of the other tests which had low or non-significant loadings involved the movement of a rudder, stick or knob. Therefore, Control Precision would seem to be an appropriate label for this factor, but as this interpretation is based on only two studies it cannot be accepted with complete confidence.

Factor F (Exhibit 7.25), although it is only based on two studies, is clearly that of Reaction Time, both auditory and visual. None of the other tests loaded significantly except for Rotary Aiming which had a low loading.

This latter test required the subject to strike at a series of buttons, going from one button to the next as rapidly as possible. This requires a fast Reaction Time to complete quickly.

Conclusions

From the re-analysis of the studies six main factor groupings were identified and were interpreted. The evidence for these factors varied both in number of studies and number of common variables. There was strong evidence for the following two abilities:

Finger Dexterity: the ability to make fast, controlled manipulations of very small objects with the fingers.

Aiming: the ability to make fast, accurate, repetitive movements of the hand in rapid succession with little or no finger movement.

There was good evidence for the following two abilities:

Perceptual Speed: the ability to visualise patterns and make quick and accurate comparisons with other patterns and thereby judge their similarity or diversity. Such decisions are based on minor aspects of the information.

Control precision: the ability to make fine, highly controlled, but not over-controlled, muscular adjustment, primarily where larger muscle groups are involved. Most critical where adjustments must be rapid but precise.

Adjustments are made to visual stimuli and can involve arm-hand or leg moving a pedal, stick or knob, but not a wheel.

There was fairly good evidence for the following two abilities:

Response Orientation: the ability to make rapid directional discrimination and orientation of movement found general to visual discrimination reaction tasks and requiring the selection of the correct direction and movement in relation to a visual pattern, especially under highly speeded conditions.

Reaction Time: the ability to respond to a single stimulus either auditory or visual very quickly. No decision is required regarding choice of stimulus nor of choice of response it is just a simple stimulus-response relationship.

Identification and interpretation of the factors found in the three new studies

In Chapter 3 the identification and interpretation of the factors found in the three studies was not undertaken until the other studies had been re-analysed. It is now possible to use those new studies to add to the evidence for the six abilities which were described above.

In these three studies the Perceptual Speed test described by Theologus, Romashko and Fleishman 1970 was used and was found to heavily load on Factor 4 (Exhibit 7.26) in the study of sewing machinists, together with the Minnesota Rate of Manipulation test, on Factor 1 in the Lego assembly study, and on Factor 3 in the study of typists.

Exhibit 7.26 Factor loadings for the reference tests used in the study of sewing machinists

	Factor				
	1	2	3	4	5
Spiral Maze - Time	23	-12	-24	-13	-91
Perceptual Speed Time	49	-07	-24	-80	-07
Perceptual Speed - Errors	-82	23	02	01	50
Discrimination R.T. Printed	85	-09	-26	-12	-06
Minnesota Rate of Manipulation	12	32	28	87	12

Only loadings of 0.6 or greater are considered significant

The fact that no other test loaded as high on these factors other than the errors associated with the Perceptual Speed test suggests that this factor may be the Perceptual Speed ability. The Discrimination Reaction Time test which has been found to load highly on the ability Response Orientation (Exhibit 7.23), though this is not so well substantiated for the printed version as for the apparatus version, was found to load highly on a factor in all three studies. These are Factor 1 in the sewing machinists' study (Exhibit 7.26), Factor 4 in the Lego assembly study (Exhibit 7.27), and Factor 1 in the typists' study (Exhibit 7.28). The latter factor is most similar to the other two factors in that there is also a moderate loading of the Aiming test on this factor in the last two studies, and also a moderate loading on the Perceptual Speed test in all three studies. This factor may be the Response Orientation ability identified in Exhibit 7.23.

The only other ability which may be identified from the factors obtained in these three studies is that of Aiming. Factor 2 in both the Lego assembly and the typists' study has high loadings on the Aiming test and the steadiness test, and moderate loadings on the Spiral Maze test. From Exhibit 7.21 it may be seen that the Aiming test is highly loaded on this ability, and also Tracing, of which the steadiness test is the printed equivalent, is moderately loaded on this ability. It would be expected that this ability would be involved also in the Spiral Maze, as the ability involves the accurate movement of the hand under speeded conditions.

These three studies have shown some further evidence of three abilities: Perceptual Speed, Response Orientation and Aiming. The remaining factors in the studies are not obviously related to the six abilities identified from the re-analysis of the ten studies by Fleishman et al.

Exhibit 7.27 Factor Loadings for the reference tests used in the Lego Assembly task experiment

	Factors			
	1	2	3	4
Discrimination Reaction Time	29	-26	62	68
Steadiness	01	80	00	-18
Perceptual Speed - Time	58	-38	02	39
Perceptual Speed - Errors	05	-08	05	26
Spiral Maze - Time	35	-78	-06	19
Spiral Maze - Errors	07	79	-02	00
Aiming	-25	62	-15	36

Exhibit 7.28 Factor loadings for the reference tests used in the study of trainee typists. Tests given prior to training course

	Factors					
	1	2	3	4	5	6
Aiming	36	62	40	08	-15	09
Steadiness - Total	12	88	09	21	20	15
Steadiness - Errors	-05	83	03	15	35	-25
Spiral Maze - Total	26	35	09	48	26	22
Spiral Maze - Errors	-03	29	03	-03	74	00
Discrimination R.T.	51	23	22	62	-30	-05
Discrimination R.T. errors	-30	19	-10	-42	01	02
Perceptual Speed - time	27	26	81	15	09	31
Perceptual Speed - errors	26	05	84	10	00	-19

An assessment of the Orthogonality assumption

The model used by Fleishman and used in the re-analysis of all the data is one which assumes that basic abilities are independent of each other. This assumption is forced on the data by carrying out a Varimax rotation which maintains all factors orthogonal to one another. Some factor analysts argue that it is rarely justified to assume orthogonality, and one of the strongest critics is Cattell who notes that "the calculation complications with oblique factors have induced some noted psychometricians, e.g. Burt, Edwards, Guilford and Horst (and Eysenck initially) to use only orthogonal factors" (Cattell 1978, pp. 127 and 128). He goes on to say that the reasons for rotation to obliquity are that "we should not expect influences in a common universe to remain mutually uninfluenced and uncorrelated . . . (and) that if factors were by some rule uncorrelated in the total population, they would nevertheless be correlated (oblique) in the sample."

Of course there are arguments for both sides. Harman (1976, p. 325) points out that with oblique rotations "there are many options open to an investigator, and also that different methods may be appropriate for different data sets." This uncertainty with oblique solution methods is reiterated by Hakstian and Abell (1974, p. 444) when they say "One conclusion that appears inescapable is that no single computing procedure - general paradigm or specialization . . . can be expected to yield uniformly optimal solutions for all kinds of data." It would still seem to be the case as Child (1970, p. 60) commented that "No entirely satisfactory analytical rotations have been devised for oblique solutions and they are still the subject of considerable experimentation and controversy."

Despite this uncertainty with the uniqueness of the solution produced by an oblique rotation method, it is worthwhile to make some assessment regarding the assumption of orthogonality with the data re-analysed. Consequently, all the eleven studies were re-analysed in the same way except that, instead of the Varimax rotation being applied, the oblique rotation "Oblique" was used which was the only oblique rotation available in the S.P.S.S. package (S.P.S.S. 1975, p. 485), and it utilises the direct oblimin criterion which does not necessitate the introduction of reference axes to determine the Factor Pattern. The programme was run with a delta value of 0 which produces a fairly oblique (correlated) solution. Therefore the correlations obtained should be viewed probably as tending to be inflated. The resulting factor patterns for the six ability factors identified using the orthogonal rotation (Exhibits 7.20 to 7.25) are given for the oblique solution in Exhibits 7.29 to 7.34. It may be seen that moderate to high loadings are almost identical but low or non-significant loadings tend to be even lower with the oblique solution. The latter would not change either the interpretation nor the identification of the factors.

The orthogonality of the abilities was assessed by inspecting the correlations between factors in the same study and where one factor was involved in one ability and the other factor in another ability. The resulting intercorrelations are shown in Exhibit 7.35. There were three factors common to Aiming and Finger Dexterity, but none between Aiming and Perceptual Speed, Control, Precision, nor Reaction Time.

Exhibit 7.29

Factor A Oblique Rotation				
	Fleishman & Ellison 1962	Parker & Fleishman 1960	Fleishman 1954	Fleishman & Hempel 1954 A
Purdue Pegboard Right Hand	62	-	64	60
Purdue Pegboard Left Hand	61	-	57	63
Purdue Pegboard Both Hands	71	-	71	75
Purdue Pegboard Assembly	69	-	62	61
Purdue Pegboard Summation	-	68	-	-
Minnesota Rate of Manip. Turning	57	49	46	45
Minnesota Rate of Manip. Placing	59	66	45	40
O'Connor Finger Dexterity	61	45	62	66
Tracing	20	-	03	04
Medium Tapping	06	-	01	03
Large Tapping	06	-	05	05
Aiming	14	-	01	07
Square Marking	15	-	08	00
Discrimination Reaction Time (Printed)	14	17	06	-
Ten Target Aiming - Errors	11	15	05	-
Ten Target Aiming - Correct	15	01	22	-
Precision Steadiness	17	12	03	-

Exhibit 7.30

Factor B Oblique Rotation			
	Fleishman & Ellison 1962	Fleishman 1954	Fleishman & Hempel 1954A
Pursuit Aiming I	75	78	-
Pursuit Aiming II	77	85	-
Medium Tapping	74	62	63
Large Tapping	75	64	47
Aiming	71	81	-
Square Marking	51	44	63
Minnesota Rate of Manip. - Placing	22	25	25
Minnesota Rate of Manip. - Turning	19	28	14
Marking Accuracy	-	62	58
Punch Board	-	22	39
Tracing	17	25	50
O'Connor Finger Dexterity	07	09	02
Purdue Pegboard Right Hand	04	00	17
Purdue Pegboard Left Hand	04	06	09
Purdue Pegboard Both Hands	03	02	05
Purdue Pegboard Assembly	06	09	02

Exhibit 7.31

Factor C Oblique Rotation			
	Parker & Fleishman 1960	Fleishman & Hempel 1954 B	Fleishman 1960 B
Speed of Identification	36	79	15
Pattern Comprehension	70	68	-
Spatial Orientation	35	62	-
General Mechanics	51	27	73
Mechanical Comprehension	65	43	-
Discrimination Reaction Time	34	61	17
Instrument Comprehension	67	54	42
Visual Pursuit	49	38	19
Rotary Pursuit	03	16	-

Exhibit 7.32

Factor D Oblique Rotation				
	Fleishman 1958 B	Fleishman 1960 B	Fleishman & Hempel 1955	Fleishman 1954
Discrimination Reaction Time	51	58	-	29
Discrimination Reaction Time (Printed)	63	-	-	27
Rotary Aiming	42	46	50	04
Rotary Pursuit	24	-	49	43
Complex Coordination	22	49	52	48
Track Tracing	44	35	-	56
Visual Reaction Time	15	-	00	14
Auditory Reaction Time	19	-	11	05
Jump Visual Reaction Time	27	47	23	-
Purdue Pegboard Assembly	-	62	42	02

Exhibit 7.33

Factor E Oblique Rotation	Fleishman 1958 B	Parker & Fleishman 1960
Rudder Control	88	68
Two Hand Coordination	51	53
Motor Judgement	33	31
Rate Control	35	38
Rotary Pursuit	28	52
Complex Coordination	23	52
Pursuit Confusion - Errors	30	37
Pursuit Confusion T.O.T.	13	46
Discrimination Reaction Time Printed	19	32
Track Tracing	03	27
Jump Visual Reaction Time	05	04
Jump Auditory Reaction Time	11	03
Steadiness - Precision	04	21
Visual Reaction Time	08	10
Auditory Reaction Time	08	12
Rotary Aiming	13	07
Single Dimension Pursuit	00	26

Exhibit 7.34

Factor F Oblique Rotation		
	Fleishman & Hempel 1955	Parker & Fleishman 1960
Jump Visual R.T.	75	51
Jump Auditory R.T.	73	63
Visual R.T.	69	52
Auditory R.T.	68	48
Rotary Pursuit	01	12
Mechanical Comprehension	07	02
General Mechanics	02	05
Speed of Identification	06	07
Pattern Comprehension	09	08
Instrument Comprehension	00	05
Visual Pursuit	06	02
Rotary Aiming	22	20

Exhibit 7.35 Correlations between factors in the ability factor groups.

	Finger Dexterity	Aiming	Perceptual Speed	Response Orientation	Control Precision	Reaction Time
Finger Dexterity	1	.55/.42/.58	.10	-.38	-.35	.16
Aiming	.55/.42/.58	1		.39		
Perceptual Speed	.10		1	-.24	-.35	.04
Response Orientation	-.38	.39	-.24	1	-.50	-.24
Control Precision	-.35		-.35	.50	1	-.16
Reaction Time	.16		.04	-.24	-.16	1

That some of the correlations are negative makes no difference for this analysis. The three correlations between Aiming and Finger Dexterity show a fairly consistent moderate correlation, but if the correlation between factors tends to be overestimated by this method of oblique rotation, with delta set at zero, then we may conclude that certainly for Reaction Time and Perceptual Speed there is little to be gained from an oblique rotation and a great deal of simplicity and ease of interpretation to be gained from an orthogonal rotation. For the remaining abilities this is probably also true, except for a possible relationship between Aiming and Finger Dexterity and also Control Precision and Response Orientation, though these are themselves not high correlations and indeed have probably been overestimated.

Thus it would appear that the assumption of orthogonality is a reasonable assumption as far as this analysis has gone and that the loadings obtained from an oblique rotation produce a factor pattern highly similar to that produced by the Varimax rotation of this data.

Summary

In the previous chapter it was shown that the approximate Centroid and Zimmerman methods, together with overfactoring, produces very different results from a computerised Principal Factor and Varimax analysis utilising procedures such as the Kaiser-Guttman and the Scree test, to determine the number of factors. Consequently, it was realised that a re-analysis of the eleven studies using the more modern methods and procedures would provide more reliable evidence, both for changes in ability contributions during learning and for factor invariance between studies, which would provide a taxonomy of abilities.

The re-analysis of the three studies of learning produced no changes in factor pattern during learning. The results for all three studies were very similar with one factor accounting for the vast majority of the variance (58-84%). No other factor contributed significantly except in one study where the first stage had a second factor contribution.

This will be seen to be different from the results from the three Atkinson studies where, though there was a dominant factor, there was also a change in factor contribution during learning. One of the main differences between both sets of studies is that Fleishman's studies involved learning for only a few hours at the most, whereas the sewing machinist and typist studies spanned months.

All eleven of the original studies were re-analysed and six factors were found to be highly similar across studies. There was strong evidence for factors identified as Finger Dexterity and Aiming, good evidence for a Perceptual Speed and a Control Precision factor, and fair evidence for a Response Orientation and a Reaction Time factor. The three new studies produced factors which were tentatively identified as Perceptual Speed, Aiming and Response Orientations.

The orthogonality assumption was examined by re-analysing all eleven studies using an oblique rotation which, however, was known to produce inflated correlations between factors. Of all the six factors there were fairly large correlations only between Aiming and Finger Dexterity and also between Control Precision and Response Orientation. In general, it was concluded that for these abilities, the orthogonality assumption was justified.

As Gorsuch (1974, p. 30) says, "The problem of when a correlation between two factors is "too high" can only be resolved by considering the impact of high correlations on the future use of the factors in practical situations or in theory development."

In practical situations it is easier to distinguish between independent ability classes, but we are still in the model building stage, and it will be suggested in Chapter 8 that some abilities may be independent and others correlated. As the evidence from the oblique rotations is that only two pairs of the factors are correlated to any degree, and that this (about 0.5) is an overestimation of the correlation, then an acceptance of air orthogonal solution may not be unreasonable until further evidence is forthcoming. Underlying any view on whether oblique or orthogonal solutions are appropriate for a model of abilities is the ontological problem of whether it is believed that there is in some sense a reality to the abilities or whether they are convenient ways of classifying individual differences. This has only been touched on by a few people but has yet to be adequately stated, far less discussed. Such a discussion is outside the scope of this research.

CHAPTER 8

DISCUSSION AND CONCLUSIONS

This research began with a practical problem which occurs in work situations where people are required to learn a task and thereby acquire, maintain and relearn skills. Questions arise concerning the suitability of individuals to learn a task, the time taken to reach terminal performance, the level of performance which could be reached, the effect of changes in task characteristics on performance and many other related questions.

It was concluded from a review of studies which utilised learning curves and Predetermined Motion Time Systems in their approach to such questions, that these studies were limited to manual repetitive tasks and assumed a model which was too simple, in that it did not include any interaction effects between the learner characteristics and the task characteristics. This simple approach meant that it was difficult to generalise from one population to another and from one task to another. To achieve this generalisability it was necessary to develop an understanding of the interaction between the learner and the task. A number of researchers have used various approaches to develop a system of task characteristics which would enable the findings from a large number and variety of studies involving learner-task interaction to be classified and, hopefully, explained. Of all these approaches the ability requirements approach appeared to be the most thoroughly researched and was claimed to have had considerable success. The main researcher in this area (Singer 1980, p. 194) was E. A. Fleishman who had carried out a systematic programme of "interlocking experimental-factor analytic studies" (Fleishman 1978, p. 1009) over a period of almost thirty years.

Although Fleishman and his co-workers had administered about 170 tasks

(Appendix 4) to several thousand subjects, from an examination of the studies it was found that none of the tasks was an industrial task and few were not laboratory tests. Further, the subjects used were almost all Air Force personnel, with the majority being trainee pilots. Consequently, although the research was extensive, it was within a very specific population and a limited range of tasks. This raised the question of the generalisability of the approach and the findings to real life industrial tasks which are carried out by a different population from Air Force personnel. This became the aim of the research which led to a critical assessment of Fleishman's methods, techniques and findings.

Methodological considerations in factor analysis

During the period in which most of the studies were carried out, computers were not readily available and even if they were, programmes had not been written for factor analysis and rotation. Consequently, many researchers were forced to use both the Thurstone Centroid method, which was a method for calculating an approximate factor pattern, and also the Zimmerman graphical rotation method, which also produced an approximate simple structure solution. The comparison of the results obtained by these two methods with the results obtained using the more exact Principal Factor and Varimax methods showed that the Centroid method produced a very close approximation for the first two factors, but that there was less similarity for the third and subsequent factors with those produced by the Principal Factor method. The differences between factors increased rapidly with number of the factor extracted. The differences were even greater between the factor patterns produced by the two rotation methods, with the added problem that it was not possible to identify those factors, if any, in the Centroid and Zimmerman analysis which were highly similar to those obtained from the Principal Factor and Varimax analysis. The finding of these differences means that, at best, two factors in each of Fleishman's original studies are reliable, as measured against modern factor analytic and rotation methods, but the remaining factors cannot be relied upon. This finding is important not just for the Fleishman studies but also raises questions about the reliability of the findings of those personality, intelligence and other studies carried out in the 1940's, 1950's and early 1960's which used the Centroid and/or Zimmerman methods.

It is not only the approximate methods used which raise doubts about the findings, but also the whole decision process which is carried out when selecting a procedure for arriving at a final factor pattern. One of the most important but also difficult decisions to be made is deciding on the number of factors which should be extracted. Fleishman and his co-workers "continued (extraction) beyond the point where any meaningful factor variance was suspected to be present" (Fleishman and Hempel 1955, Fleishman and Ellison 1962) or "beyond the point where the product of the two highest Centroid loadings became less than the standard error of the original correlation of the same two variables" (Fleishman 1954, 1958B). No justification is given for either of these criteria, but the first is similar to Tucker's Phi criterion which is described by Fruchter in his "Introduction to Factor Analysis" (1954, p. 77), although the formula was not applied by Fleishman, only the principle. The second criterion referred to above is similar to Humphrey's Rule also described by Fruchter (1954, p. 79), but different in that Humphrey's Rule requires the product of the two highest loadings to exceed twice the standard error for the factor to be considered significant. All these criteria were considered as guidelines only. This led to overfactoring in most of the studies, but in any case this used to be considered the correct procedure (Fruchter 1954, p. 84). More recently the effects of underfactoring and overfactoring have been stressed by Cattell (1978) as having serious consequences for the factor patterns which are obtained. The most favoured methods for determining the number of factors are the Kaiser-Guttman criterion (referred to by some as the Guttman-Kaiser criterion - Yeomans and Golder 1980) and the Scree test which has been developed by Cattell. These two methods are now accepted as more exact in determining the number of common factors than the methods cited above. From the re-analysis of the eleven studies shown in Exhibit 6.1 it can be seen that in most cases the Fleishman studies overfactored considerably. However, the K-G criterion and the Scree test do not always give similar answers, and it is shown in Exhibit 6.3 that the K-G criterion accepts increasingly more factors than the Scree test as the number of variables increases above twenty. The effect of the overfactoring in the Fleishman studies is for the later factors to split the earlier factors. This leads to differences in factor loadings and, consequently, differences in factor interpretation. However, there is as yet no agreed mathematical way of determining the number of common factors, only the psychometric ways described above. It would appear that the Scree test in general gives a cut off above the factor which contributes less than about 4% to 5% of the variance, and indeed this appears to be a psychometrically reasonable criterion (Harman 1976, p. 185).

The decision about whether to carry out an oblique or orthogonal rotation to meet simple structure requirements is one which is still debated. Researchers such as Cattell argue that all attributes of human behaviour must necessarily be related and therefore an oblique solution is necessary, whereas many researchers, such as Burt and Guilford, have argued that orthogonal solutions are more readily interpreted and do produce a unique solution which the oblique rotation does not. In the oblique re-analysis of the Fleishman studies shown in Exhibit 7.29 to Exhibit 7.34 it was found that using an oblique method which tends to overestimate the correlation, of the six factors, only two pairs of the 12 pairings available showed moderately high correlations of around 0.5. This is probably an overestimation. Consequently, it may be reasonable to assume a model where abilities are independent, though the possibility arises of some abilities being independent whilst others are related to one another.

The centroid method is rarely used nowadays. As discussed earlier, it is a variation of the multiple-group factor analysis, and in the form used in the studies reported here it utilized an approximate, though extremely good, method for determining the factors. As Gorsuch (1974, p. 73) says regarding the centroid method, "Since the advent of high-speed computers with relatively large storage this procedure has bee replaced by the more sophisticated one of principal factors for many exploratory analyses."

Throughout the studies the Principal Factor method was used and it may be asked why other methods were not used, especially the Maximum Likelihood method. The first reason for not using the Maximum Likelihood method was because it was not available on S.P.S.S. at Aston or Manchester University until the end of 1980, when the work had been finished and written up. This raises the question of whether this practical constraint meant that the studies are methodologically deficient. The vast majority of factor analytic studies reported in the learned journals use the

Principal Component or Principal Factor method, and it has been argued in previous chapters that the latter is the most appropriate of the two. That other studies use the Principal Factor method is important not only for corroboration of the value of the method, but it also allows for the direct comparison of findings between studies. However, with the availability of Maximum Likelihood on S.P.S.S. a number of studies do use this method. Of course, the basis of Maximum Likelihood was laid in the early 1940's by Lawley, D.N., but the computerisation of the method was not achieved until the 1960's (Joreskog, K.G, 1966) and it was not available on S.P.S.S. until the late 1970's. It is accepted as the most efficient method for estimating the parameters of the Factor Analytic model (Maxwell 1977, p. 46), but it is yet to be shown that it produces more meaningful results from psychology. As Vernon (1961, p. 24) says about various methods, including Lawley's Maximum Likelihood method, they "do not provide appreciably more psychological information about the make up of the analysed tests." More recently Gorsuch (1974, p. 293) states that "principal factor and maximum likelihood analyses lead to essentially the same factors, provided that the diagonals of R_{VV} are similar. Therefore, it is expected that the replicability of these factors will also be quite similar." (R_{VV} is the matrix of correlations among the V variables.) Nevertheless, the continuation of the work reported here would probably require the use of the powerful confirmatory factor analysis, using the Maximum Likelihood method to build on the exploratory factor analysis carried out in the studies reported here.

The approximate factor analytic methods and procedures used by Fleishman have beeen shown to produce different results from the modern computer programmes of the Principal Factor and Varimax methods. This was found in the use made of the Centroid method in conjunction with the Zimmerman rotation method in the original studies, and also the procedures adopted for determining the number of factors to be extracted, which led to gross overfactoring.

Small sample considerations were discussed because, in the studies which were carried out on the sewing machinists and the Lego assembly task, small samples were involved but they were included because they formed an important part of the research process. Further, the studies of Aleamoni (1973, 1976) gave support to the belief that Factor Analysis, followed by a Varimax rotation was valid for the first three factors when it was used as an exploratory technique with small samples. The validity of using factor analysis on small samples is important for industrial studies, as it is often only in military settings that samples of 100 or more subjects are available or in more limited and often trivial laboratory settings. This limits the types of tasks, the complexity of the environment and the population variety.

Interpretation of factors and identifying abilities

It is argued that the method for identifying abilities which Fleishman used would not now be considered the most valid method. This method consisted of interpreting a factor in a study and giving this interpretation a label which referred to the ability. Those studies where the same label was used were given as evidence for the existence of that ability. Apart from different variable sets being used to define the same ability with few or no common variables, it also lays the researcher open to interpreting new sets of variables in a way which supports his model even where little support is in evidence. On close examination of the original loadings of factors in Fleishman's studies, which were supposedly common to an ability, it was found that there was either too great a variation in the size of loadings between studies and/or too few variables common to three or more studies to justify the claims of ability identification which Fleishman and his co-workers had made.

The procedure for showing that a factor has been consistently replicated, as stated by Cattell (1978, p. 526), is to obtain a significant congruence between the factors in at least three studies. The need to assess the statistical significance of a congruence coefficient, such as that of Wrigley and Newhaus (1955), necessitates the use of either the tables of Schneewind and Cattell (Exhibit 6.22) or Korth (Exhibit 6.23), and both of these require a minimum of ten variables common to the studies. A number of these variables must have some significant loadings because the comparison of ten non-significant loadings in one study with ten non-significant loadings in another study will probably result in a highly significant congruence coefficient but this only tells us that they are similar in what they are not, but does not tell us that they are the same. Although this is not discussed in any of the text books, it would seem reasonable to have a minimum of 50% of the variables as significant and a minimum of 20% as non-significant. This is based on the premise that non-significant variables help to define the boundary or limits of a factor. Once three or more factors in different studies are found to be significantly congruent then the next step is to interpret the factor. This requires an examination of the variables to identify what common elements exist between them.

The re-analysis of Fleishman's studies described in Chapter 7 was carried out by subjecting the published intercorrelation matrix to a Principal Components analysis, which gave the latent roots for each factor. These were plotted and the Scree test applied to determine the number of factors to be extracted. The intercorrelation matrix was then subjected to a Principal Factor analysis with the number of factors to be extracted defined. This factor pattern was then rotated to simple structure using the Varimax rotation method giving a final factor pattern. From each of the factors those variables with prominent loadings, arbitrarily taken as in excess of 0.3, were then listed and these prominent loading patterns were then compared with all other ones to identify two or more factors which could be significantly congruent. The Wrigley and Newhaus congruence coefficient given in Chapter 6 was then calculated for all pairs of factors in a group, using all the variables common to each factor. Those factors which were found to be significantly congruent in two or more studies were then interpreted and a label ascribed to the factor.

Where in Chapter 5 it was concluded that there was little or no evidence for a factor which could be interpreted as Aiming, from the re-analysis of the studies there was strong evidence for such an ability, and there was also strong evidence for a factor of Finger Dexterity, for which it was concluded in Chapter 5 that there was some evidence but not strong evidence. Similarly for the Control Precision ability, for which it was concluded in Chapter 5 that Fleishman's analysis had provided little or no evidence for it, the re-analysis in Chapter 7 provides good but not strong evidence for it. The ability of Perceptual Speed was not identified by Fleishman, but a factor emerged in the re-analysis which was best described as the ability of Perceptual Speed used in the study by Theologus, Romashko and Fleishman (1970), Mallanad, Levine and Fleishman (1980), and identified by Hakstian and Cattell (1974), following Pemberton (1952) in their factor analysis of 57 ability tests, in which they defined this ability as involving rapid assessment of visual stimuli usually to determine the sameness or difference of the members in pairs of such stimuli.

The two abilities of Response Orientation and Reaction Time, for which it was concluded that Fleishman's analysis gave little or no evidence, were found in the re-analysis to have fairly good evidence in support of their identification. Of the rest of the abilities which Fleishman (1978) claims to have identified, namely:

Rate Control

Manual Dexterity

Multi-limb Coordination

Speed of Arm Movement

Wrist-Finger Speed

Arm-Hand Steadiness

there was no substantial evidence for their identification in the re-analysis of the eleven studies.

The study of 39 trainee typists and 35 control group subjects afforded the opportunity for a factor analysis of all 74 subjects' performance on the first administration of the test battery. Three factors were identified but only one of these, Perceptual Speed, could be related to the abilities identified in Chapter 7. The other two factors were tentatively labelled Speed of Forearm, which is similar to that which Fleishman claimed to have identified as Speed of Arm movement, and Movement error correction for which there is no evidence from any other studies.

Validity of using factor analysis in skill acquisition studies

That highly similar factors were obtained in three studies which involved different combinations, different subjects and with up to eight years between the studies, suggests that a high degree of factor invariance has been achieved. However the question arises of what is the nature of these factors, that is, whether it is valid to interpret these factors as basic abilities. Bechtoldt (1962, p. 328) argues that factor analysis in its exploratory form, as used by Fleishman, is not sufficient for defining abilities, nor is it sufficient in its confirmatory form. That it is an extremely powerful tool which provides "a mathematical model which attempts to explain the correlation between a large set of variables in terms of a small number of underlying factors" (Mardia, Kent and Bibby 1979) is disputed by some. Where Kerlinger (1980, p. 659) says "factor analysis can be called the queen of analytic methods", some critics such as Adams (1964) argue that "factor analysis is descriptive, not predictive" (p. 192) and he shows far less enthusiasm for accepting it as a tool when he says, "After all, investigators in all sciences have somehow managed to develop fruitful hypotheses and laws for complex phenomena without factor analysis." This appears to be an emotional response rather than a strong conceptual argument for not using factor analysis.

Another strong critic has been Jones, who argued that correlations among tests reflect the organisation of the tests not of the people who take them, but who, unlike Adams, thinks that although abilities identified by factor analysis may have predictive validity they would not further our understanding of the basic structure of human performance (Parker 1967). In a later article, Jones argues that factor analytic factors "are purely analytic; they appear nowhere in pure form but only in conjunction with other factors." (Jones 1970, p. 234.) However, it is possible theoretically to have a one factor solution, although one would expect error variance factors to be evident even in the most controlled experiments, but we are only concerned here with common factors. Jones goes on to state that in his two process theory the rate process is empirically separable from the terminal process. However, even if this is a necessary requirement, it is only possible with tasks where there are no differences in terminal proficiency. This is too great a limitation to be a requirement of skill acquisition studies.

The argument by Jones appears to assume that the performance scores on tests are determined neither by inter nor by intra-individual differences, but by the organisation of the tests. That a person scores differently on a test on different occasions does not reflect changes in the test, but changes within the individual which affect the interaction with the test. It is from performance that we infer ability and skill, and this implication is also made by Jones in his two factor theory. According to Fleishman (1966), correlations observed among tests reflect the operation of behavioural elements involved in test performance and there is considerable support for this view and little or no support for the arguments of Jones.

The factors obtained from factor analysis are themselves measures of the common variance among a number of variable measures. From them we infer hypothetical constructs, such as ability, personality traits and intelligence. The variance is assumed to reflect differences in cognitive structure such as abilities, personality traits, etc. which results in consistencies in either behaviour or changes in behaviour. As Fleishman (1964, p. 9) stated,

> "ability refers to a more general trait of the individual which has been inferred from certain response consistencies (e.g. correlations) on certain kinds of tasks."

The problem is not whether factor analysis is more or less valid in identifying abilities than other correlational techniques, such as analysis of variance or multiple regression analysis, but whether the concept of ability is a valid notion. This question would require an assessment of the reductionist approach in psychology and would take the discussion in a very different direction. In this discussion the validity of the concept of ability must be assumed, but what has been described above is the argument for accepting that the response consistencies represented by factors are an external manifestation of these abilities. The search for a finite set of basic abilities which would account for performance on a large number of tasks led Fleishman to carry out his programme of research and to use factor analysis as his main technique because of its properties. As Kerlinger (1980, p. 659) says,

> "Factor analysis serves the cause of scientific parsimony. It reduces the multiplicity of tests and measures to greater simplicity."

The identification of a set of basic abilities involves the development of an ability taxonomy. The taxonomy as Fleishman (1978, p. 1007) says "is a system for classifying such tasks which would lead to improved generalisations and predictions of human performance." The use of factor analysis to this end is not the only means of developing such a taxonomy, for as Miller (1969, p. 68) points out,

> "Formal taxonomy development has many approaches and possible approaches."

Hackman (1969) concluded that there were four kinds of task taxonomies (discussed in Chapter 2) and each may be most useful for certain purposes. Fleishman's approach of an ability requirements taxonomy may be most useful in selection, training and man-machine systems design. The development of a reliable taxonomy in these areas would be of great benefit to systems designers. The re-analysis of Fleishman's data and the three new studies suggest that a reliable taxonomy could be developed using the more modern techniques of factor analysis and our greater knowledge of the decisions which must be made in carrying out a factor analysis. Although most of the abilities were either uncorrelated or of very low correlation, one pair showed a medium to low correlation. This suggests that the model may require both orthogonal and oblique factors and consequently the taxonomy should include related and unrelated abilities. Bechtoldt (1962, p. 325) makes the criticism that:

> "the results of the factor techniques used by Fleishman, for example, are not as unambiguous as are those of other available procedures; for instance, orthogonal rotations by graphic methods are rarely precisely reproducible."

The re-analysis of the eleven studies did produce different results. It has been shown that the Centroid method produced factors which were dissimilar to those produced by the Principal Factor analysis from the third factor extracted. The Zimmerman graphical rotation in conjunction with the Centroid method was found to increase the differences markedly when compared with the Principal Factor method in conjunction with a Varimax rotation. This bears out and disposes of Bechtoldt's criticism when he says (Bechtoldt 1962, p. 325),

> "Other investigations using more objective factor analytic techniques . . . would obtain somewhat different results."

From this discussion of the validity of using factor analysis in skill acquisition studies it is concluded that, as a method of developing a taxonomy of abilities, it is a powerful technique and as valid as any other statistical analysis. However, the particular design which Fleishman used to investigate changes in factor contribtuion to performance during learning a psychomotor task still raises doubts about its validity among some researchers. Nevertheless, from the re-analysis of his studies, on learning it would appear that even if his experimental design is accepted the data does not given the results he claims.

The contribution of abilities to performance during the learning of psychomotor tasks

In one of his first articles Fleishman (1953) outlines the need to investigate continued practice of complex motor tasks to identify how different abilities are brought into play at different stages of task performance. Twenty-five years later he summarised his findings from the programme of research carried out during that period. He states (Fleishman 1978, p. 1010) that:

"(a) the particular combinations of abilities contributing to performance on a task change as practice on this task continues; (b) these changes are progressive and systematic and eventually became stabilised; (c) in perceptual-motor tasks, for example the contribution of non-motor abilities (e.g. verbal or spatial) may play a role early in learning, but their contribution decreases systematically with practice relative to motor abilities; and finally (d) there is also an increase in a factor specific to the task itself not common to the more general abilities."

These conclusions have been accepted, or at least assumed, to be based on valid inference, by many writers (e.g. Alvares and Hulin 1972, Atkinson 1973, Singer 1980, Goldstein 1980). It was seen as important to return to the original studies and follow Fleishman's arguments to determine their validity. In Chapter 5 this was carried out and it was concluded that though there was some evidence from his analysis for changes in the combinations of abilities contributing to performance on the criterion tasks during learning, these changes were neither systematic nor progressive. In none of the studies was there found a clear progression from non-motor to motor abilities, and there was little evidence for some of the factors becoming stabilised. However, from Fleishman's analysis of the data, there was evidence of a factor which was specific to the task whose contribution increased steadily with practice.

The critique of methodological aspects of Fleishman's analysis in Chapter 6 led to a realisation that the original data should be re-analysed using more modern techniques and procedures. Of the four studies, Fleishman and Hempel 1954B, 1955, Fleishman 1957 and Fleishman 1960B, which involved performance measures during learning, three were re-analysed using Principal Factor analysis and Varimax rotation, together with improved procedures for determining the number of common factors to be extracted.

The fourth, Fleishman 1957, did not contain the necessary intercorrelation matrix which is the data on which the re-analysis is carried out. Indeed the study was of a rather different design to the other three studies.

From the re-analysis of the three studies it was concluded that one factor was dominant throughout learning, accounting for between 60% and 85% of variance on the criterion task. The dominant factors in all three studies were also loaded on reference tests, though the loadings were marginally significant in one study at around 0.25. Nevertheless, the suggestion is that the dominant factors are identifiable and not task specific factors. There was no systematic or progressive changes in the dominant factor contribution except that in each study the contribution, was much lower in the first trial or stage.

In only one study (Fleishman and Hempel 1954B) did a second factor contribute to any extent. This second factor contributed 30%, 13%, 14%, 7% and 5% for the first five stages of practice. This latter factor may be tentatively identified as Perceptual Speed and as such would be some evidence for a decrease in non-motor abilities with practice.

The four claims which have been made by Fleishman (1978, p. 1010) and which are stated earlier and are:

(a) The particular combinations of abilities contributing to performance on a task change as practice on this task continues.

(b) These changes are progressive and systematic and eventually, become stabilised.

(c) In perceptual-motor tasks, for example, the contribution of non-motor abilities (e.g. verbal or spatial) may play a role early in learning, but their contribution decreases systematically with practice, relative to motor abilities.

(d) These is also an increase in a factor specific to the task itself not common to the more general abilities.

These have not been wholly upheld by the re-analysis of the studies. More specifically:

1 There is little or no evidence for changes in the particular combinations of abilities contributing to performance on the tasks with practice.

2 Stabilisation of factor contribution appears after the first trial or stage.

3 In only one study was there evidence of another factor which may be identified as the Perceptual Speed ability. This non-motor ability did decrease in variance contribution over the first five stages. However, no such evidence was found in the other two studies.

4 There was no clear task specific factor in any of the studies, though the dominant factor in one study had only marginal loadings on four reference tests.

From the re-analysis it may be concluded that there is little or no evidence for the four claims made by Fleishman. The three new studies described in Chapter 3 also provide evidence which contradicted Fleishman's claims, although in the sewing machinists study there was evidence of a change in factor contribution with practice, but the sample sizes involved in two of these studies makes it necessary to be extremely cautious about the results. Nevertheless, the study of typists showed a single dominant factor which had loadings on two reference tests, which was tentatively identified in Chapter 7 as the Response Orientation ability. This pattern was very similar to those obtained from the Fleishman studies. The Lego assembly study was also similar to the latter studies in as much that whilst one factor was dominant another factor contributed 50% of the variance in the first stage, but a negligible amount to subsequent stages. The study of sewing machinists was different from the majority of the other studies, as two factors changed systematically and progressively over the eleven weeks. One factor decreased steadily from contributing 83% in the first week to 0% in the final week, and the other factor steadily increased from 0% contribution to 71% contribution to performance variance. None of the reference tests loaded significantly on either of these factors and, consequently, they cannot be identified. One may be a task specific factor or both may be abilities which are not represented by the reference tests.

From these six studies it would appear that, in general, there is little evidence for the four claims made by Fleishman, but in the study of sewing machinists, the Lego assemby study and the study by Fleishman and Hempel (1954B) a second factor was involved and its contribution changed in a progressive and systematic way during practice. The remaining two studies by Fleishman involved much simpler criterion tasks, namely Rotary Pursuit and the Discrimination Reaction Time apparatus test. This may be the reason for a single ability accounting for the vast majority of the variance. The typing task would appear to fall into the same category, whereas the two factor tasks were more complex, especially that of sewing machine operation. That more complex tasks require more abilities for successful learning of them has been assumed by many. For example Kleinman (1977, p. 833) says,

> "Clearly complex tasks involve not only a greater number of abilities than do simple tasks, but they also . . . ."

However, this is as yet to be demonstrated, but in the studies discussed above there is the suggestion of such a relationship.

Criticisms of Fleishman's conclusions by Bechtoldt (1958, 1960, 1961, 1962, 1969), Corballis (1965) and Jones (1962, 1966) centred on methodological grounds. Bechtoldt's article in 1962 is detailed and puts forward four methodological issues. The main criticism was that Fleishman in his studies of ability contribution during learning included both independent and dependent variables together in one factor analysis. Cattell (1978, p. 358) discusses this type of design, which he calls the "factor change score method". There are two versions of this method as described by Cattell, the variable-tied method and the person-tied method. It is the former which is closest to Fleishman's method. However, apart from stating that this method has shortcomings, it is not discussed further. Indeed the criticisms of Bechtoldt and others have produced little response. This may be because the mathematical aspects are yet to be worked out or perhaps because there is no clear conceptual answer. It may be that Canonical factor analysis or DR technique (Cattell 1978, p. 340) would be more appropriate, but this would require a discussion outside the scope of this research. Fleishman and his co-workers gathered a large amount of data from well designed experiments and applied the most modern of techniques and decision procedures available at the time. But even if Fleishman's analytic design is valid the re-analysis of his data, which has only become possible with the development of computers and the software to carry out the calculations, has produced very different results. The findings reported here should not be seen as an attempt to deny the importance or quality of the original studies, but as a part of the process of developing the work of Fleishman and his co-workers. The re-analysis suggests that the methods used in the original studies - use of the Centroid method, Zimmerman graphical rotation, and overfactoring - gave results which were less valid than modern methods, and that many of the findings from the original studies are an artifact of the approximate methods and procedures used. However, Fleishman's considerable contribution to our understanding of psychomotor learning should not be underestimated, as his general approach which he developed is still valid and his work has stimulated much valuable research.

Implications for a model of learning

In a review article Alvares and Hulin (1972) put forward two models which would account for

> "both temporal changes in behaviour during training and temporal decreases in correlations between ability measures and performance measures" (p. 295).

The first model presented is that of the changing task model which is exemplified by Fleishman's analysis and interpretation of his studies. For Fleishman the process of skill acquisition is one where the person brings to the situation a repertoire of overlearned abilities and, as practice continues, the structure of the task changes and is defined by the contributions of abilities to individual differences in performance on the task. These individual differences are the result of the differences between individuals in their level of performance on any one basic ability. However, if this was the only determinant then performance at the end of practice would be as predictable from ability tests as performance at the beginning of practice. This has been shown by many researchers not to be the case, as Alvares and Hulin (1972, p. 295) say,

> "One of the most discouraging findings for the person who would predict the behaviour of people in complex situations is the decreasing relationship between ability measures and performance measures as a function of time or interpolated practice."

Therefore the process must be more complicated and the other determinants of performance variance need to be identified.

The alternative model put forward by Alvares and Hulin (1977) is the Changing Subject model which is represented by the work of Adams 1957, Corballis 1965, Jones 1962. This model does not assume that abilities are overlearned but that they are little different from any other measure of current performance level and may be learned at any time, forgotten or enhanced by practice. Abilities are assumed to differ between individuals and within any one individual over time. Alvares and Hulin conclude from their analysis that an empirical evaluation of the two models is well nigh impossible. However, in a study of pilot training, Alvares and Hulin (1973) conclude that the changing subject model accounts for their results more readily than the changing task model. The experimental and control groups were given a battery of tests both before the experimental group was given 15 weeks of pilot training and after this training. The control group was given no pilot training. They claim to have found significantly greater changes in the experimental group after training than in the control group. However, on close examination of the data presented, inconsistencies are found. For example, they claim that the effect of training was shown by changes in the mean scores for the two groups on such tests as the Card Rotations test, but the results presented for the means of this test are:

	Pre-test mean		Post-test mean	
	Experimental	Control	Experimental	Control
Card Rotations	90.8	90.3	94.6	94.7

Difference for experimental group = 3.8

Difference for control group = 4.4

With inconsistencies such as this the findings would be suspect until they are cleared up.

The study described in Chapter 4, where the experimental group of typists was tested with the control group of non-typists at the beginning, middle and end of 10 months, suggested a more complex model of skill acquisition than the two proposed by Alvares and Hulin. Indeed, Fleishman has not made explicit his model, nor accepted the labelling of his conclusions as a changing task model. Fleishman accepts that practice may increase ability scores though not by a great deal. That people show high scores on the first few trials of tests suggests that they do bring an ability to the situations. However, the study of typists suggests a model where the subject and the task change during learning. It was concluded from the correlational and factor analytic analysis of the typists and the control group that some abilities are overlearned and, because they are frequently practised, they show little or no change over time; some abilities are overlearned but are little used and consequently show a practice effect; and some abilities are not overlearned, perhaps because they are rarely needed in everyday life, and these show large changes in performance over time. Consequently, each individual brings a different repertoire of competence on the abilities required to carry out the criterion task, and the trainee changes the task (temporarily or structurally) to suit the abilities which they have at any time during practice. What is now required is the identification of coordinating abilities or strategy abilities which would be required to control the patterning of these abilities. They may be akin to the second order factors in an oblique factor analysis.

This notion of a changing task model implies that differences in tasks are moderators of performance. The latter has been severely criticised recently by Schmidt, Hunter and Pearlman (1981). They claim to have shown in an analysis involving a total of almost 400,000 subjects and 40 jobs that, "The moderating effect of task is negligible even when jobs differ grossly in task make-up and is probably non-existent when task differences are less extreme" (p. 182). They refer to the work by Fleishman as evidence of task moderator effects, but suggest that the difference in results are due to the molecular level of the Fleishman tasks and relatively short duration of learning time, where their study was of later stages of training after weeks, months or even years. They also state that they have carried out a refactoring of Fleishman's three studies of learning and are convinced that his findings are real. However, from my personal discussions with the authors on this re-analysis, they state that they did not carry out a refactoring but a cluster analysis which was not designed to check the findings of changes in factor contribution during learning. The results obtained from the re-analysis reported in Chapters 5, 6 and 7, and the Atkinson studies described in Chapters 3 and 4 suggest that if tasks do have a moderating effect on performance during learning, then that effect will not be very large but may be large enough to necessitate the initial changes in ability contributions to be taken into account (Atkinson 1973). Schmidt et al (1981) also conclude that job analysis requires methods "such as those that permit the grouping of jobs on the basis of their broad content structure or their similarity in inferred ability requirements . . . are the most appropriate and powerful techniques" (p. 195). The development in the previous chapters of Fleishman's work on an ability taxonomy increases the possibility of applying such a method.

The model of learning which now has to be developed is one in which the subject and the task change as practice and learning continues. Factor analysis would appear to be a valid and powerful technique, not only for investigating the changes in the subject and the task which occur with their interaction, but also to provide an ability taxonomy. With the rapid development of Maximum Likelihood methods of confirmatory factor analysis applied to data from a wider variety of populations and tasks, greater progress will be made.

APPENDIX 1

FACTORY VISIT AND STUDY

To find out how learning curves are used in industry visits were made to four large companies in the Birmingham area who have training and work study departments. These were chosen as representative of a large proportion of industrial companies.

The factories were:

(a) a light engineering company making car components

(b) a bed and upholstery manufacturer

(c) a carpet manufacturer

(d) a plating company

The following is a report of the visits to the four companies. The specific objectives were to find out:

1. If there was any explicit use of learning curves in the training of personnel as a check on their progress and/or in setting their rate of pay.

2. If there was any implicit use of learning curves.

3. If data was already available in a suitable form for analysis in work study and training departments.

From the interview and observations made, it was evident that little use was made of learning curves even though recognition of their existence was shown in the wage payment schemes for trainees. The management said in discussions that there was no method of determining learning curves which was fairly accurate even for groups of trainees, far less for individuals. The payment schemes were supposed to be based on work study practitioners' knowledge and experience on how long it 'normally' took to learn the job. However, payment schemes were actually the result of bargaining between workers and management. Where there was a P.M.T.S. in use the planning and costing department made use of straight line estimates of learning similar to those in the M.T.M. research handbooks.

In another large electrical company visited later, the training officers in one factory had used ratings of trainees as a measure of performance and compared the average learning curve for a group of trainees on two tasks:

1. Wire wrapping, and
2. Wiring and soldering with labour retention within the group.

However, little use was made by the company of the resulting graphs, Exhibits A1 and A2, and they are only included here to show the simplicity of the information on learning which may be obtained from training departments of companies.

It was concluded that no data on learning curves of individuals or even groups was to be obtained from Work Study Departments, whose role was mainly concerned with looking into complaints from management about labour costs or from workers about times being too 'tight'.

Training departments did not use learning curves except where trainees timed themselves and used the resulting graph as a progress chart. This data was unreliable and together with a predominance of part method

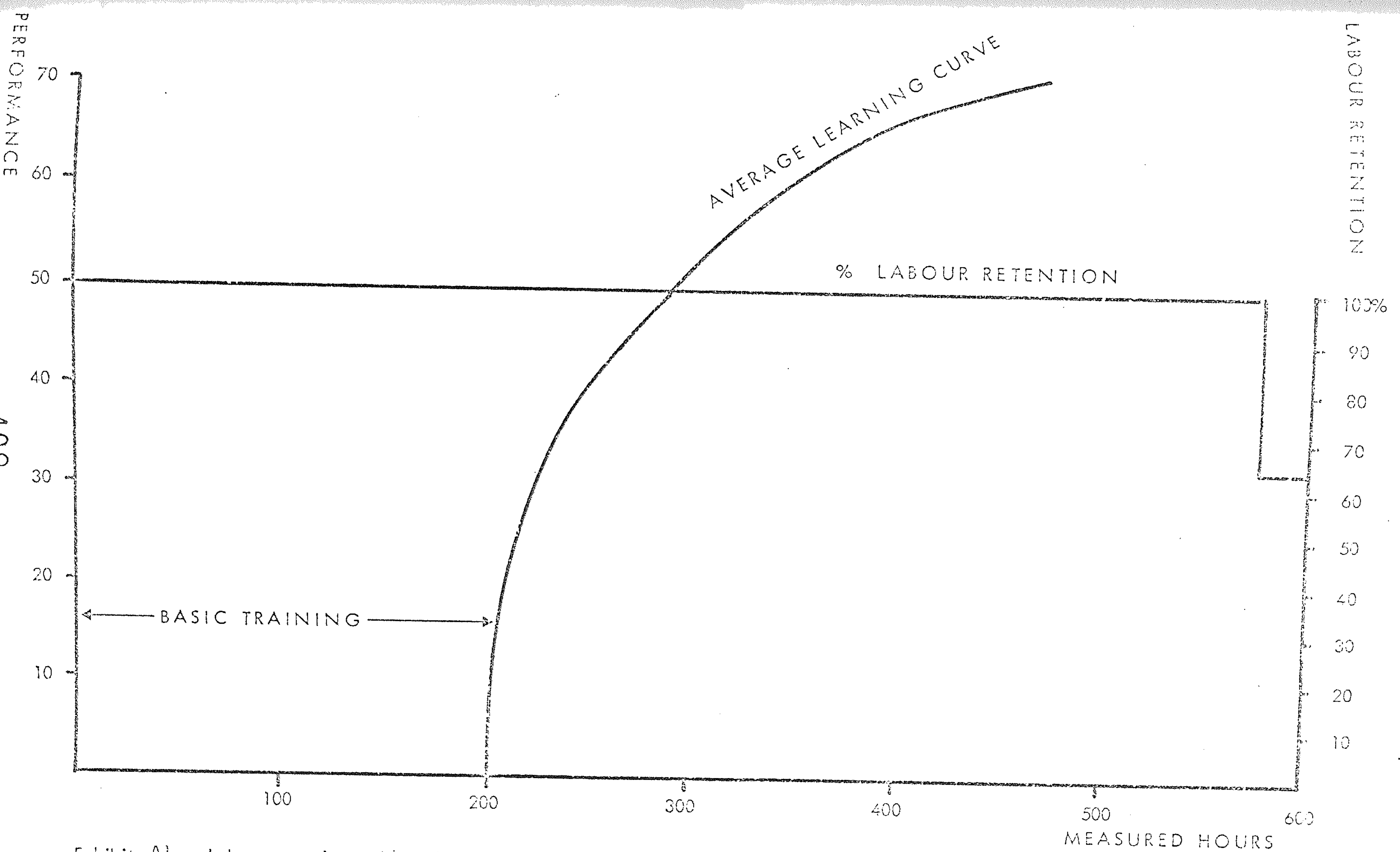


Exhibit A1 Labour retention and learning curves for 'Wire wrapping' task. Produced and supplied by the training officer of a large company.

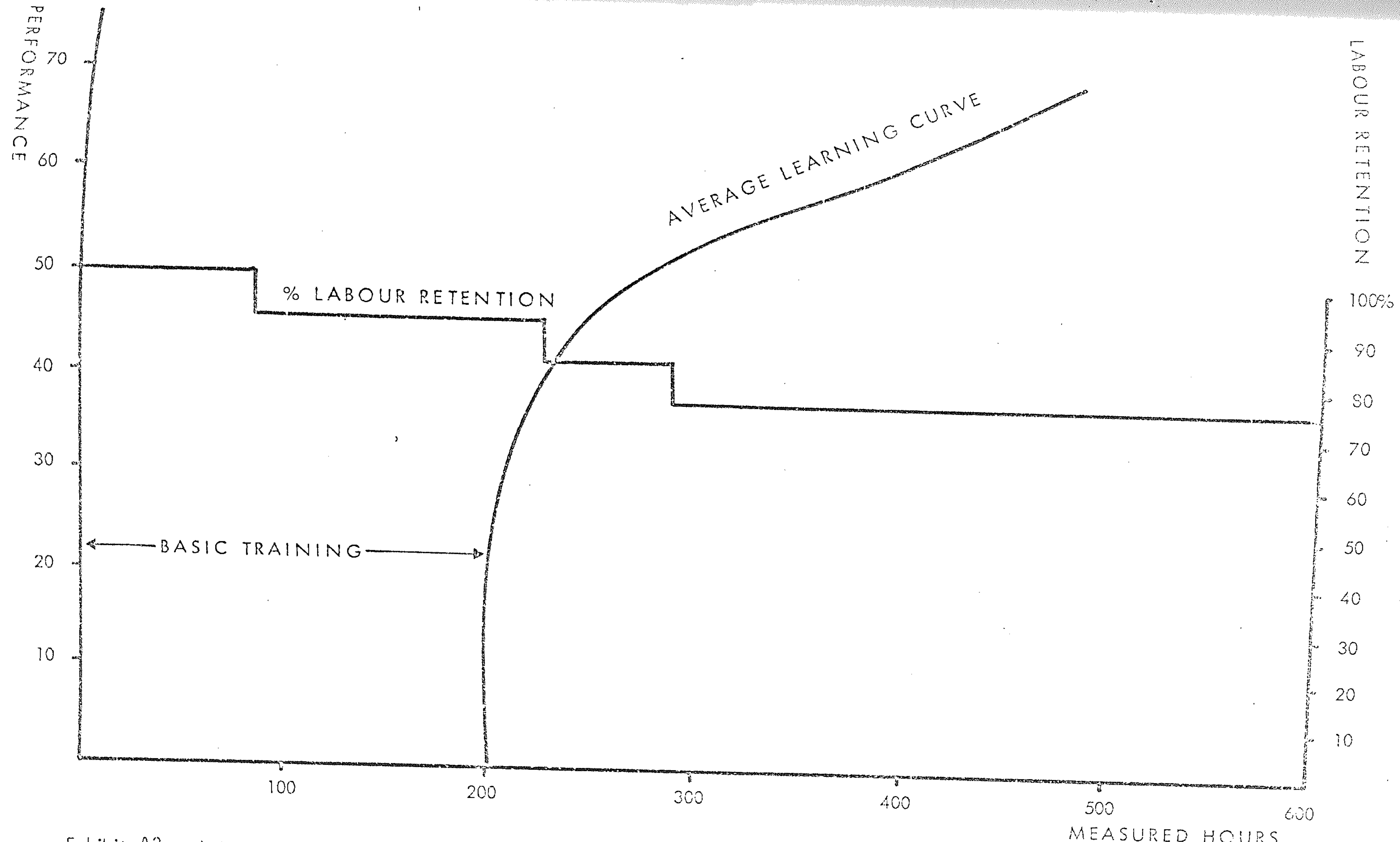


Exhibit A2 Labour retention and learning curves for 'Wiring and soldering' task. Produced and supplied by the training officer of a large Company.

training suggested that it was not worthwhile to continue visiting training departments.

From this rather negative situation it was decided to carry out a shopfloor study of a trainee in a training school and on the shopfloor. In this way it would be possible to produce a learning curve and in so doing would not only make obvious the practical problems of data logging, data analysis, but problems with the subject, the management and the unions. Hopefully it would also suggest hypotheses, experiments, models and ideas.

The company chosen was at Witton in Birmingham and had a newly set up training department. This factory was chosen because the tasks available were manual repetitive assembly tasks which make up a large proportion of industrial tasks. It was possible to study only one operator at a time because it was forbidden to run electric leads across the factory floor.

Therefore, there were three main aims:

1. To determine the methodological and hardware problems of time studies on actual tasks on the shopfloor.

2. To identify the analytical problems associated with learning curves.

3. Develop ideas, hypotheses for models and experiments.

Hardware problems were not to be taken lightly. The data event recorders available were few, the best one at the time was the Murrell DER, designed by Professor Murrell of UWIST.

The study at Witton

In the training school there were five trainees who were studied. One of these was selected to be the subject of the pilot study. The training school was arranged such that each trainee was given instruction on the tasks associated with winding and assembly of the fans. As soon as it was known where there was a vacancy, the training instructor with the personnel manager would select the girl who, they felt, would be most appropriate for the job. The girl would then be given what is called stamina training, i.e. she carried out only that task which she was going to take up on the shopfloor.

Method

Only one girl of the five could be followed on to the shopfloor because they were all to take up different jobs which were physically well separated and the running of leads across the factory floor was not permitted.

In the training school, the girls timed themselves with an accuracy of about 2 or -2 seconds. The Data Event Recorder was also used and some times were obtained though, because of problems of placement of the lever microswitch, many more went unrecorded except by the girl herself.

Time Schedule

The trainee studied started training on Monday 9 August but it was not known which job she was going to until Wednesday 18, that is, after 8 days in the training school. She had training at all the tasks taught in the training school, but for the 18th, 19th and 20th she concentrated on the job she was going to do on the assembly line.

She started on the shopfloor on Monday 23 August, but time recordings were held up for the week because the flow line union representative had not been informed of the study by the management or the senior shop steward. Recordings began on 30 August. For a day or so the trainees' times were not good because of personal problems outside the factory. However, she soon recovered. During part of this first week and some of the second week she was helped out by the other workers on the flow line who did part of her job for her.

Method of Data Collection

The Murrell Data Event Recorder was an 8 channel variable speed recorder which outputed data on paper tape. One channel was required for parity and therefore only seven channels were available for actual input. It was not possible to code the input channels and therefore no more than the seven channels could be used.

A lever activated micro-switch was attached to the box-like container for the soldering iron. When the soldering iron was lifted out or returned the lever was moved. However, after a number of trials the method changed from laying the soldering iron down in the box to inserting it point first and thereby not contacting the lever. The photo-electric cell was placed on one of the bins in such a way that the hand of the girl broke the beam when a pin was taken from the bin (Exhibit A3). This was to indicate the beginning and end of each cycle. This worked well for a time but the

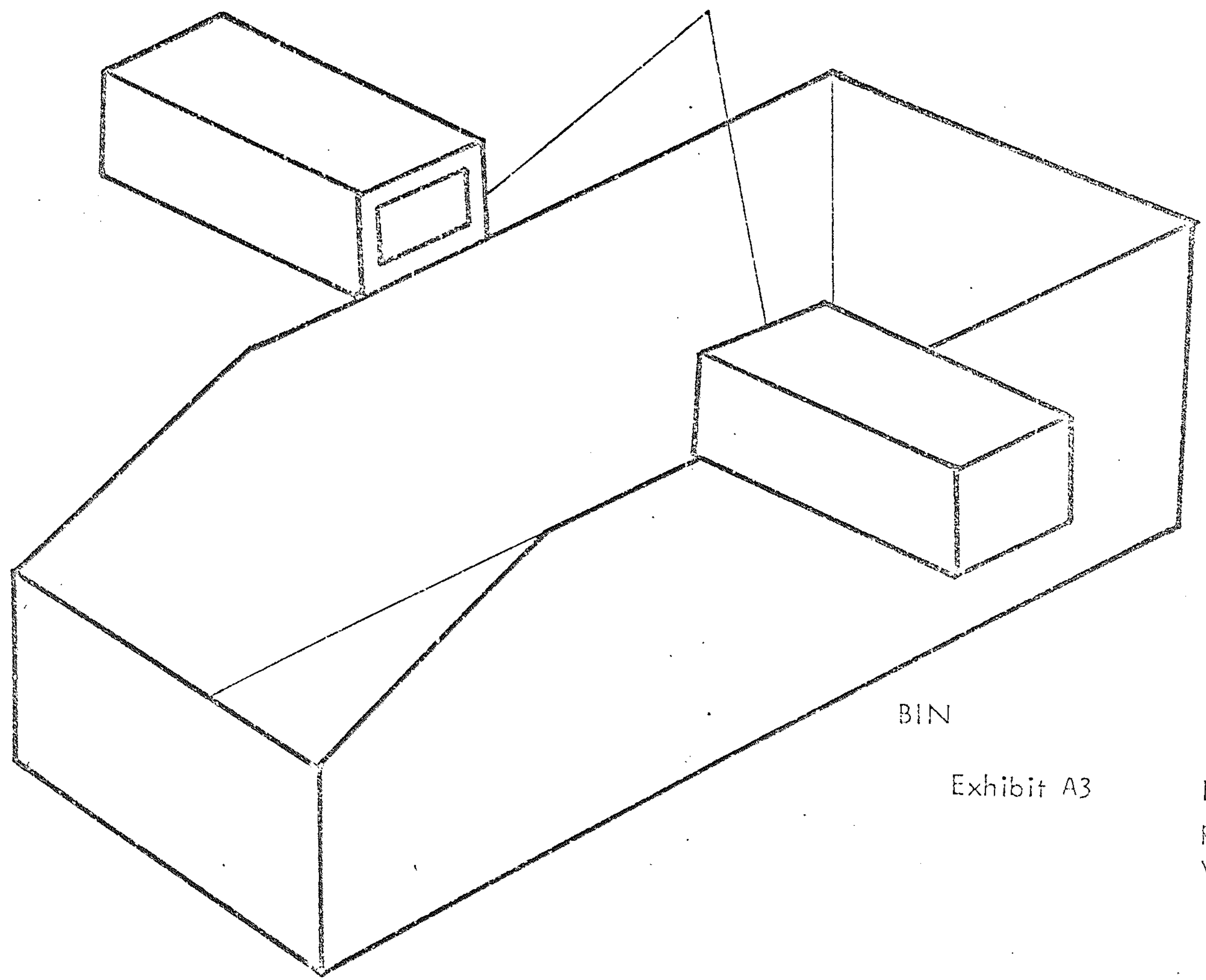


Exhibit A3 Drawing showing the placement of the photo-electric cell on the bin which was used in the assembly task.

motion changed from one of a straight-on reach to a more side-way reach and the beam was not broken. She also soon learnt from the other workers on the flow line another method which meant she did not use the bin at all. The pins were placed in her lap. This is in fact not as fast as using the bins, however, it is probably less tiring.

Timings were therefore lost first because of a subtle change in motion and then by a change in method. Nevertheless, the photo-electric cell was found to be efficient, though it was rather large and therefore conspicuous.

The DER was located under the track and was only accessible between breaks in production. This meant that monitoring of the DER was impossible.

Films

Eight hundred feet of film was taken. Three tasks were filmed:

1. The subject carrying out the assembly task of station 3.

2. Instructors executing assembly task and coil binding task by the official method.

3. A trainee in the training school inserting coils into stators. The films were taken in 16 mm Ektachrome Colour at 16 fps. At this speed only 4 minutes 10 seconds are available and therefore any cycle time longer than this cannot be filmed in entirety.

Placement of the camera is often difficult and this is especially true with two-handed work where one hand may block out a view of the other hand. Placement is further restricted on the shop floor by machinery, workers, etc. Extra lighting is usually required and this must also be well placed to avoid shadows.

The presence of a camera and lighting equipment obviously has an effect on the performance of the subject. However, this effect decreases rapidly with the subject's familiarity with the situation.

Results

Cycle times were obtained by three different methods:

I In the training school by the subject timing herself.

II On the shop floor by the Data Event Recorder (DER).

III Analysis of films taken on four separate occasions.

I In the training school the trainee timed herself. Much of the time was spent learning tasks other than the one she actually took up on the shopfloor. There was also a policy of part method training and under these circumstances the trainee carried out relatively few complete cycles. Exhibit A4 is a graph plot of the cycle times. The "learning curve" is very steep initially but after a few trials becomes less erratic and more gentle in overall slope.

II DER recordings on the shopfloor

Exhibits A5 and A6 show graphical plots of part of two days during which the operator was on the assembly line. These times are rather unreliable

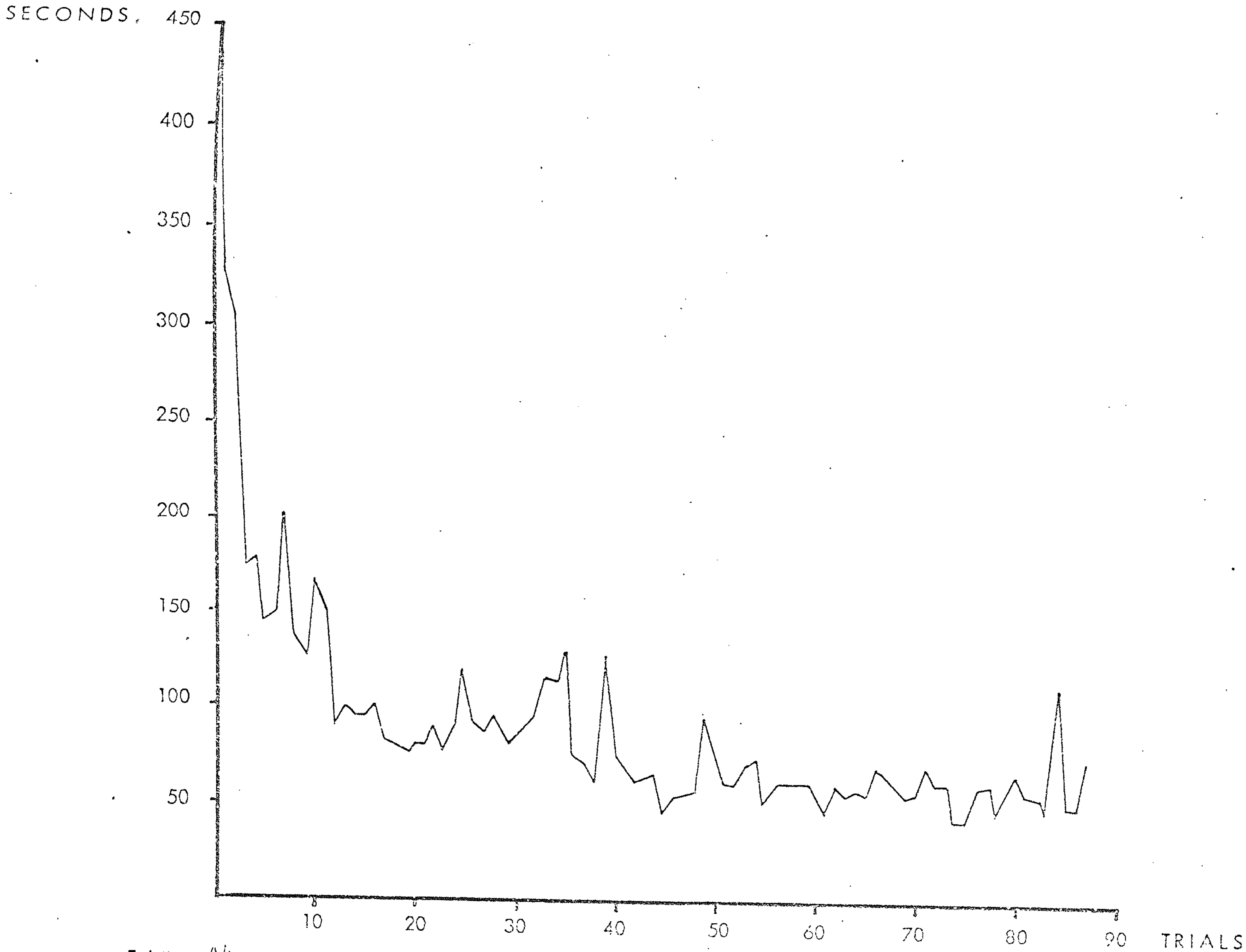


Exhibit A4 Cycle times as recorded by the trainee herself in the training school.

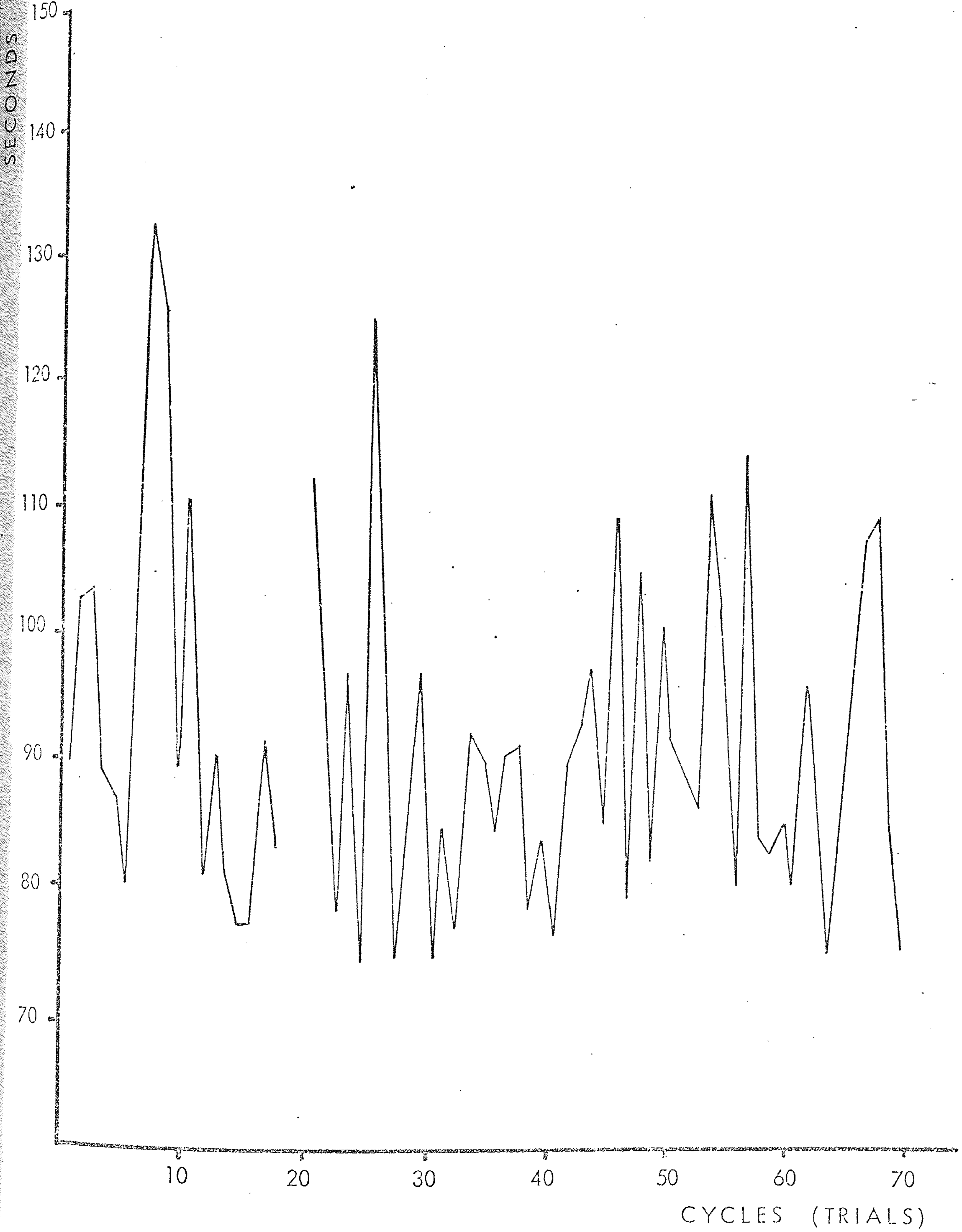


Exhibit A5 Cycle times of the trainee on the assembly line as recorded by the Murrell D.E.R. for the day of the 23rd of August.

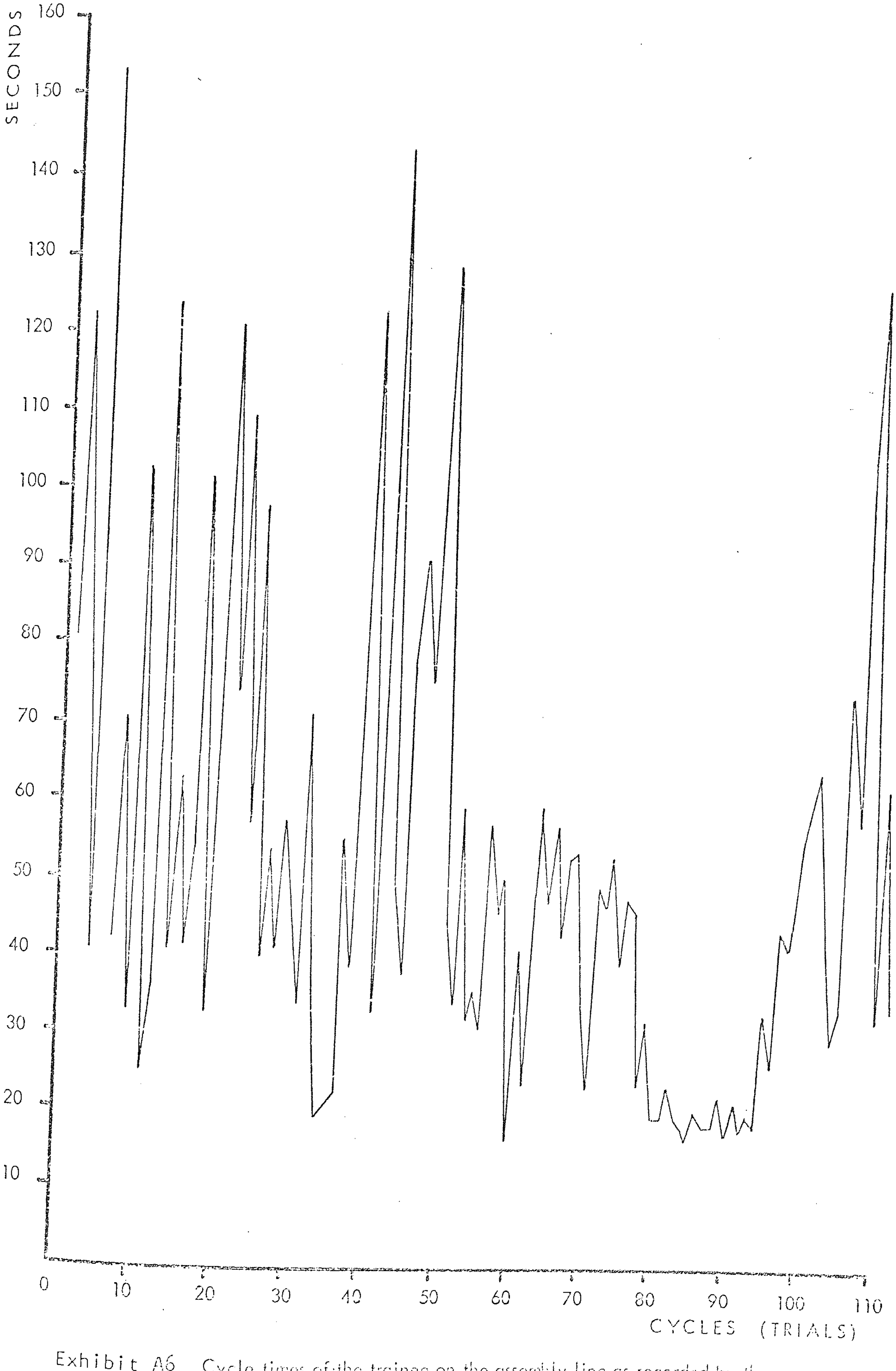


Exhibit A6 Cycle times of the trainee on the assembly line as recorded by the Murrell D.E.R. for the one day of the 8th September.

especially the longer cycle times because there were numerous sources of error.

1. The task was part of an assembly line and as such was paced by the speed of the line flow, though for many weeks the operator was working at less than experienced worker standard and, consequently, often held up the speed of the line.

2. Many times, mainly during the first and second weeks on the shopfloor, the trainee was helped out by the other workers on the flow line.

3. Because of changes in method the micro-switch on the box for the soldering iron was rendered useless. The photo-electric cell on the bin from which the pins were taken was the most reliable, though after a few weeks the method had changed enough to render this transducer useless.

4. The operator would occasionally leave the flow line, or take short rest pauses and these were included in the cycle times.

Exhibit A7 shows the averages of the cycle times of each of Exhibits A4, A5 and A6 plotted against the number of trials which had taken place.

III Analysis of the films taken

Exhibit A8 shows the results of the film analysis. These times were obtained by counting the number of frames and transforming this to seconds. Because of the nature of this two-handed task it was not possible to carry out an M.T.M. analysis on the films. Instead the task was broken

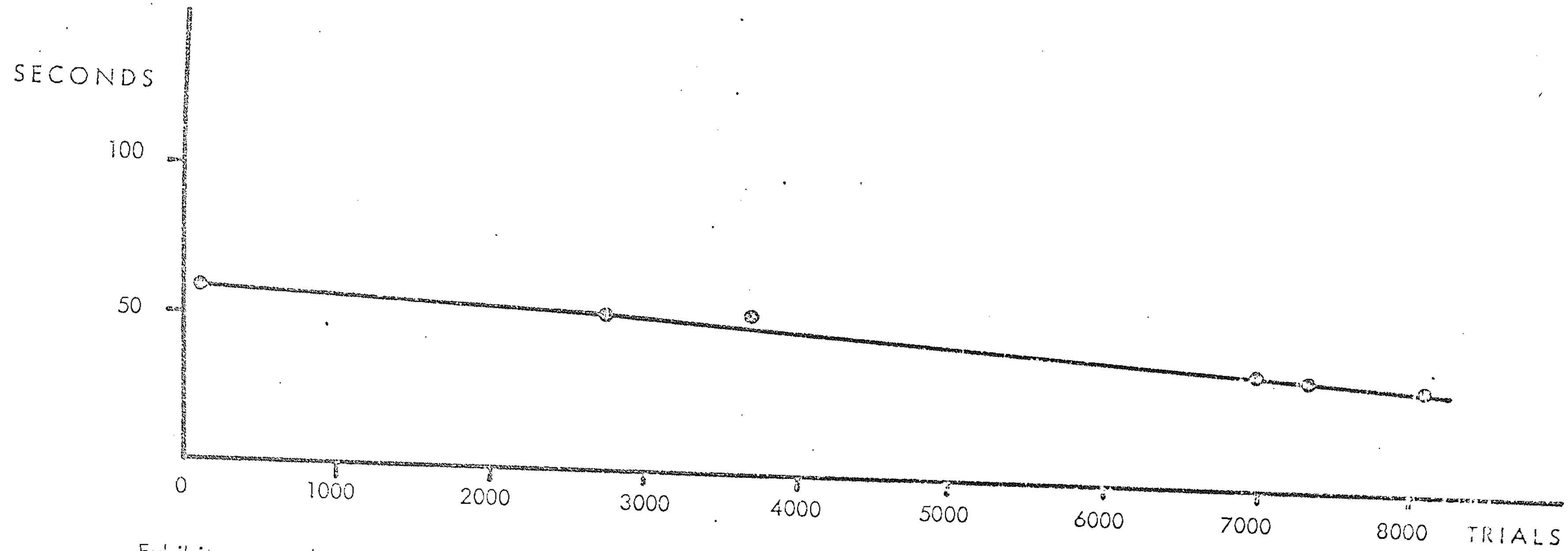


Exhibit A7 Average of the cycle times shown in Exhibits A4, A5 and A6 and those obtained from the later film analysis, plotted against the number of trials which had taken place.

	DATE ON WHICH THE FILMING TOOK PLACE			
	13/8	16/8	31/8	11/9
BIN - JIG	17.37	18.12	7.81	6.12
SCREWING	16.80	12.06	9.37	6.10
SOLDERING WIRE	112.50	69.00	36.50	25.87
TOTAL CYCLE TIME	146.67	99.18	53.68	38.09

Exhibit A8 Cycle times obtained from the film analysis of the three subtasks and of the complete task.

into its three main subtasks. Exhibit A9 shows the learning curve of total cycle time and the time for each of the subtasks plotted against number of days.

Discussion

The cycle times recorded in the training school by the subject show what has been called a typical learning curve (Exhibit A4). Some researchers make a distinction between 'threshold' and 'conditioned' phases of learning (Hancock and Sathe, 1969). They are defined as:

> "1. Threshold learning is that learning which occurs prior to the time the operator can do the operation from memory.
>
> 2. Conditioned learning is that learning which occurs after the person 'remembers' how to perform the operation."

The distinction made here is arbitrary and has no theoretical basis but is often a useful distinction in practice. It restricts the study of the learning curve to performance under conditions of no help and where "trial and error" is not evident.

In this study it can be reasonably assumed that conditioned learning has started by at least the tenth cycle (Exhibit A4). The average of these 87 trials, together with the average of the recordings from the DER (Exhibits A5 and A6) and the cycle times from the film analysis, may be plotted against the number of cycles (Exhibit A7). The number of cycles which had been carried out was estimated from production figures which showed an average of 400 units per day for this particular assembly line. If we draw a straight line to link the points we get what looks like a very good fit. This line suggests that experienced worker standard of 42 seconds

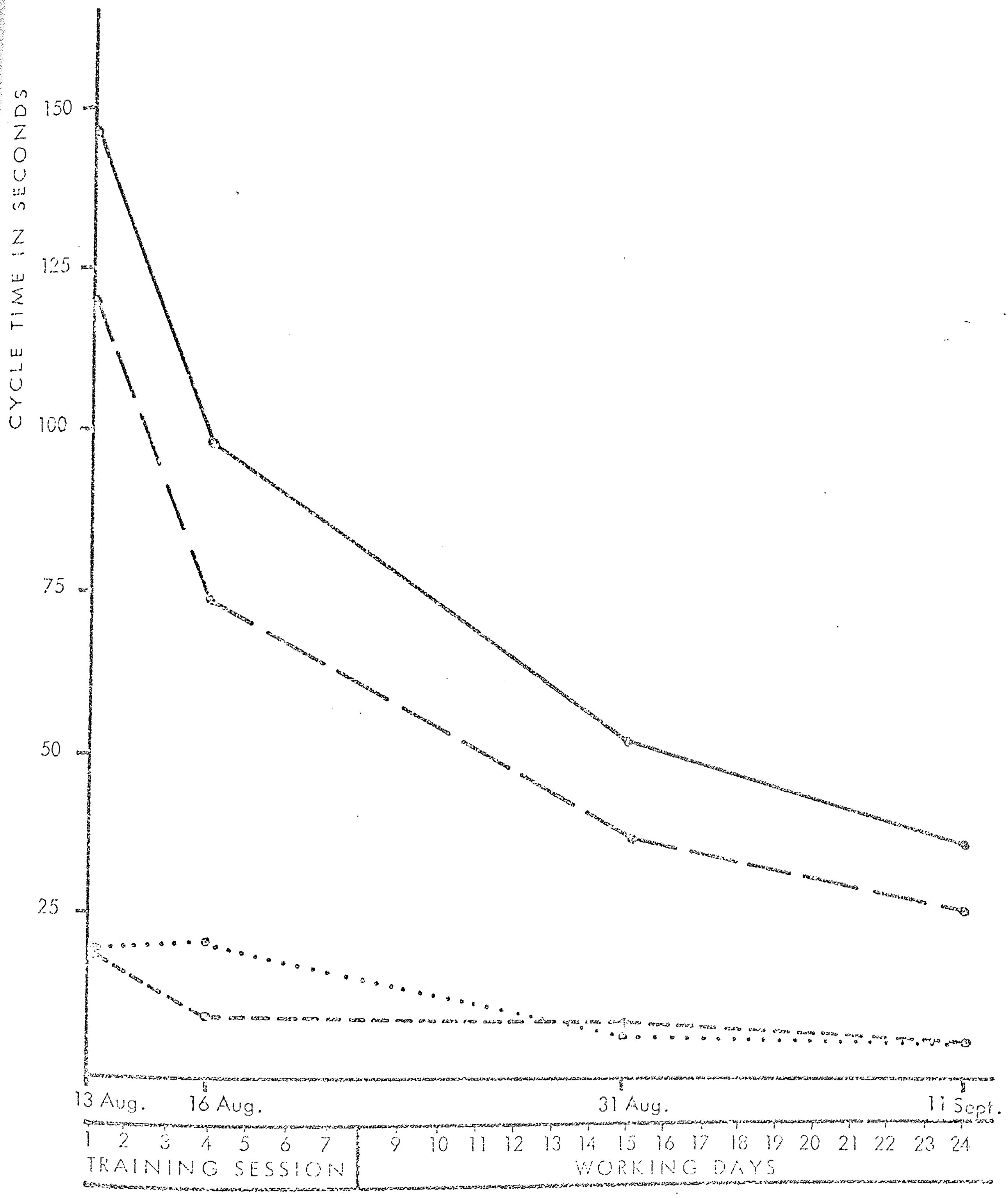


Exhibit A9 Graphical representation of Exhibit A8 showing change in cycle times of the three subtasks and of the complete task.

is not reached until 6,000 trials have been completed. That is, about 15 days' work or three weeks after starting on the shopfloor. This is the kind of learning curve which is used in industry for costing and planning.

But, of what use is it? If we change the slope of the straight line on Exhibit A7 by a small amount we get large changes in predicted number of cycles before experienced worker standard is reached. This is a very important prediction for learning curves. How representative would this line be if it were taken from a group's performance rather than an individual? It is an average of the data and some standard deviations could be computed, but we are still left with four main problems:

1. The learning curve is based on 'averages' of the cycle times and standard deviations become less applicable as learning continues because the distribution of cycle times becomes skewed - it is more difficult to do shorter times than that taken by the experienced worker, but it is always possible to do longer times.

2. How generalisable is the curve to new employees? How do we assess how similar they are to the population group from which the data was obtained?

3. We can say little about new tasks for which we have no data available.

4. We cannot predict the performance of individuals.

The films could not be M.T.M. analysed but the times for the total cycle time and the three main subtasks were obtained (Exhibit A8). Exhibit A9 shows the improvement in times for each of these over the 24 working days. It can be seen that the soldering task shows the most amount of improvement in terms of number of seconds. The other two subtasks tend to be what De Jong calls incompressible elements. Little improvement is evident in absolute terms even though both show a relative improvement to a time .50% of the initial time. The soldering task showed an improvement to a time which is 20% of the initial time.

Conclusions

The practical difficulties of recording accurately and reliably the cycle times for even a simple task were considerable. When the task is on the shopfloor of a factory there are even more problems. Great care is required to ensure that there is no interference with the trainee's performance. It is clear that a number of transducers is required in order that a clear indication of subtask or even micro-motion times may be evident from the recordings. This may interfere with the trainee's work. The problem of method changes means that effective transducer placement is extremely difficult.

The learning curve was of little help but the relative changes in subtask times indicated that an element-pattern analysis of tasks may be a valuable approach to take in the study of learning.

Further work using total cycle time to produce learning curves would get us no further than other researchers. It seems that a more complex model of a person learning a task which would account for both differences in individual characteristics and differences in task characteristics is required.

APPENDIX 2

TEST BATTERY

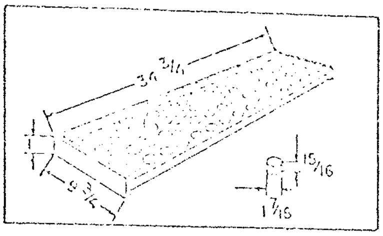
Test Reliabilities

Reliabilities for the following tests which were used in the three new studies described in Chapters 3 , Test-retest correlations were calculated for the Perceptual Speed, Steadiness, Aiming and Spiral maze test in the study of trainee typists using all 74 subjects. This information is given in addition to previous published test reliability sources.

Test	Reliability	Source	Test/Retest Reliability in trainee typist study
Minnesota Rate of Manipulation - Turning	0.79	Fleishman & Hempel 1954A	-
Printed Discrimination Reaction Time	0.87	Fleishman 1958B	-
Steadiness	0.84	Fleishman 1954	0.958
Aiming (Pursuit Aiming II)	0.93	Fleishman 1954	0.935
Perceptual Speed	-	-	0.784
(Similar to Speed of Identification)	0.74	Parker & Fleishman 1960	
Spiral Maze	-	-	0.894

Apparatus

Minnesota Rate of Manipulation (turning)



Description

The S is required to remove the blocks from the holes with one hand, turn them over with the other hand, and replace them in the same holes, moving from block to block as rapidly as possible. Score is the number of blocks turned. Two 35-sec. trials.

In the starting position, the board filled with the blocks is placed in front of the S.

Instructions

The object is to see how fast you can turn the blocks over.

"With your LEFT hand, lift the block from the upper right-hand hole, and with your RIGHT hand put it back, bottom side up, into the same hole."

"Work to the left across the board, picking up the blocks with your LEFT hand and putting them down with your RIGHT, bottom side up."

Having finished the top row, you go down to the next row and work back to the right.

"As you work back to the right in the next row, you pick them up with your RIGHT hand and put them down with your LEFT."

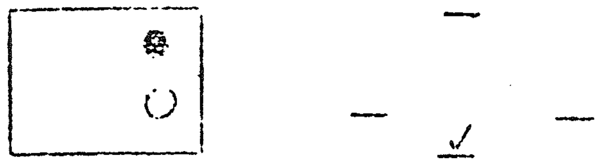
"Always pick UP the blocks with the hand that LEADS and put them DOWN with the hand that FOLLOWS. Before you finish be sure that every block is all the way down."

Instructions

This is a test of speed of reaction to a signal. The signal will be an arrangement of a black and a white circle. There are only four arrangements of the circles, and four ways to mark your answer. Look at the sample problems below and the corresponding illustrations of the correct ways to mark your answer.

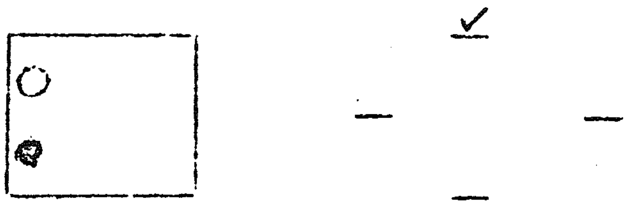
Sample Problems

A.



When the white circle is below the black circle, place a check on the bottom line.

B.

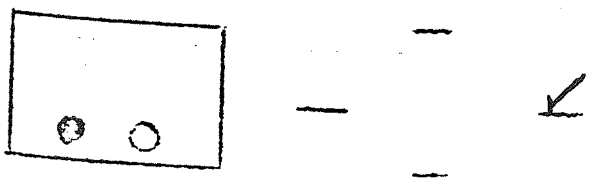


When the white circle is above the black circle, place a check on the upper line.

C.

When the white circle is to the left of the black circle, place a check on the line to the left.

D.



When the white circle is to the right of the black circle, place a check on the line to the right.

We are now ready to begin the test. Remember, this is a speed test. Work as fast as you can.

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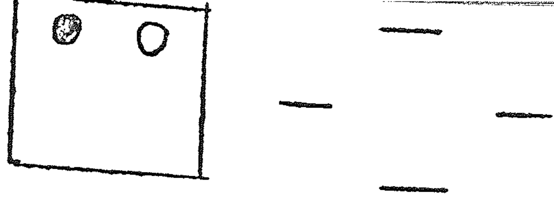

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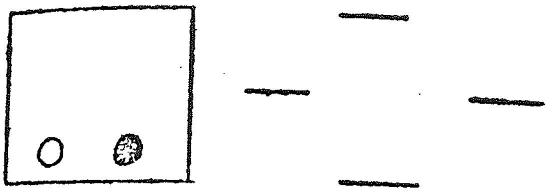

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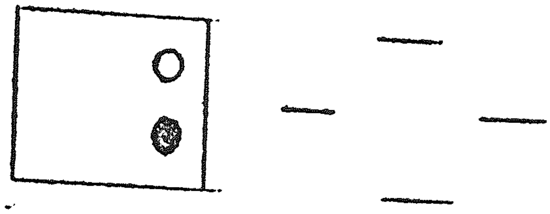

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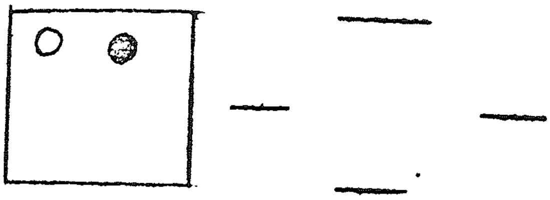

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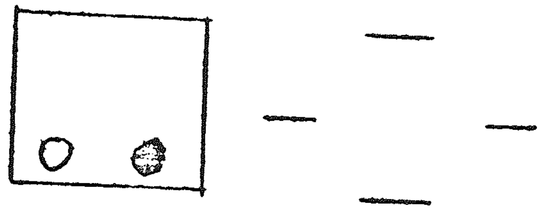

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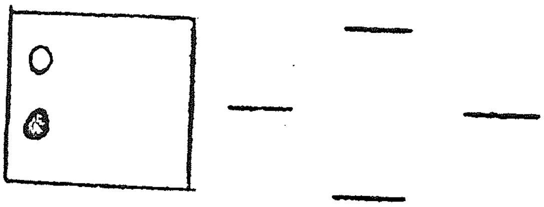

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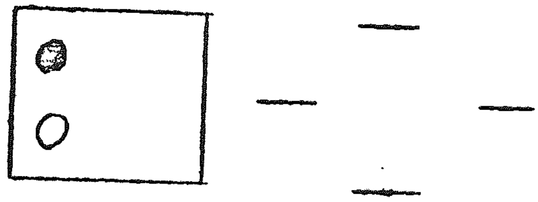

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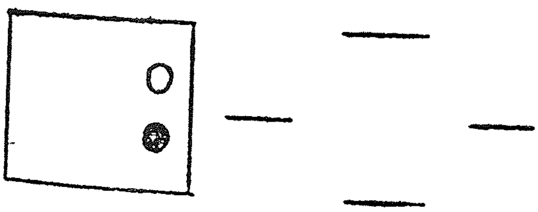

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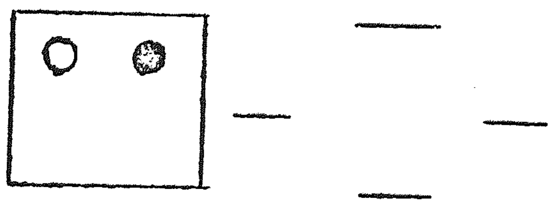

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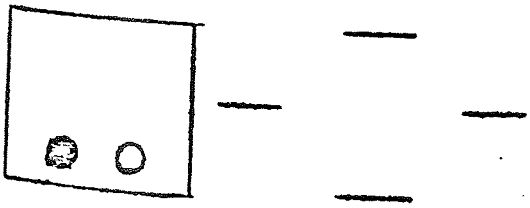

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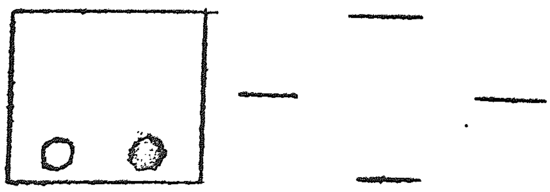

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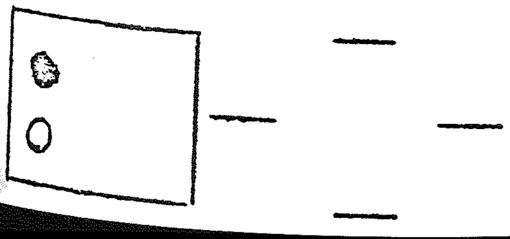

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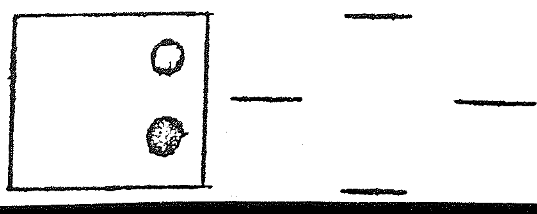

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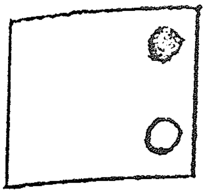

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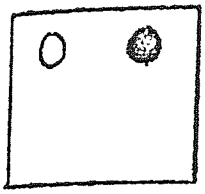

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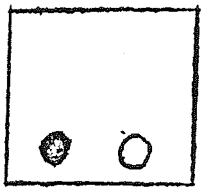

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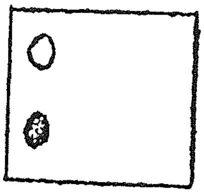

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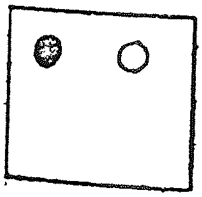

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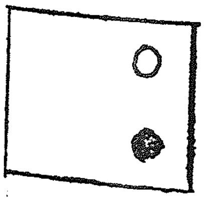

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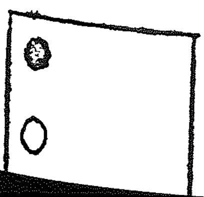

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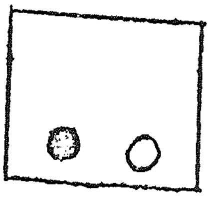

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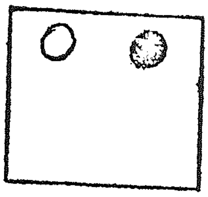

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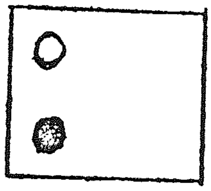

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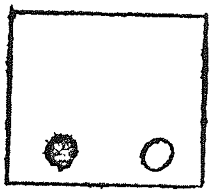

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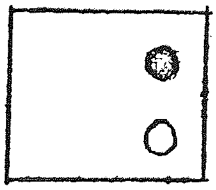
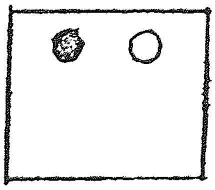
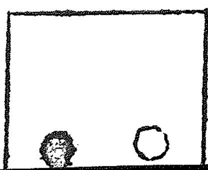


27.



28.



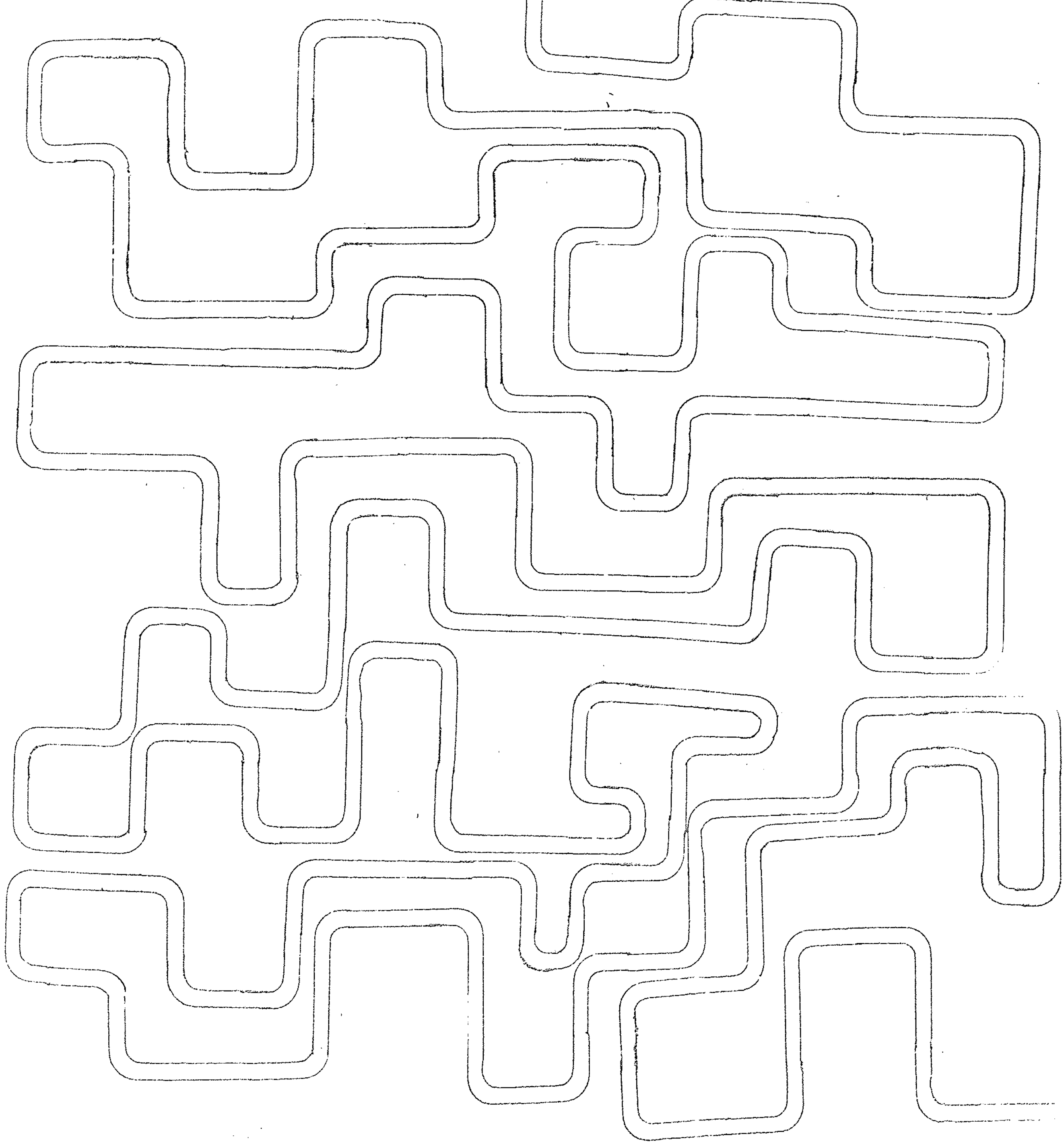
STEADINESS

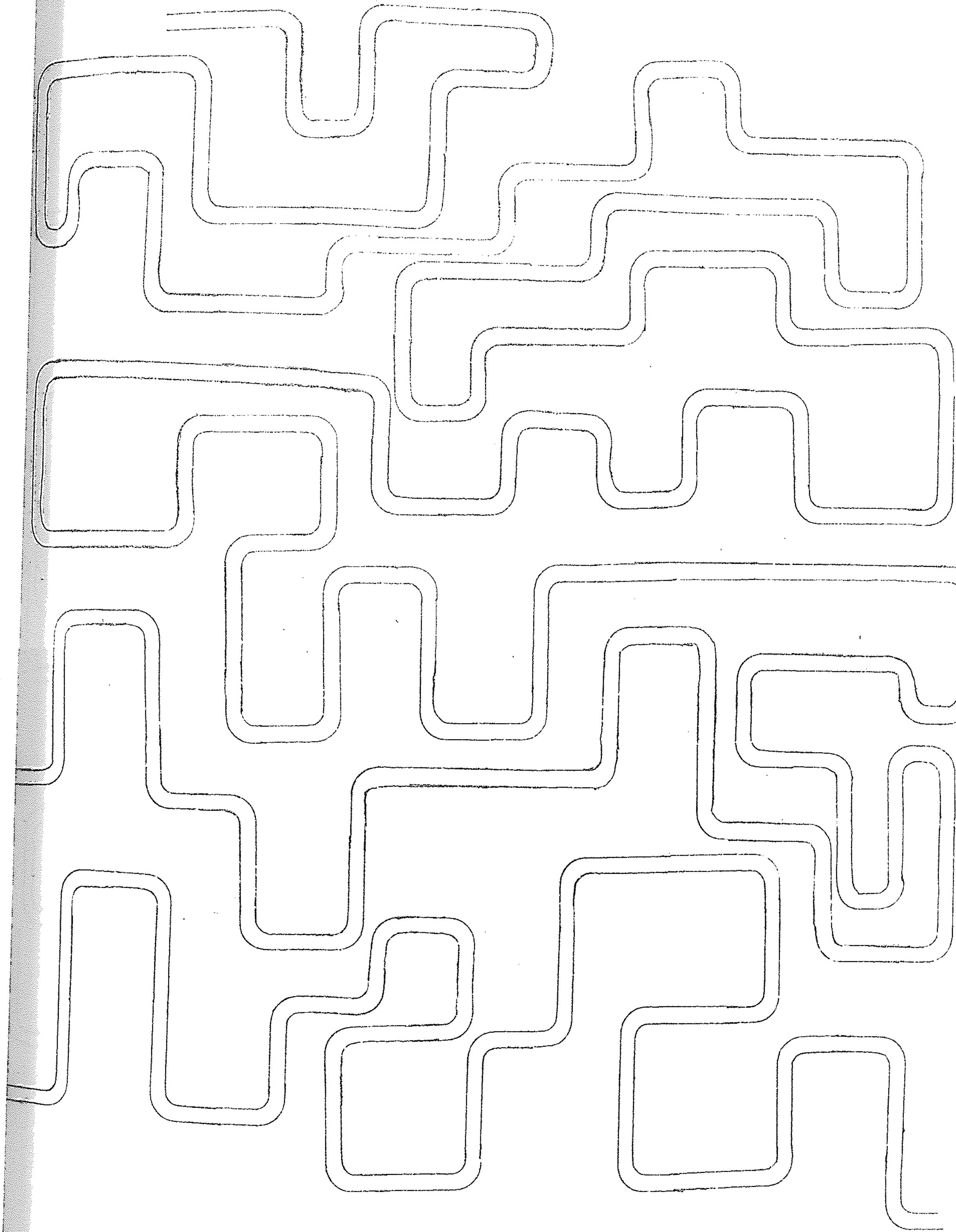
Description

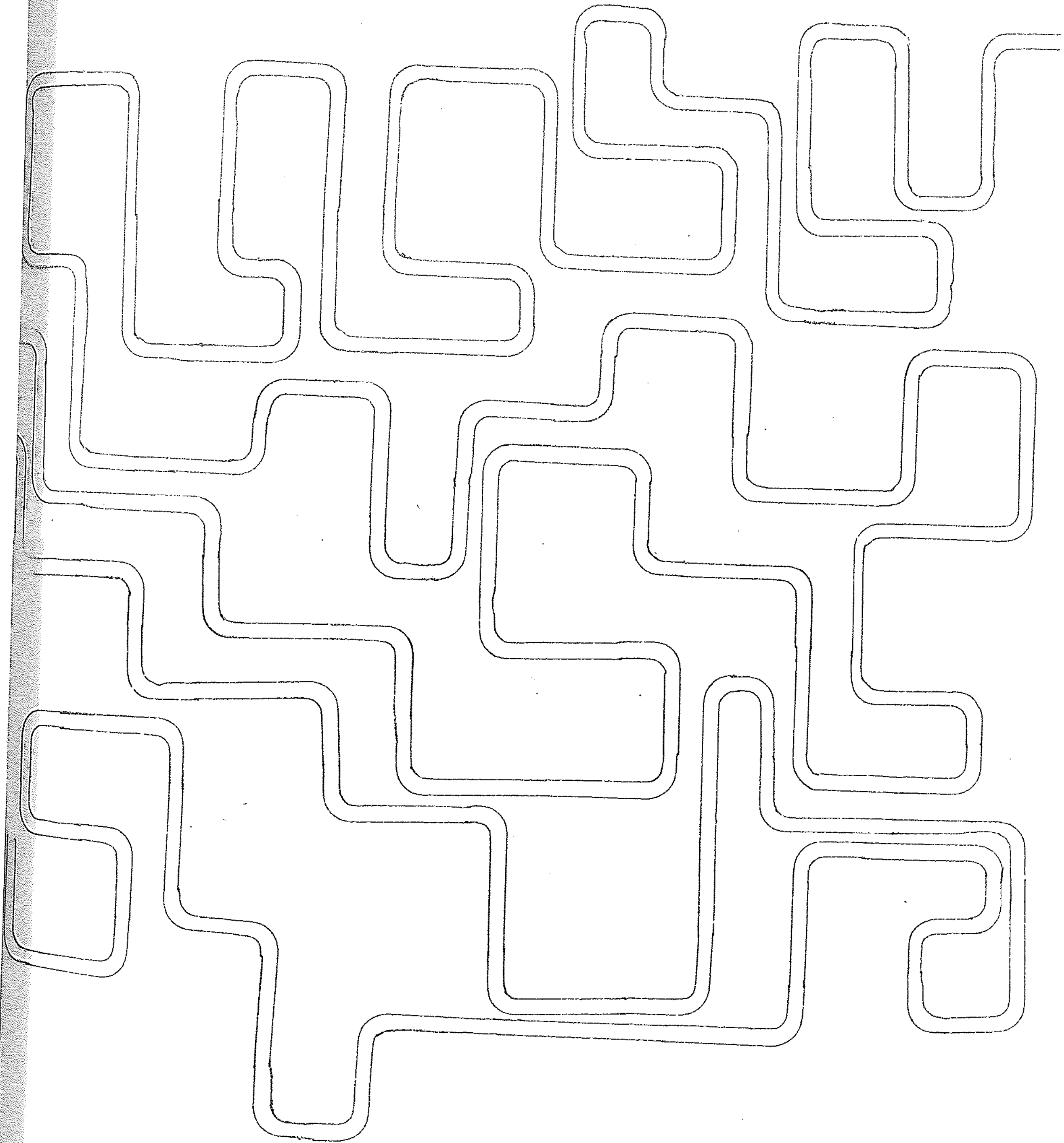
The S must trace between a pair of narrowly separated lines (1/16 inch) which form a pattern. Score is the number of segments negotiated without touching the lines. Five trials of 30 seconds.

Instructions

In this test you are to trace between the lines of a pattern as steadily as you can. Start by placing your pencil in the dot at the beginning of the pattern. When told to begin, move your pencil steadily between the lines. Try as much as possible to stay within the lines without touching the sides of the pattern. Do not lift your pencil while you are tracing, but continue as best as you can to the end of the pattern. Place your pencil on the dot. Now begin tracing.







PURSUIT AIMING

Description

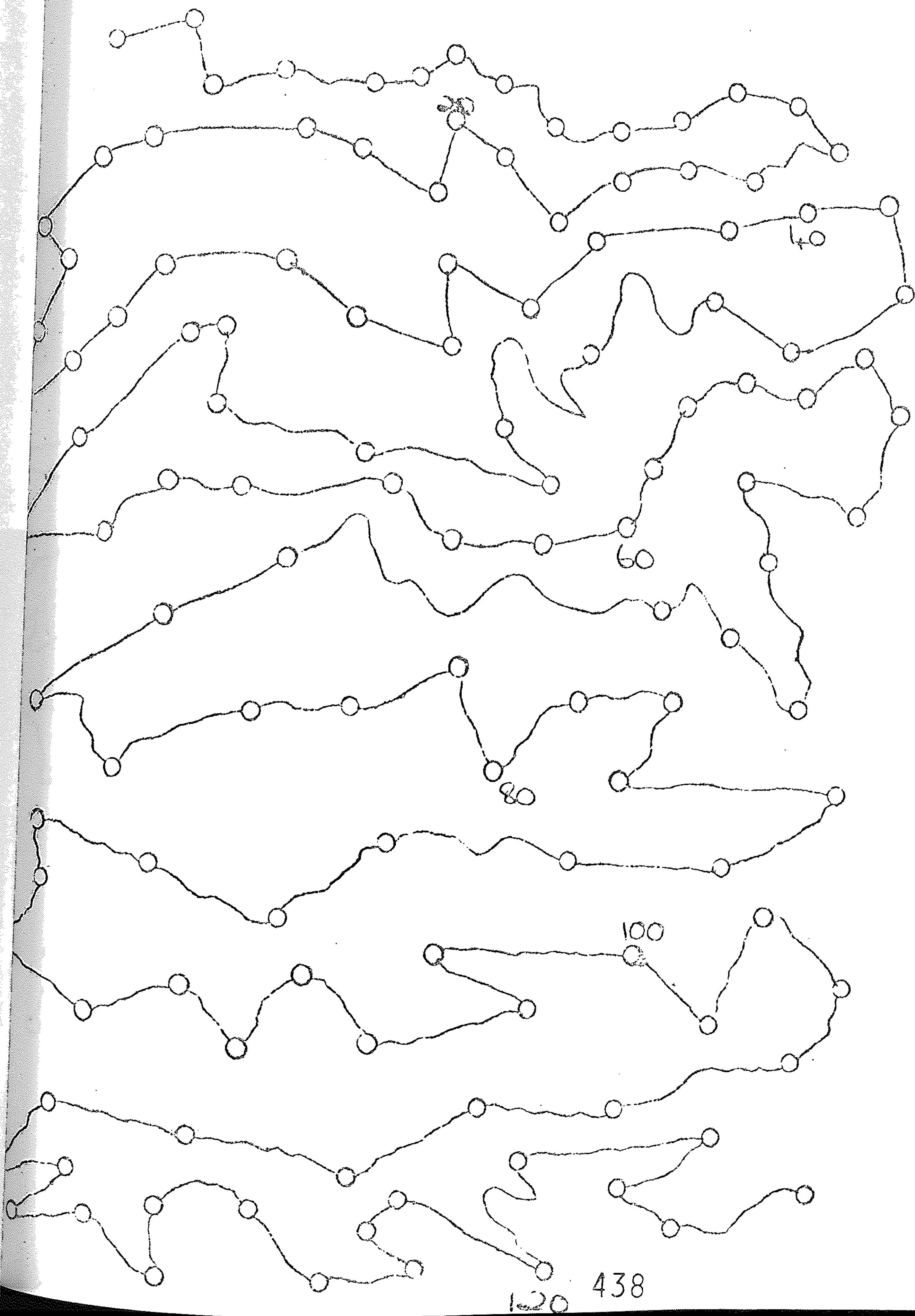
The S is required to follow a pattern of small circles ($\frac{1}{8}$ inch in diameter) placing one dot in each circle around the pattern. Five 60 second trials.

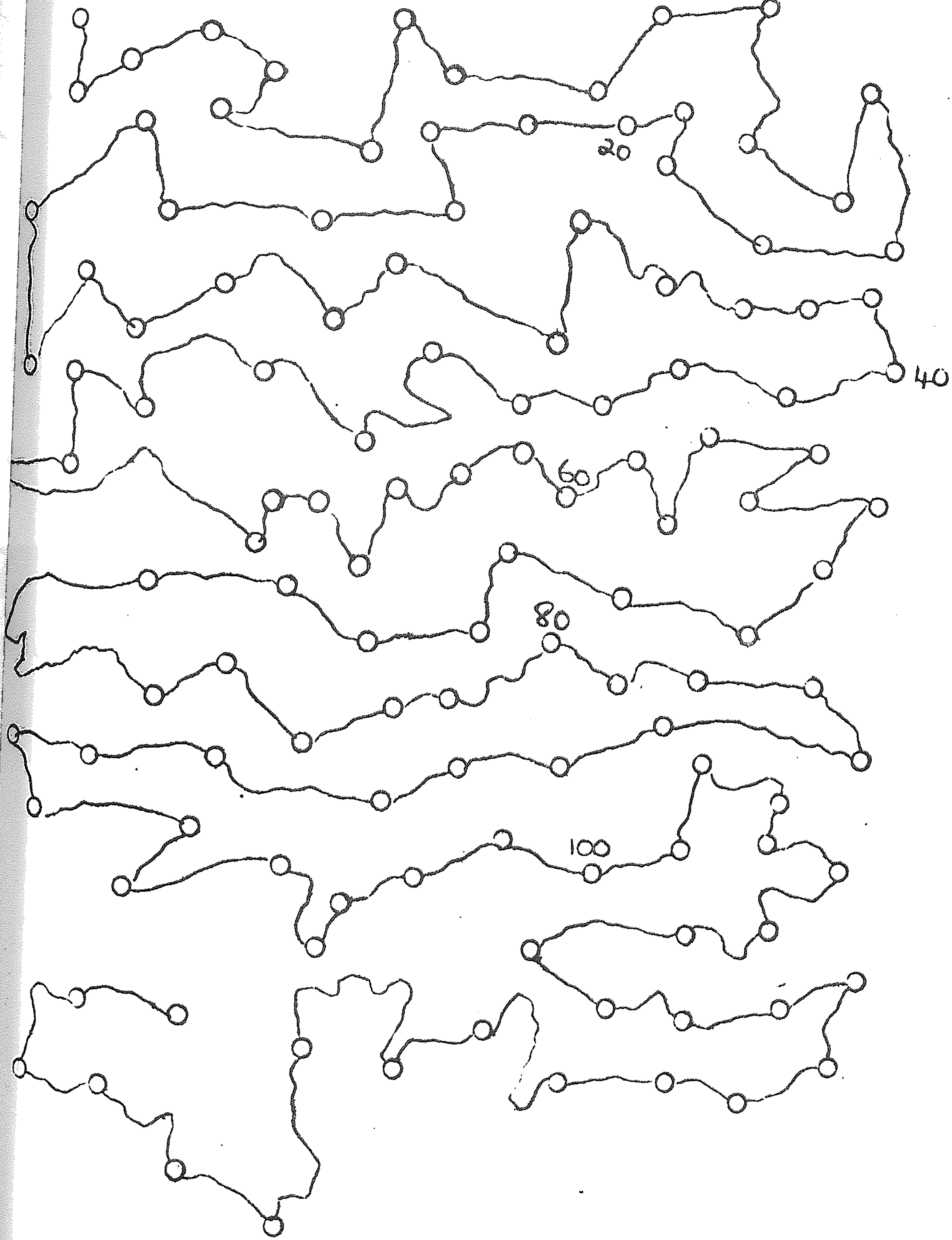
Scoring

Number of circles with dots in them in 60 seconds.

Instructions

When the examiner says 'BEGIN' put a dot in each circle on the line. Begin at the upper right corner, and follow the line. When you come to the bottom of the first page continue on the top of the second page and work down the second page. Work as quickly as possible.


20
40
60
80
100
120


20
40
60
80
100
120

PERCEPTUAL SPEED

Description

Subject required to do quick and accurate judgement as to whether two items are exactly the same.

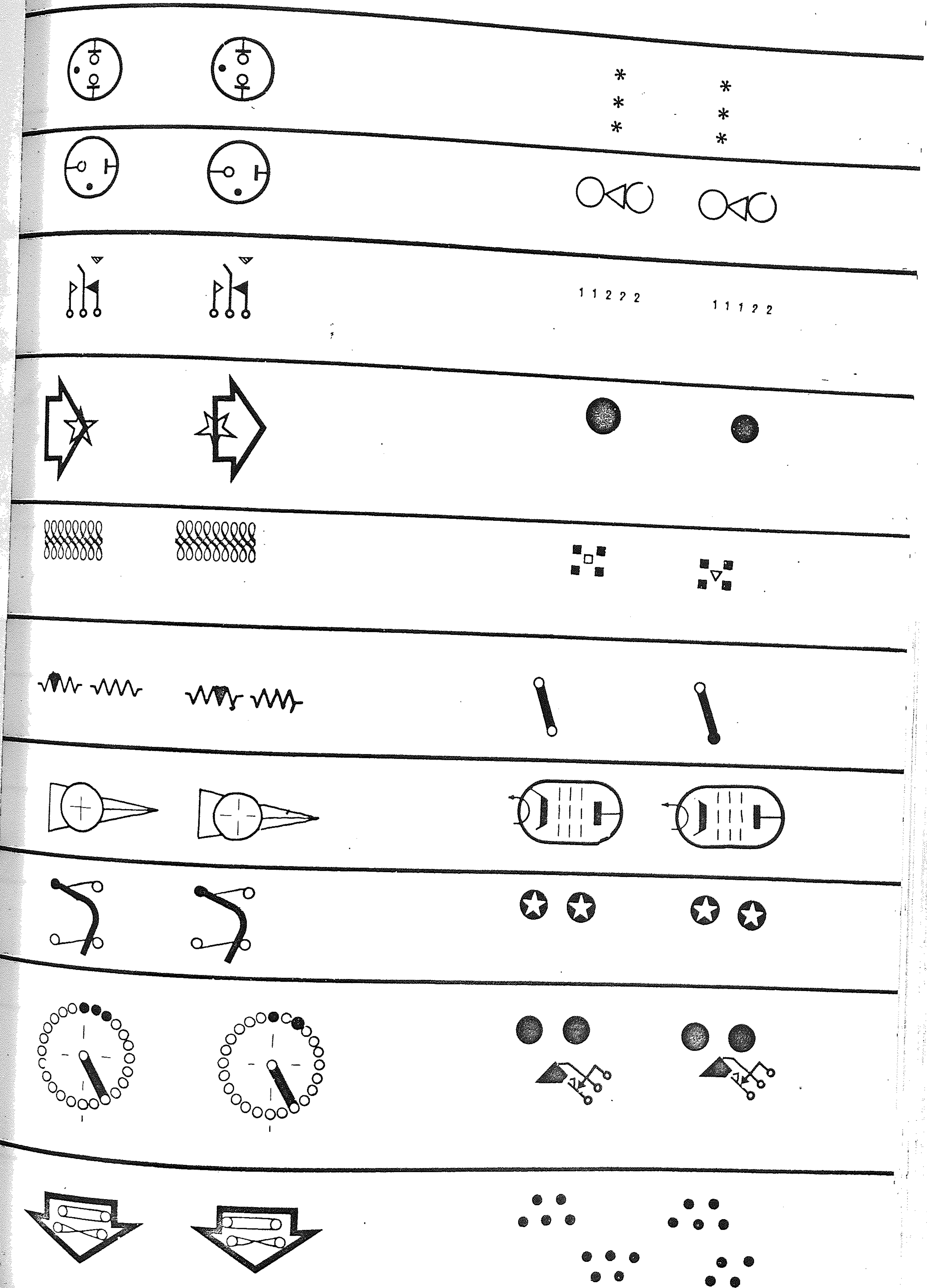
The subject ticks 'SAME' or 'DIFFERENT' depending on whether they think the items are the same or different.

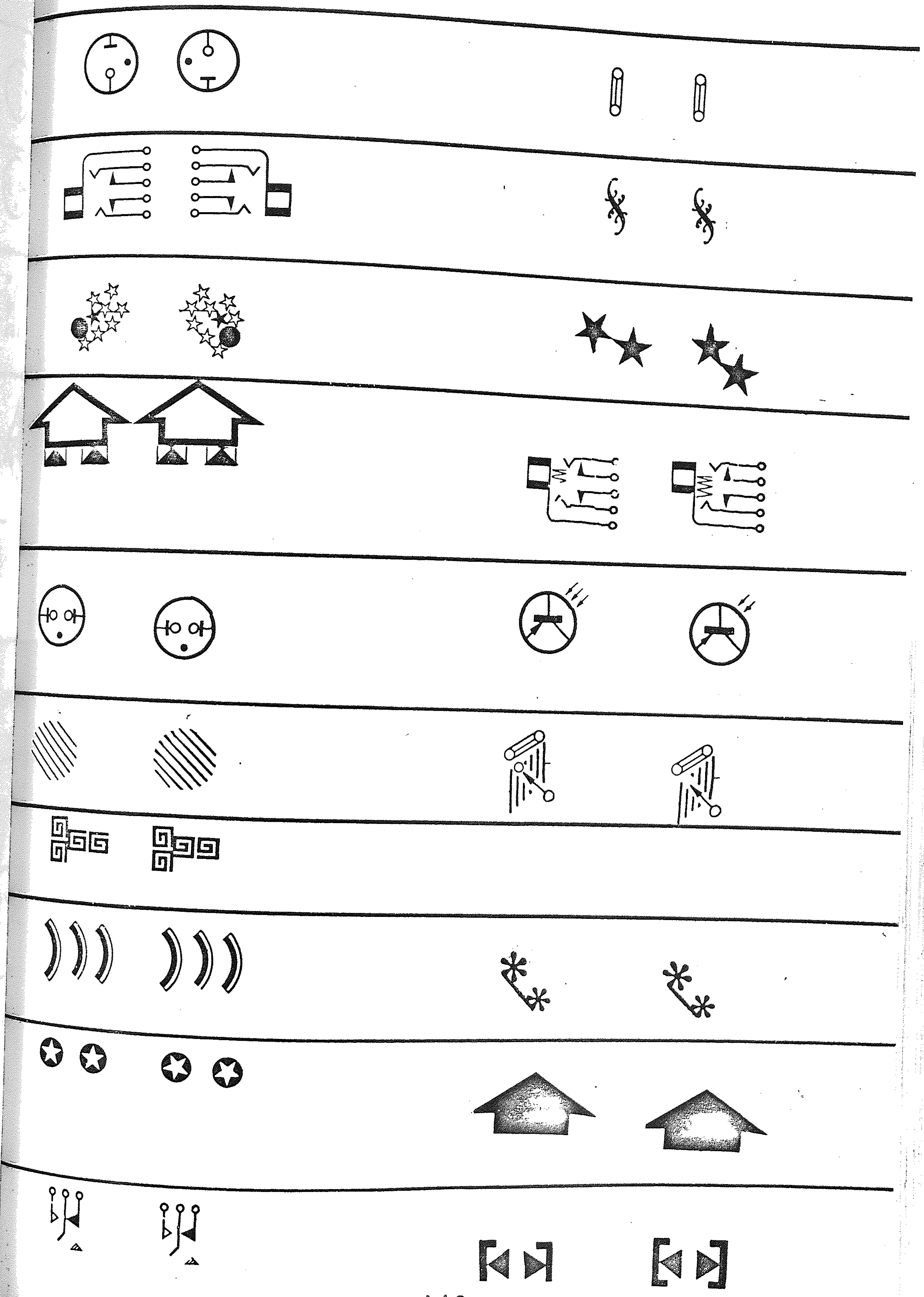
Score

Number of correct responses in one minute

Instructions

Please start at the top of Page 1, and compare the first two shapes. If they are the same, place a tick under 'SAME', if they are different place a tick under 'DIFFERENT'. Do as many as you can in 60 seconds. When you have finished the first column do the columns beside it and then go on to the next page.


1 1 2 2 2
1 1 1 2 2



SPIRAL MAZE

Apparatus

Paper test sheets A1
Biro which is not empty
Stop watch

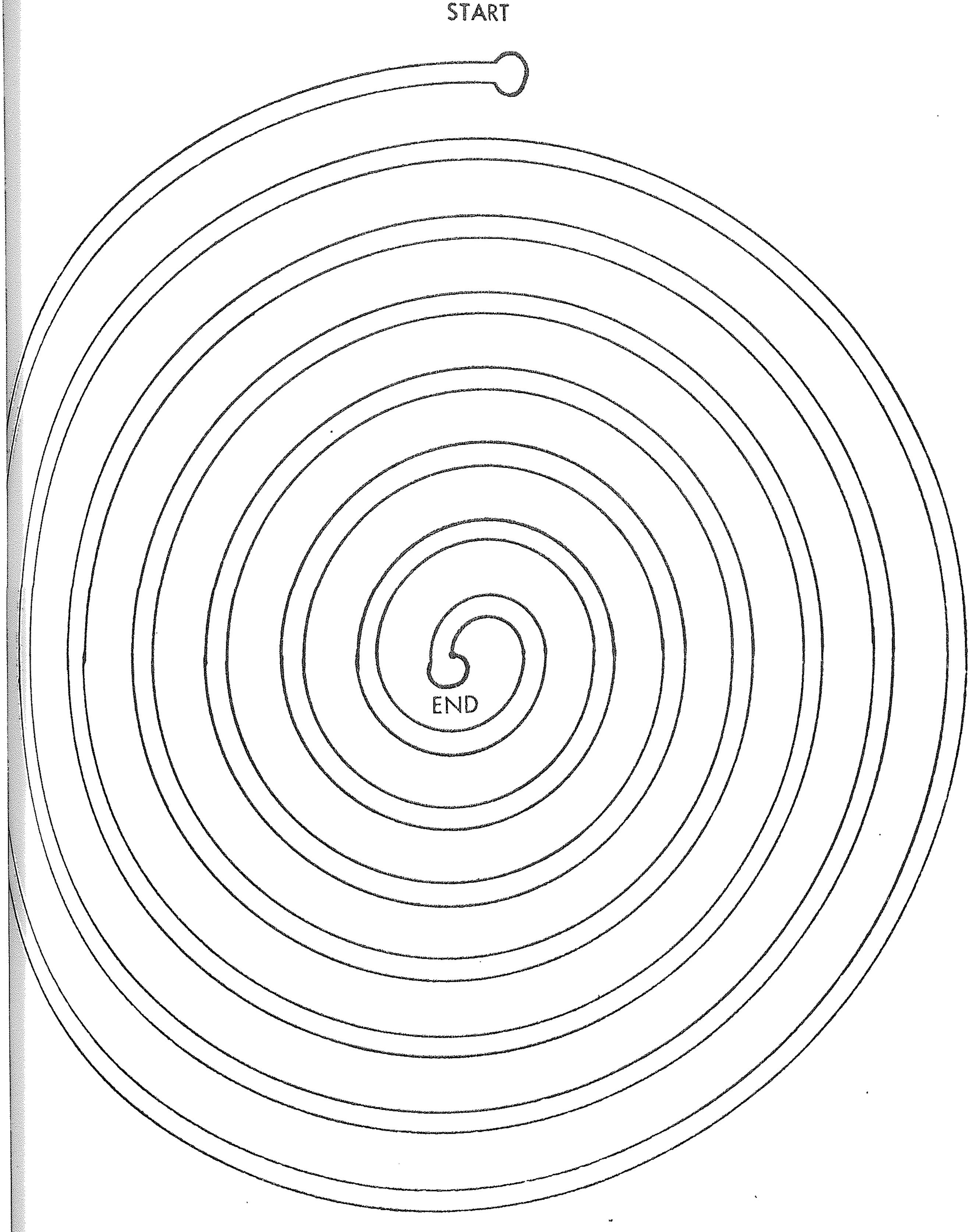
Method

The subject is required, with his preferred hand, to place the biro in the circle marked 'START' and when told to 'GO' to trace between the lines without touching the lines until the subject reaches the centre circle marked 'END'. He is not allowed to rest his arm on anything.

Instructions

Would you please pick up the biro with your writing hand. Place the point of the biro in the circle marked 'START'. When I say 'GO' I want you to draw a line between the two lines of the spiral until you reach the centre circle marked 'END'. Try not to touch or cross the lines of the spiral and do it as quickly as you can. Do not rest your arm on anything. Any questions?

Task I Self-paced Rotary Pursuit/ Paper and Pencil version



APPENDIX 3

HOLZINGER AND HARMAN TABLES

Appendix 3.

Statistical Tables

The sampling distribution of statistics arising in factor analysis has been largely neglected during the rapid development of descriptive procedures. An early exception was the work of Spearman and Holzinger (1924) on the sampling error of tetrad differences. When Hotelling (1933) presented the general theory and computing procedures for the principal-factor method, he also included discussions of the sampling errors of the roots of the characteristic equation and of the sampling of variables from a hypothetical infinite population of such variables. In 1940 came the next major contribution to the statistical theory of factor analysis, when Lawley (1940) introduced the maximum likelihood methods into factor analysis.

Because of the lack of precise sampling error formulas for factor coefficients and residuals, approximation procedures were developed by Holzinger and Harman (1941, pp. 122–36). Without repeating this development here, nor giving the details of the various assumptions, the principal results are presented in the first two tables. The basic assumption is that the individual correlations may be replaced by the mean (r) of the set. Additional assumptions which led to the approximations tabled were out of consideration of computational labor. For each successive approximation the sampling error formulas generally became smaller. Knowing that the sampling errors are probably underestimated, a more stringent level of significance should be required. In Table A the standard error of a residual (with one factor removed) is given for samples from $N = 20$ to $N = 500$ for an average correlation from $r = .10$ to $r = .75$. For the same range of values of N and r, the standard error of a factor coefficient a is given in Table B.

Table A

Standard Errors of Residuals with One Factor Removed

$\sigma_r = (1 - r)\sqrt{(5 + 8r + 2r^2)/2N}$

N \ r	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	.75
20	.343	.336	.327	.317	.305	.292	.277	.261	.244	.225	.205	.184	.161	.138
30	.280	.274	.267	.258	.249	.238	.226	.213	.199	.184	.167	.150	.132	.112
40	.243	.237	.231	.224	.215	.206	.196	.185	.172	.159	.145	.130	.114	.097
50	.217	.212	.207	.200	.193	.184	.175	.165	.154	.142	.130	.116	.102	.087
60	.198	.194	.189	.183	.176	.168	.160	.151	.141	.130	.118	.106	.093	.079
70	.183	.180	.175	.169	.163	.156	.148	.139	.130	.120	.110	.098	.086	.074
80	.172	.168	.163	.158	.152	.146	.138	.130	.122	.113	.103	.092	.081	.069
90	.162	.158	.154	.149	.144	.137	.131	.123	.115	.106	.097	.087	.076	.065
100	.154	.150	.146	.142	.136	.130	.124	.117	.109	.101	.092	.082	.072	.062
110	.146	.143	.139	.135	.130	.124	.118	.111	.104	.096	.087	.078	.069	.059
120	.140	.137	.133	.129	.124	.119	.113	.107	.099	.092	.084	.075	.066	.056
130	.135	.132	.128	.124	.120	.114	.109	.102	.096	.088	.080	.072	.063	.054
140	.130	.127	.124	.120	.115	.110	.105	.099	.092	.085	.078	.070	.061	.052
150	.125	.123	.119	.116	.111	.106	.101	.095	.089	.082	.075	.067	.059	.050
160	.121	.119	.116	.112	.108	.103	.098	.092	.086	.080	.073	.065	.057	.049
170	.118	.115	.112	.109	.105	.100	.095	.090	.084	.077	.070	.063	.055	.047
180	.114	.112	.109	.106	.102	.097	.092	.087	.081	.075	.068	.061	.054	.046
190	.111	.109	.106	.103	.099	.095	.090	.085	.079	.073	.067	.060	.052	.045
200	.109	.106	.103	.100	.096	.092	.088	.083	.077	.071	.065	.058	.051	.044
250	.097	.095	.092	.090	.086	.082	.078	.074	.069	.064	.058	.052	.046	.039
300	.089	.087	.084	.082	.079	.075	.071	.067	.063	.058	.053	.047	.042	.036
350	.082	.080	.078	.076	.073	.070	.066	.062	.058	.054	.049	.044	.039	.033
400	.077	.075	.073	.071	.068	.065	.062	.058	.054	.050	.046	.041	.036	.031
450	.072	.071	.069	.067	.064	.061	.058	.055	.051	.047	.043	.039	.034	.029
500	.069	.067	.065	.063	.061	.058	.055	.052	.049	.045	.041	.037	.032	.028

Note: r is the average value in the correlation matrix.

Table B

Standard Errors of Factor Coefficients

$\sigma_a = \frac{1}{2}\sqrt{(3/r - 2 - 5r + 4r^2)/N}$

N \ r	.10	.12	.14	.16	.18	.20	.22	.24	.26	.28	.30	.35	.40	.45	.50	.55	.60	.65	.70	.75
20	.587	.530	.485	.448	.417	.390	.360	.345	.326	.309	.293	.258	.227	.201	.177	.155	.134	.115	.097	.079
30	.479	.433	.396	.366	.340	.318	.299	.282	.266	.252	.239	.210	.186	.164	.144	.126	.110	.094	.079	.065
40	.415	.375	.343	.317	.295	.276	.259	.244	.231	.218	.207	.182	.161	.142	.125	.109	.095	.081	.068	.056
50	.371	.335	.307	.283	.264	.247	.232	.218	.206	.195	.185	.163	.144	.127	.112	.098	.085	.073	.061	.050
60	.339	.306	.280	.259	.241	.225	.211	.199	.188	.178	.169	.149	.131	.116	.102	.089	.077	.066	.056	.046
70	.314	.283	.259	.239	.223	.208	.196	.184	.174	.165	.157	.138	.122	.107	.094	.083	.072	.061	.052	.042
80	.293	.265	.242	.224	.208	.195	.183	.173	.163	.154	.146	.129	.114	.100	.088	.077	.067	.057	.048	.040
90	.277	.250	.229	.211	.196	.184	.173	.163	.154	.146	.138	.121	.107	.095	.083	.073	.063	.054	.046	.037
100	.262	.237	.217	.200	.186	.174	.164	.154	.146	.138	.131	.115	.102	.090	.079	.069	.060	.051	.043	.035
110	.250	.226	.207	.191	.178	.166	.156	.147	.139	.132	.125	.110	.097	.086	.075	.066	.057	.049	.041	.034
120	.240	.216	.198	.183	.170	.159	.150	.141	.133	.126	.120	.105	.093	.082	.072	.063	.055	.047	.039	.032
130	.230	.208	.190	.176	.163	.153	.144	.135	.128	.121	.115	.101	.089	.079	.069	.061	.053	.045	.038	.031
140	.222	.200	.183	.169	.158	.147	.138	.130	.123	.117	.111	.097	.086	.076	.067	.058	.051	.043	.036	.030
150	.214	.193	.177	.164	.152	.142	.134	.126	.119	.113	.107	.094	.083	.073	.065	.056	.049	.042	.035	.029
160	.207	.187	.171	.158	.147	.138	.129	.122	.115	.109	.104	.091	.080	.071	.062	.055	.047	.041	.034	.028
170	.201	.182	.166	.154	.143	.134	.126	.118	.112	.106	.100	.088	.078	.069	.061	.053	.046	.039	.033	.027
180	.196	.177	.162	.149	.139	.130	.122	.115	.109	.103	.098	.086	.076	.067	.059	.052	.045	.038	.032	.026
190	.190	.172	.157	.145	.135	.126	.119	.112	.106	.100	.095	.084	.074	.065	.057	.050	.044	.037	.031	.026
200	.186	.168	.153	.142	.132	.123	.116	.109	.103	.098	.093	.081	.072	.064	.056	.049	.042	.036	.031	.025
250	.166	.150	.137	.127	.118	.110	.104	.098	.092	.087	.083	.073	.064	.057	.050	.044	.038	.032	.027	.022
300	.151	.137	.125	.116	.108	.101	.095	.089	.084	.080	.076	.067	.059	.052	.046	.040	.035	.030	.025	.020
350	.140	.127	.116	.107	.100	.093	.088	.083	.078	.074	.070	.062	.054	.048	.042	.037	.032	.027	.023	.019
400	.131	.118	.108	.100	.093	.087	.082	.077	.073	.069	.065	.058	.051	.045	.040	.035	.030	.026	.022	.018
450	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.017

APPENDIX 4

TESTS USED BY FLEISHMAN AND HIS CO-WORKERS

A

Aerial Orientation

Auditory Reaction Time

Aiming

Army Radio Code

Arm Tremor

Arm Drift

Addition

Auditory No. Span

Abdominal Pivot

B

Bimanual Matching

Background Current Affairs

Block Turning

Backing Down Wall

Balance-A-Test

Broad Jump

Ball and Pipe

Backward Jump

C

Complex movements

Coordinate Movements

Control Sensitivity

Complex Coordinator (Coordination)

Control Adjustment

Compensatory Balance

Controls Orientation

Cox Pin Board

Cox Eye Board

Cable Jump

Circular Tie Walking

Copying Behind

Concealed Figures

Control Movement

Cancelling Numbers

Circling Words

Complex Multiple Reaction

Criterion

Circle Dotting

Chinning

D

Directional Control

Discrimination Reaction Time

Dial Setting

Dot Perception

Designs

Direction Tracing

Discrimination Square Marking

Dynometer

Dynamic Flexibility

Decoding

Dial and Table Reading

Drift Correction

Discrimination Pursuit

Dowel Manipulation

Dynamic Balance

E

Estimation of Length

Empty Interval Judgements

F

Following Directions

Forced Landings

Formation Visualisation

Finger Dexterity

Four Letter Words

Forward Stick Positioning

Foot Balance

G

General Mechanics

Gestalt Completion

H

Hidden Tunes

Hex Nut Stacking

Hurdle Jump

Hand Precision Aiming

Hands

I

Instrument Comprehension

Irregular Dotting Pursuit

J

Jump Visual Reaction Time

Jump Auditory Reaction Time

Jump and Click Heels

Jump and Turn

Jump and Balance

Jump and Touch

K

Knob Positioning

Key Tapping

Kinaesthetic Coordination

Kicking Height

L

Lever Positioning

Line Drawing

Length Judgment

Large Tapping

Log Book Accuracy

Leg Bending

Leg Raising

M

Mechanical Comprehension

Motor Judgement

Marking Accuracy

Mutilated Words

Medium Tapping

Minnesota Rate of Manipulation

Mechanical Principles

Multi-dimensional Pursuit

N

Nut and Bolt

Numerical Operations

O

O'Connor Finger Dexterity

Orthorator

P

Pattern Comprehension

Planning a Course

Purdue Peg Board

Pursuit Confusion

Plane Control

Proficiency Criterion

Position Finding

Pattern Discrimination

Postural Discrimination

Pursuit Aiming I

Pursuit Aiming II

Pin Stick

Punch Board

Pull Ups

Pin Punch

Push Ups

R

Rate of Manipulation (Placing)

Rate of Manipulation (Turning)

Rate Control

Rotary Aiming

Rudder Control (Single Target)

Rotary Pursuit

Rate of Movement

Rhythm Discrimination

Rotary Positioning

Reaction Time

Rising from Supine

Recognition Memory

Restricted Manipulation

Rad Walking

Rate of Jump

S

Speed of Manipulation

Signal Discrimination

Speed of Marking

Signal Interpretation

Spatial Orientation

Speed of Identification

Stick and Rudder Orientation

Steadiness Precision

Square Marking

Simple Reaction Time

Speed of Reaction

Spatial Visualisation

Speech Intelligibility

Steadiness Aiming

Single Dimension Pursuit

Santa Ana

Steadiness Tremor

Stick Reaction

Small Tapping

Single Dimension Pursuit Meter

T

Two Plate Tapping

Target Aiming (Target Location)

Track Tracing

Two-hand Coordination

Two-hand Pursuit

Two-hand Matching

Tool Functions

Track Steadiness

Two-foot Rail Balance

Table Vault

Toe Touching

U

Unidimensional Matching

V

Vocabulary

Visual Pursuit

Visualisation of Manoeuvers

Visual Reaction Time

Visual Coincidence

Visual Line Tracing

V.O.C. Rings

W

Word Knowledge

APPENDIX 5

COMPUTER PROGRAMME FOR ANALYSIS OF LEGO EXPERIMENT

```
C FOCAL V'A
01.01 DATA IN LEGO
01.02 S I=1;S N1=0;S N2=0
01.03 S B(I)=100;S C(I)=100
01.05 S I=I+1;I (I-10)1.03,1.03,1.08
01.08 S A(0)=5
01.10 S A(1)=9;S A(2)=4;S A(3)=4
01.12 S A(4)=7;S A(5)=4;S A(7)=1
01.14 S A(7)=2;S A(8)=6;S A(9)=7
01.15 S B(5)=10;S B(7)=3;S A(10)=8
01.16 S B(6)=0;S B(8)=7;S C(8)=9
02.01 S I=0
02.02 S Z1=-1;S Z2=-1;S Z3=-1
02.03 S ZA=0;S ZB=0
02.10 S I=I+1
02.12 A T(I);A X(I)
02.14 I (I-30)2.2,2.15,2.15
02.15 A P1;A P2
02.16 I (P2-9)2.15,2.17,2.15
02.17 T "100",!,"100",!
02.18 G 1.01
02.20 I (X(I)-9)2.1,2.3,2.1
02.30 S IX=I;S I=0
02.40 G 6.3
03.01 S D(1)=A(X(I));S D(2)=B(X(I))
03.02 S D(3)=C(X(I))
03.05 S TS=T(I)
03.10 S J=I+1
04.10 I (D(1)-X(J))4.2,4.9,4.2
04.20 I (D(2)-X(J))4.24,4.95,4.24
04.24 I (D(3)-9)4.3,4.25,4.3
04.25 I (X(J)-8)4.3,4.26,4.3
04.26 S D(3)=100
04.30 I (D(3)-X(J))4.4,5.3,4.4
04.40 S K=1
04.50 I (D(K)-100)6.01,4.6,4.6
04.60 S K=K+1
04.70 I (K-3)4.5,4.5,6.3
04.90 S P=0
04.92 G 5.01
04.95 S P=1
05.01 I (X(I)-8)5.02,6.7,5.02
05.02 I (P)5.03,5.03,5.5
05.03 I (D(1)-8)5.06,5.04,5.06
05.04 I (X(I)-5)5.08,5.05,5.05
05.05 S ZA=1
05.06 I (P)5.09,5.09,7.6
05.08 S ZB=1
05.09 T %2.,X(I),!,D(1),!;D 8.1
05.10 S D(1)=100;S D(2)=100;S D(3)=100
05.11 G 4.4
05.30 I (Z3)5.32,5.32,5.34
05.32 T %2.,X(I),!,D(3),!;D 8.1
05.33 G 6.51
05.34 S D(3)=100;S Z3=1
05.35 S D(3)=100
05.38 G 4.4
05.50 I (D(2)-8)5.6,5.04,5.6
05.60 D 7.6
05.70 G 5.1
06.01 S J=J+1
06.05 I (J-IX)4.1,4.1,6.3
06.30 S I=I+1
06.35 I (I-IX)3.01,3.01,6.5
06.50 G 2.01
06.51 S N2=T(J);S CT=N2-N1
06.52 T %4.,CT,!
06.54 S N1=N2
06.56 G 5.34
06.70 I (P)7.01,7.01,7.5
07.01 I (Z1)7.1,7.05,7.3
07.05 I (ZA)7.3,7.3,7.1
07.10 T %2.,X(I),!,D(1),!;D 8.1
07.15 S D(2)=100;S D(3)=100;S Z1=Z1+1;S ZA=0
07.30 S D(1)-100
07.31 G 4.4
07.50 I (Z2)7.5,7.55,7.8
07.55 I (ZB)7.6,7.8,7.6
07.60 T %2.,X(I),!,D(2),!;D 8.1
07.62 S D(3)=100;S Z2=Z2+1;S ZB=0
```

```
C FOCAL V'A
02.05 DATA IN TEST
02.10 S RT=0;S GT=0;S MT=0;S PT=0;S AT=0;S MT=0;S MP=0
02.30 S ZB=0;S ZA=0;S RP=0;S GP=0;S MP=0;S PP=0;S AP=0
02.35 S TT=0;S TP=0
02.50 A A,B,C
02.52 I (C)2.5,2.5,2.54
02.54 I (A-100)2.56,2.6,2.56
02.56 I (B-100)2.7,2.6,2.7
02.60 S A=C
02.63 A B,C
02.70 I (B-3)5.1,9.1,2.9
02.90 I (B-6)6.1,7.1,3.1
03.10 I (A-5)8.1,8.1,3.3
03.30 I (B-8)7.1,8.7,10.1
05.10 S GP=GP+1
05.20 S GT=GT+C
05.40 G 2.5
06.10 S MP=MP+1
06.20 S MT=MT+C
06.40 G 2.5
07.10 S RP=RP+1
07.20 S RT=RT+C
07.40 G 2.5
08.10 S PP=PP+1
08.20 S PT=PT+C
08.40 G 2.5
08.70 S AP=AP+1
08.80 S AT=AT+C
08.94 G 2.5
09.10 S ZB=ZB+1
09.20 I (ZB-1)5.1,5.1,2.5
10.10 S MP=MP+1
10.20 S MT=MT+C
10.22 A CT
10.40 G 11.1
11.10 S TT=RT+GT+MT+PT+AT
11.20 S TP=RP+GP+MP+PP+AP
11.30 I (RP)11.4,12.1,11.4
11.40 S XR=(RP/TP);S YR=(RT/TT)
11.50 I (GP)11.6,12.3,11.6
11.60 S XG=(GP/TP);S YG=(GT/TT)
11.70 I (MP)11.8,12.5,11.8
11.80 S XM=(MP/TP);S YM=(MT/TT)
11.90 I (PP)11.92,12.7,11.92
11.92 S XP=(PP/TP);S YP=(PT/TT)
11.94 I (AP)11.96,12.9,11.96
11.96 S XA=(AP/TP);S YA=(AT/TT)
11.98 G 13.1
12.10 T "NO REACH MOTIONS ",!
12.20 G 2.1
12.30 T "NO GRASP MOTIONS",!
12.40 G 2.1
12.50 T "NO MOVE MOTIONS",!
12.60 G 2.1
12.70 T "NO POSITION MOTIONS ",!
12.80 G 2.1
12.90 T "NO APPLY PRESSURE ",!
12.92 S ZA=1
12.94 G 13.1
13.10 S UM=1.443*(XR*FLOG(XR)+XG*FLOG(XG)+XM*FLOG(XM)+XP*FLOG(XP))
13.20 I (ZA-1)13.3,13.4,13.4
13.30 S UM=UM+(XA*1.443*FLOG(XA))
13.40 S UT=1.443*(YR*FLOG(YR)+YG*FLOG(YG)+YM*FLOG(YM)+YP*FLOG(YP))
13.60 I (ZA-1)13.7,13.75,13.75
13.70 S UT=UT+YA*FLOG(YA)*1.443
13.75 T "E",%4.00,TP,!
13.77 T "CT",CT,!
13.80 T "S U ",%5.04,UM,!
13.90 T "T U ",%5.04,UT,!,!
13.92 G 2.1

*OX\
```

```
P
DBDI=6500
CLAB=6133
SPF=6040
DBEI=6501
CAF=6007
        /DATA LOGGER PROGRAME TO TIME EVENTS ENTERING
        /VIA 12 CHANNEL I/O BUS, STORES TIME AND CHANNEL NUMBER
        /IN LOCATIONS 600 ONWARDS,PRINTS END WHEN
        /FULL. S.A. 502 WILL PRINT TIME AND CHANNEL ON HSP
                             PUNCH
*100
END,    0
        ISZ TALLY
        JMP I END
        HLT
*110
STORE,  0
K577,   577
*120
INIT,   0
        DCA SAVE
        TAD CO
        DCA CONST
        TAD MC
        DCA MCONST
        JMP I INIT
*130
PUNCH,  0000
        DCA FACIT
        CMA
        PUCI
        PUCO
        PUDI
        CLA
        TAD FACIT.
        TAD BITONE
        PUSO
        PURI
        SMA
        JMP.-2
        CLA CMA
        PUCO
        CLA
        JMP I PUNCH
FACIT,  0000
BITONE, 2000
*230
SERV,   CLSK
        SKP
        JMP CLOCK
        CLA
        TAD HIGH
        DCA I 10
        CLCA
        DCA I 10
        DBRI
        DBCI
        DBDI
        DCA I 10
        ISZ STORE
        ISZ MAX
        ISZ MAX
        ISZ MAX
        SKP
        JMP FULL
        DBEI
        ION
        JMP I 0
CLOCK,  CLSA
        SPA CLA
        ISZ HIGH
        CLA
        TAD MOCTAL
        CLAB
        CLA
        ION
        JMP I 0
```

```
FULL,   TLS
        TAD E
        JMS TYPE
        TAD N
        JMS TYPE
        TAD D
        JMS TYPE
        HLT
*200
        CAF
        CLA CLL
        TAD MOCTAL
        CLAB
        CLA
        DCA NUMB
        DCA TIMEA
        DCA HIGH
        TAD K602
        DCA MAX
        TAD K577
        DCA 10
        DCA STORE
        TAD ENABLE
        CLOE
        CLA CMA
        DBCI
        DBEI
        ION
        NOP
        JMP.-1
E,      305
N,      316
D,      304
*0
        0000
        JMP I 2
        SERV
*20
CRLF,   0
        CLA
        TAD CR
        JMS PUNCH
        CLA
        TAD LF
        JMS PUNCH
        CLA
        JMP I CRLF
CR,     0215
LF,     0212
TYPE,   0000
        TSF
        JMP.-1
        TLS
        CLA
        JMP I TYPE
*400
DECPRT, 0000
        JMS INIT
        JMS CALC
        ISZ MCONST
        ISZ CONST
        JMS CALC
        ISZ MCONST
        ISZ CONST
        JMS CALC
        TAD SAVE
        JMS LOOK
HERE,   TAD K260
        JMS PUNCH
        JMP I DECPRT
CALC,   0000
        DCA ANS
        TAD SAVE
        TAD I MCONST
        SPA
```

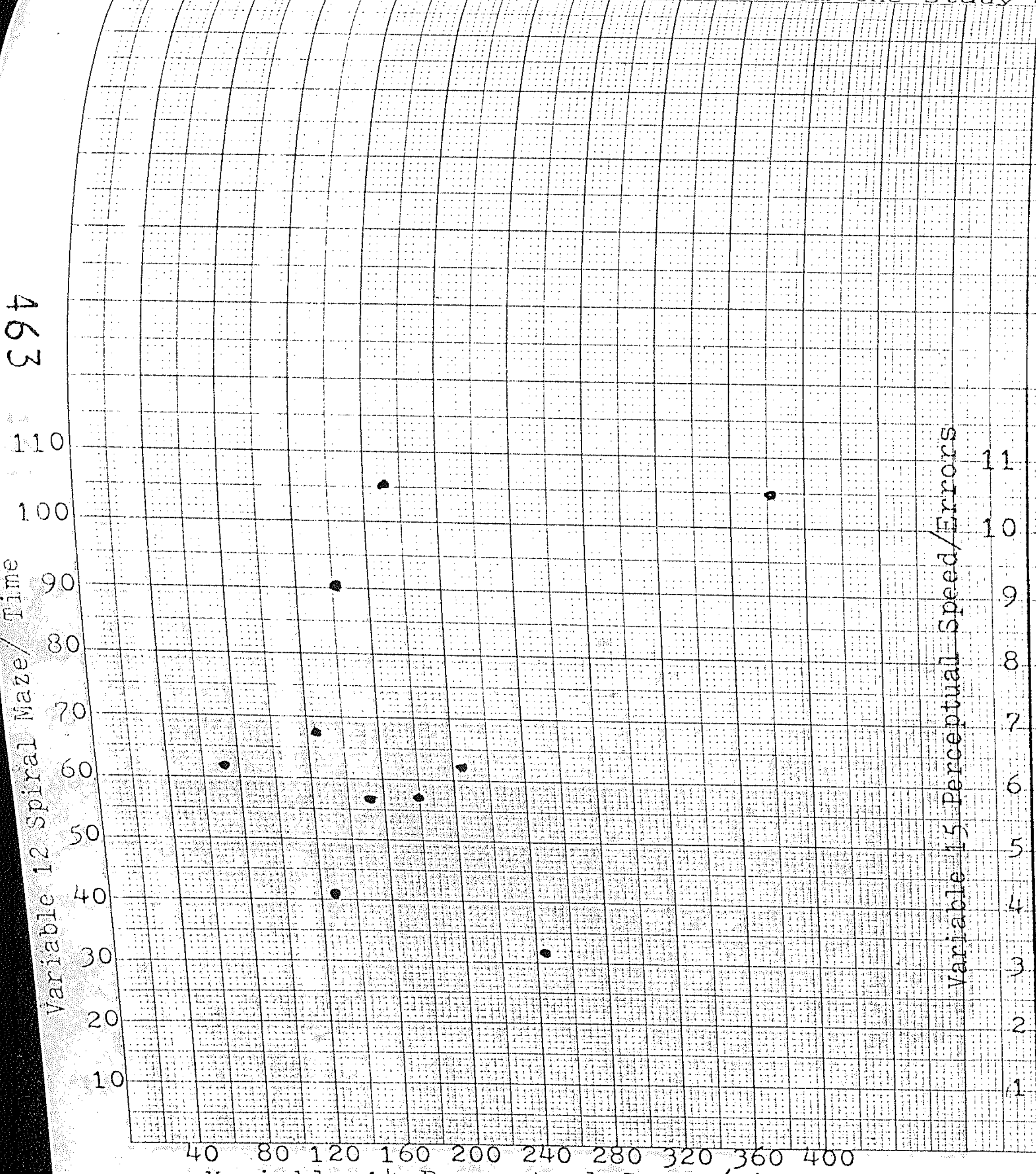
```
         CLA
         TAD ANS
         TAD K260
         JMS PUNCH
         JMP I CALC
SECOND,  CLA
         ISZ WHAT
         TAD WHAT
         TAD A
         SZA
         SKP
         JMP I CALC
         ISZ NON
         JMP I CZEK
LOOK,    0
         SZA
         JMP FINI
         TAD NON
         SZA
         JMP FINI
         TAD NUM
         TAD C
         SZA
         SKP
         JMP G
         CLA
         DCA WHAT
         DCA NON
         JMP I DECPRT
THIRD,   CLA
         ISZ WHAT
         TAD WHAT
         TAD B
         SZA
         JMP FIRST
G,       TAD SAVE
         JMP HERE
B,       -4
C,       -3
*60
CO,      EIGHT
MC,      MOCTAL
CONST,   EIGHT
MCONST,  MOCTAL
EIGHT,   1750
         144
         12
MOCTAL,  -1750
         -144
         -12
MINUS,   25
PLUS,    253
NUMB,    0
TALLY,   0
MAX,     602
K602,    602
*41
K260,    260
SAVE,    0
ANS,     0000
ENABLE,  4210
TIMEA,   000
INPUT,   0000
HIGH,    0000
SPACE,   240
NUM,     0
NON,     0
A,       -1
WHAT,    0
CLSK=6131
CLOE=6132
CLCA=6137
CLSA=6135
DBSK=6502
DBCI=6503
DBRI=6504
PUCI=6513
PUCO=6515
PUDI=6510
PUSO=6516
```

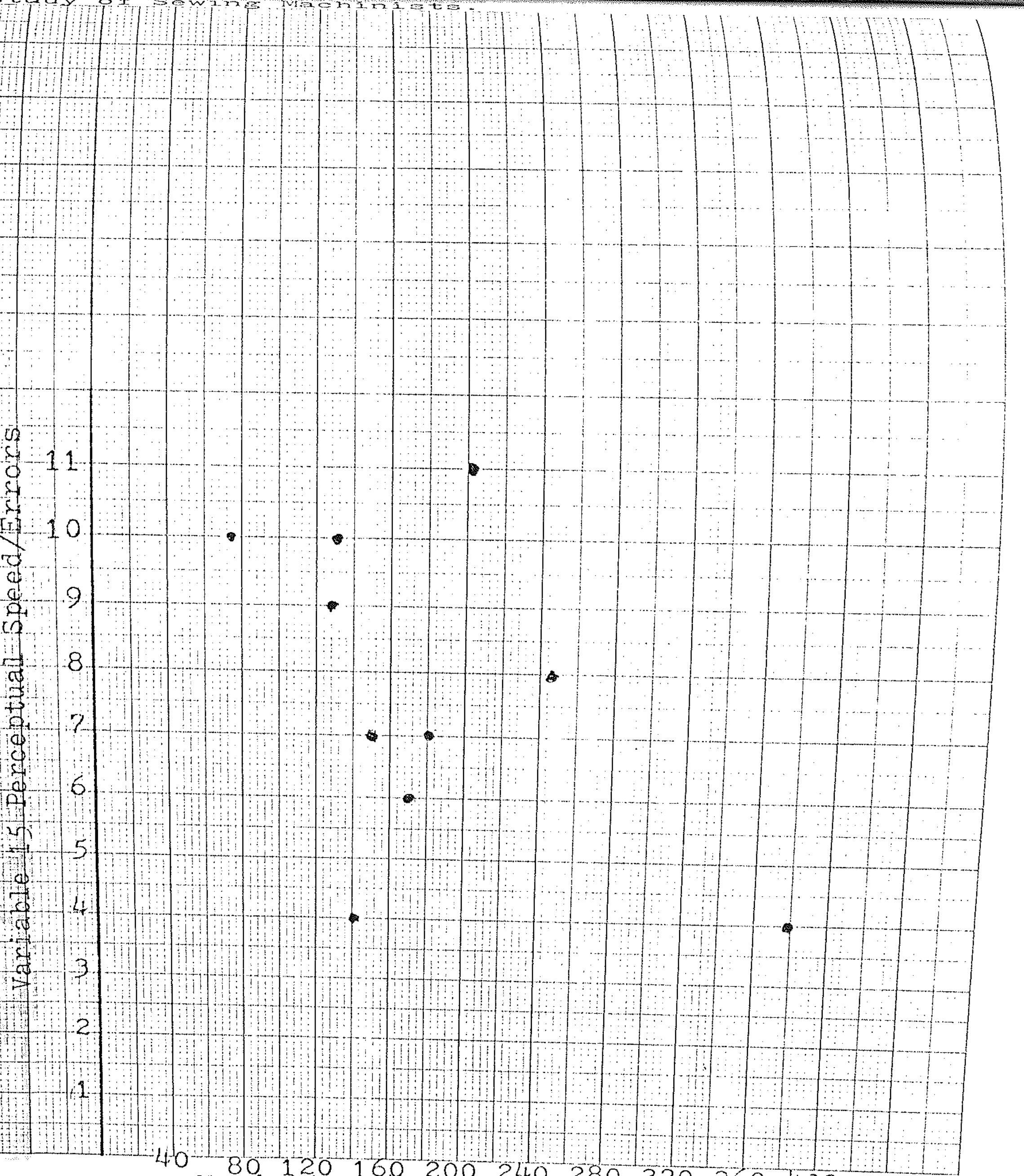
```
*502
        SPF
        CLA
        TAD STORE
        CIA
        DCA TALLY
        TAD K577
        DCA 10
RSTART, TAD I 10
        ISZ NUM
        JMS DECPRT
        TAD I 10
        ISZ NUM
        TAD EIGHT
        JMS DECPRT
        JMS CRLF
        TAD I 10
        ISZ NUM
        JMS CHECK
        JMS CRLF
        JMS END
        JMP RSTART
CHECK,  0
        SPA
        JMP LESS
        ISZ NUMB
        RAL
        JMP.-4
LESS,   CLA
        TAD NUMB
        JMS DECPRT
        DCA NUMB
        DCA NUM
        DCA WHAT
        JMP I CHECK
CZEK,   0
        CLA
        TAD NUM
        TAD A
        SZA
        SKP
        JMP FIRST
        TAD A
        SZA
        SKP
        JMP SECOND
        JMP THIRD
FIRST,  CLA
        TAD ANS
        SZA
        JMP BINARY
        TAD NON
        SZA
        JMP I CZEK
        JMP I CALC
BINARY, CLA
        ISZ NON
        JMP I CZEK
FINI,   CLA
        DCA WHAT
        DCA NON
        JMP G

$
$

F
```

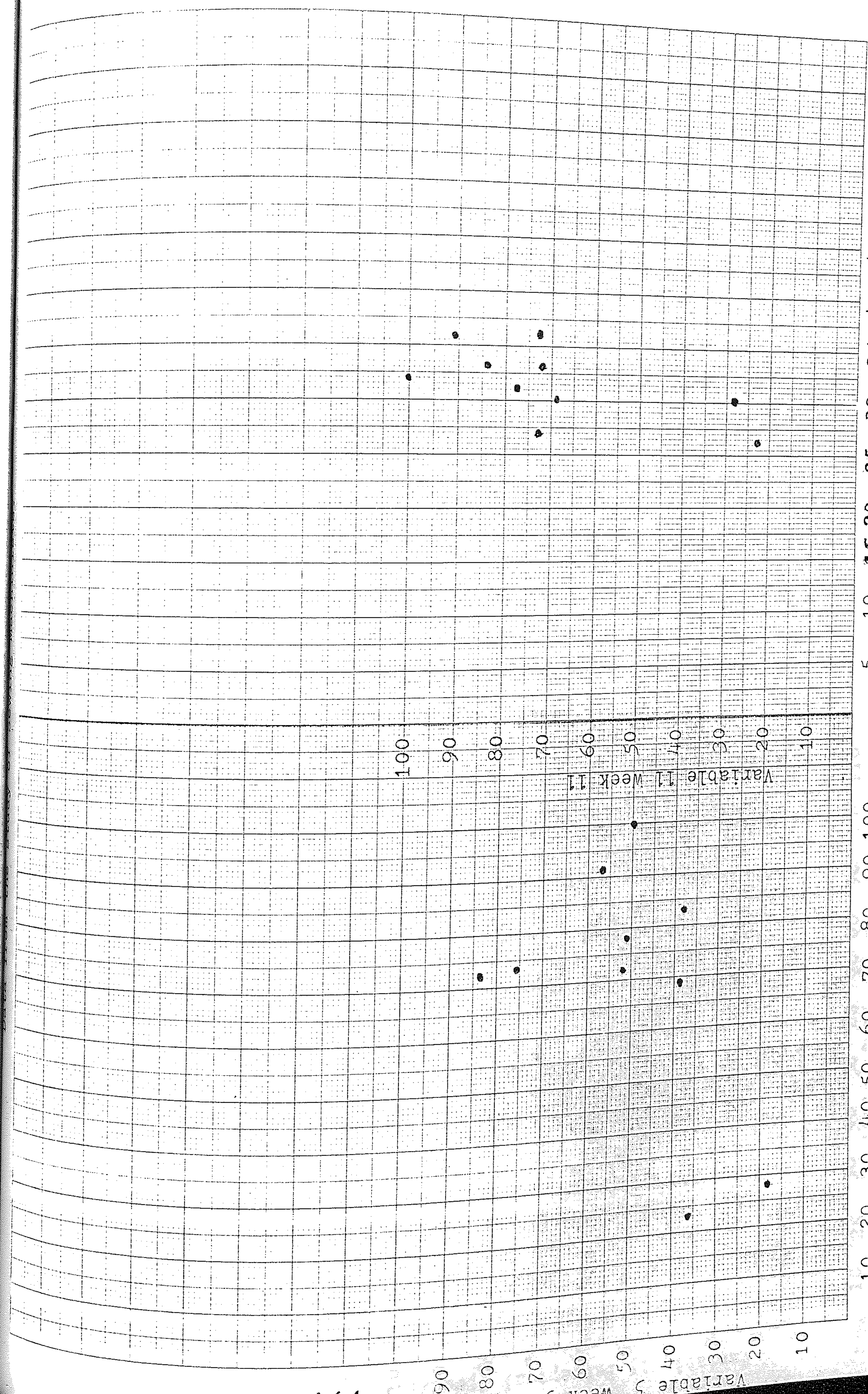
APPENDIX 6

SCATTERGRAM EXAMPLES FOR THE TESTS USED IN THE THREE NEW STUDIES

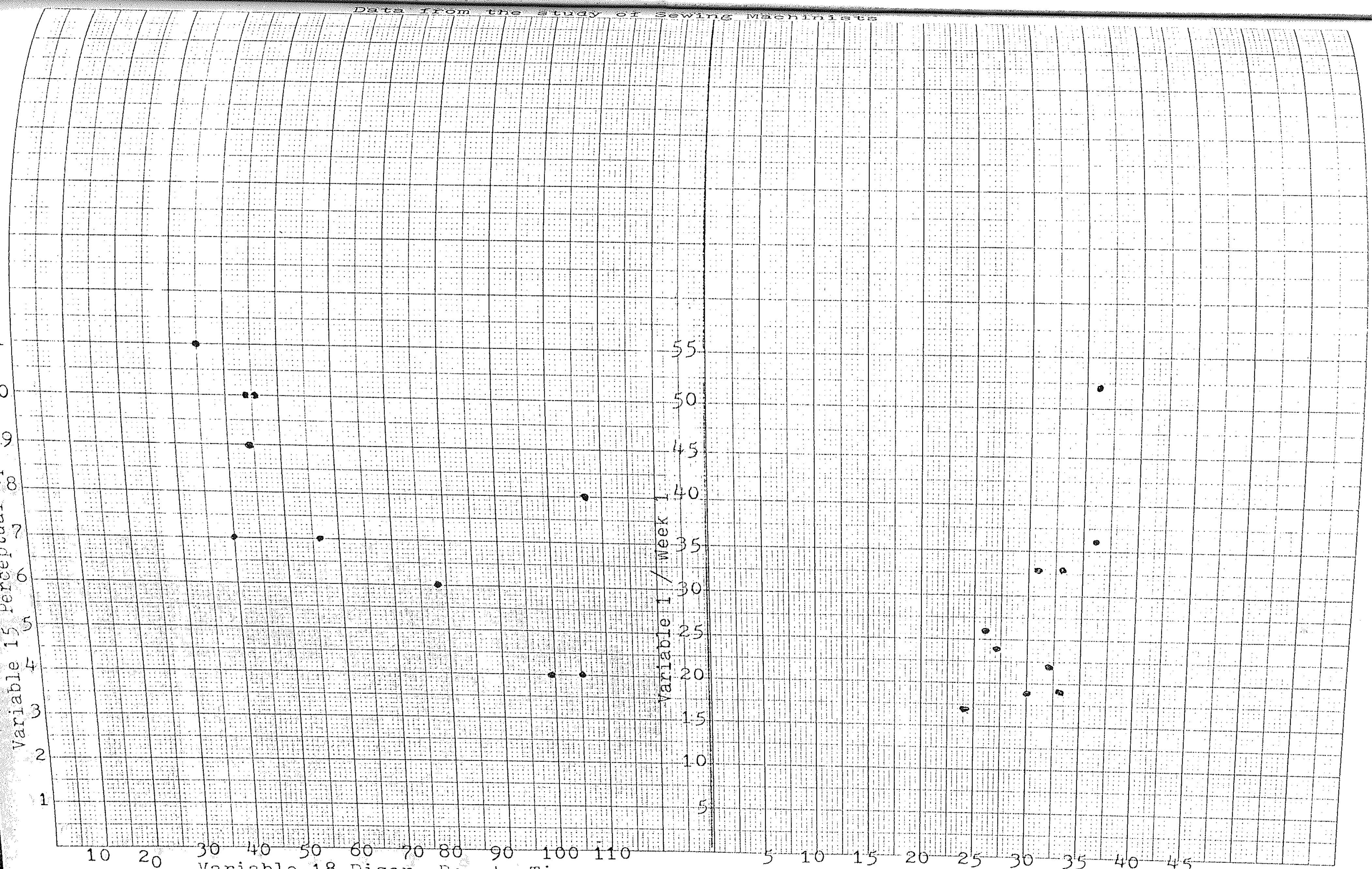
Data from the study of Sewing Machinists.



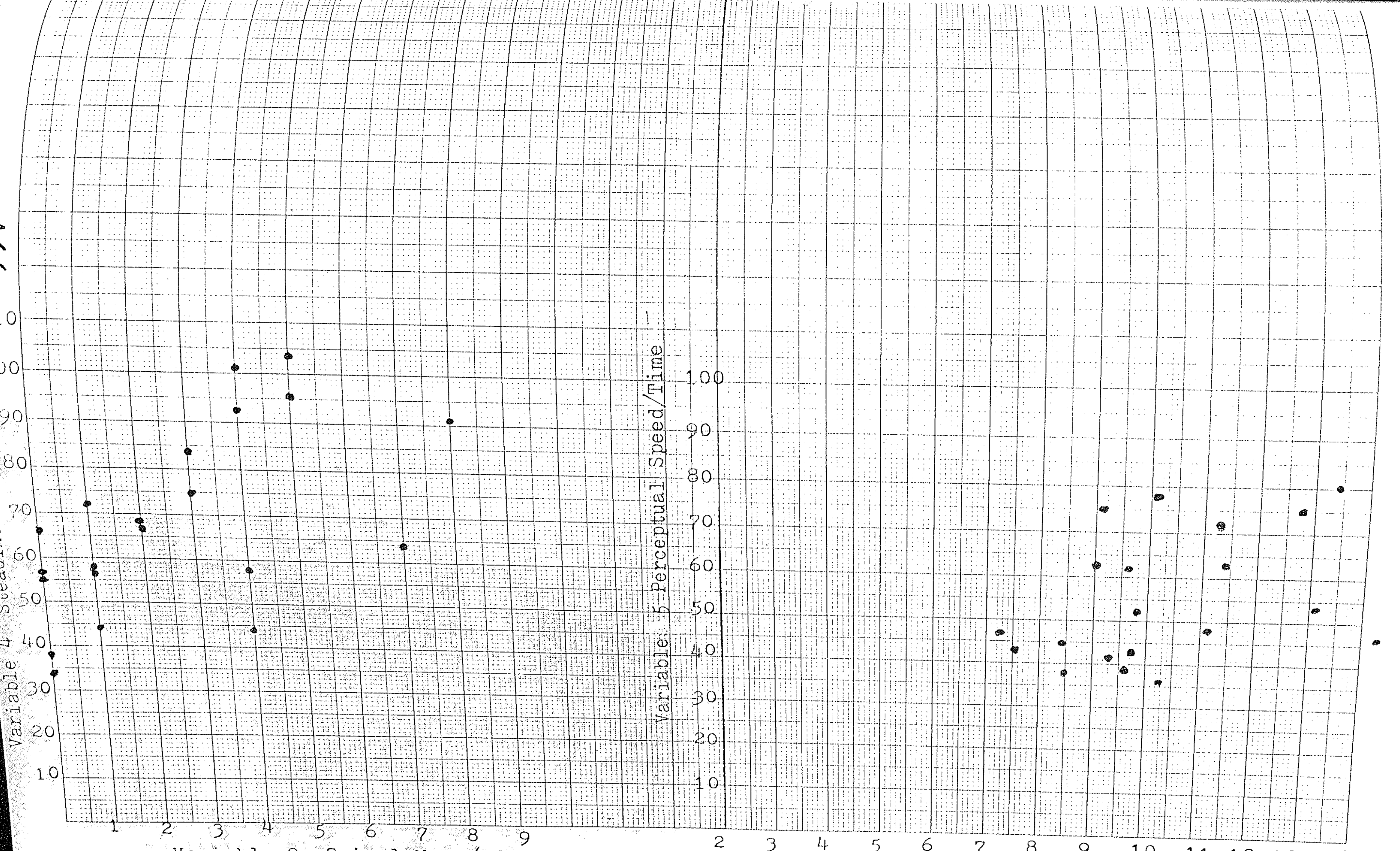



Variable 11 Week 11
100
90
80
70
60
50
40
30
20
10
Variable 5 Week 5
90
80
70
60
50
40
30
20
10

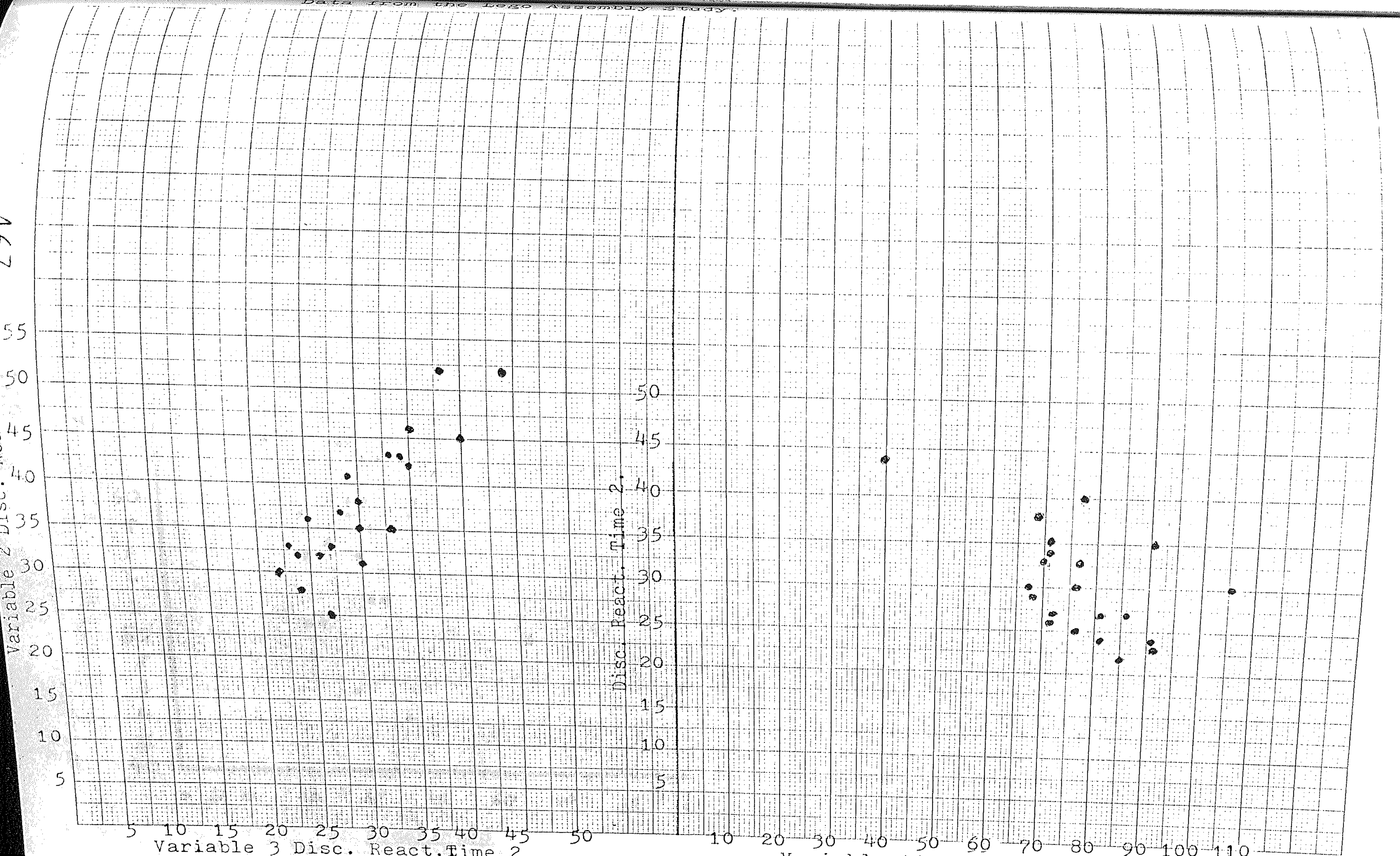
Data from the Study of Sewing Machinists



Data from the Bogo Assembly Study.

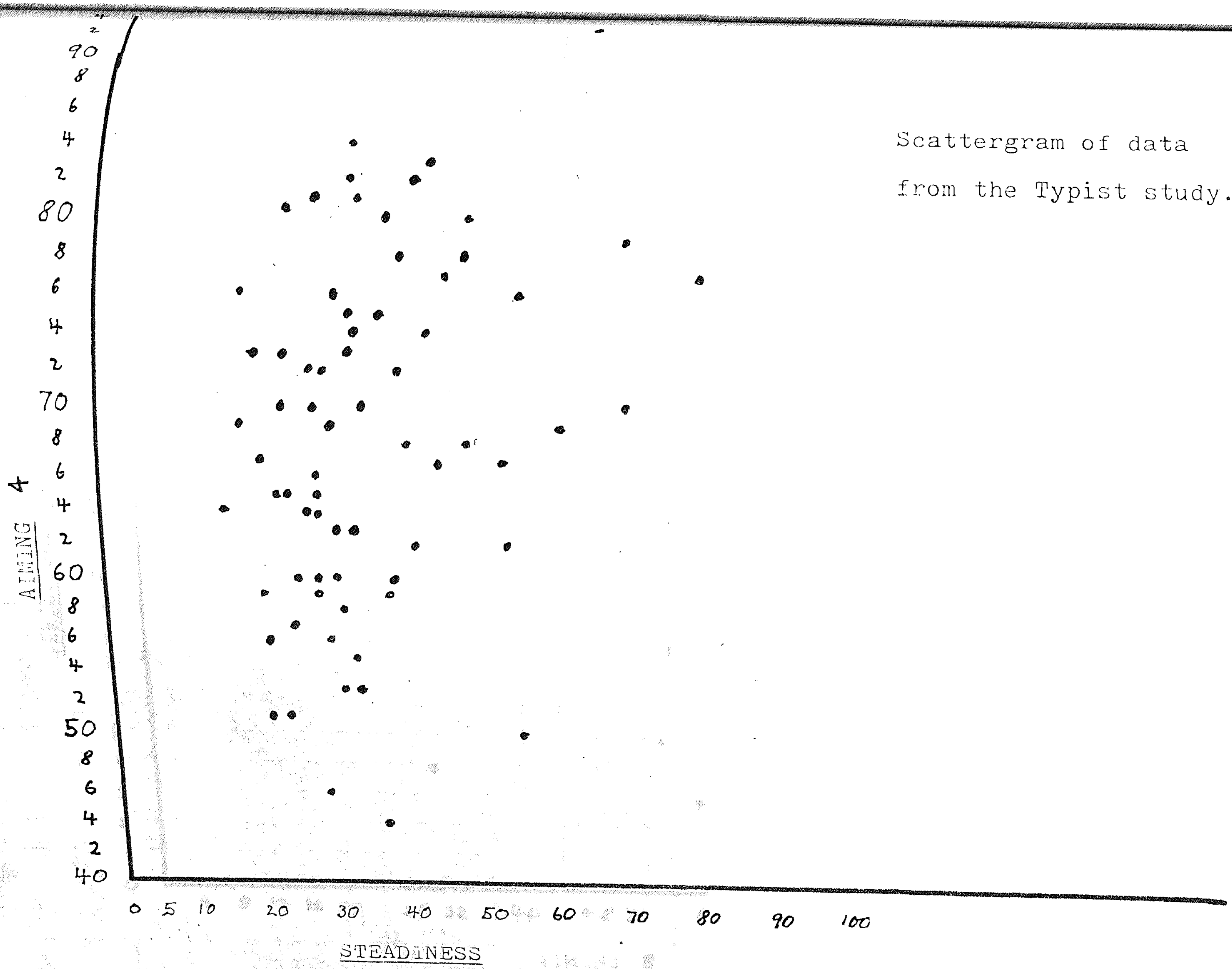


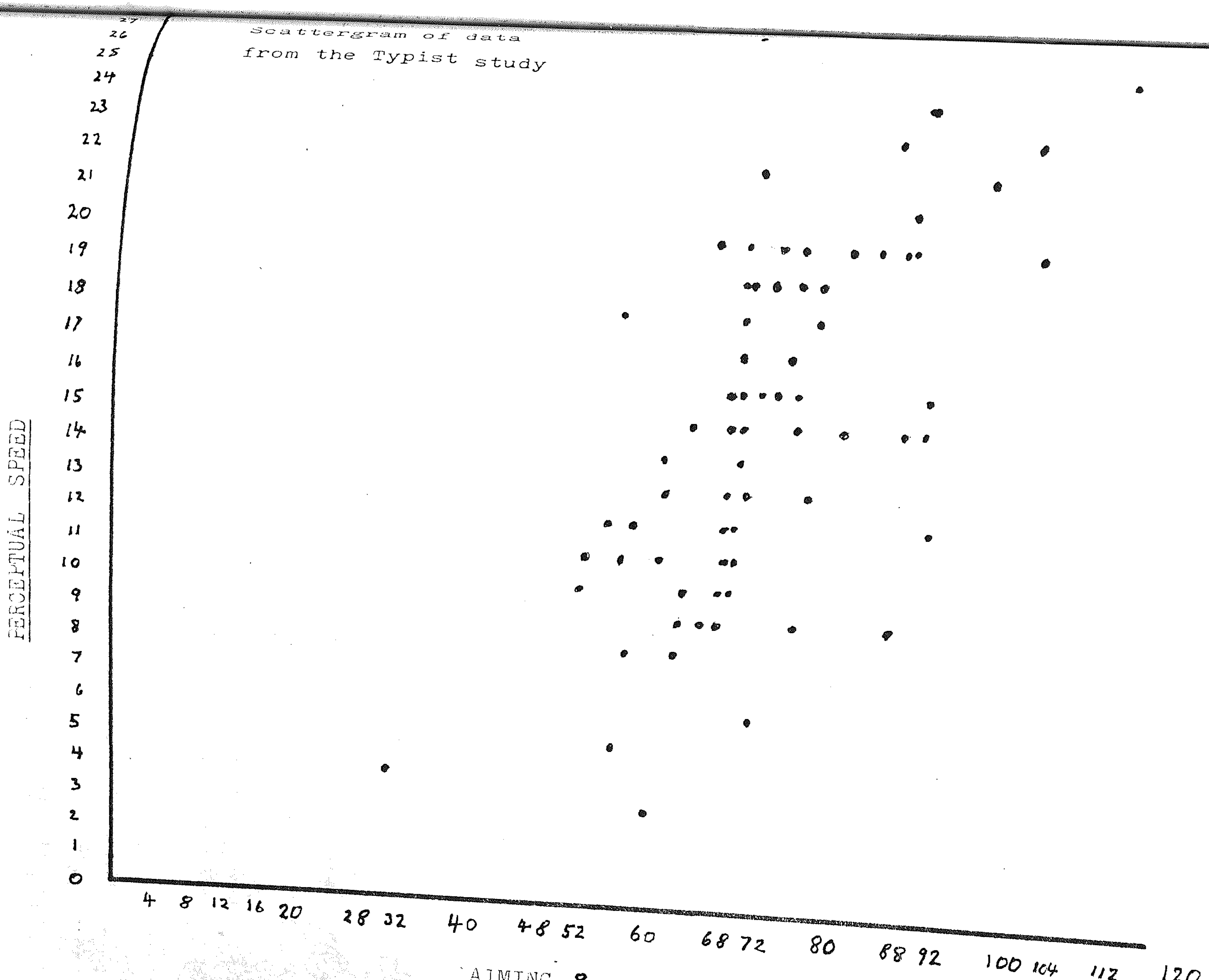
Data from the Lego Assembly Study.



Scattergram of data

from the Typist study.





Scattergram of data
from the Typist study
PERCEPTUAL SPEED
AIMING

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