PART I

VISUAL AND TELEVISUAL DETECTION STUDIES

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PART I

THE EFFECT OF NAVIGATIONAL UNCERTAINTY AND TARGET DIFFICULTY ON DETECTION PERFORMANCE

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SUMMARY

The experiment described in this report was intended to investigate the effect of navigational uncertainty, range to target and target difficulty on performance at an air-to-ground target detection task, simulated statically by means of oblique aerial photographs. The performance measures used were detection probability, search time, confidence level of decision, and time taken for map-briefing. The experiment was based on a 7 x 7 (targets x conditions) Latin Square design. Seven skilled subjects, pilots and navigators, and 21 unskilled subjects, students of comparable intelligence and personality, took part.

The results showed that none of the performance measures made were affected by navigational uncertainty. For the unskilled subjects detection probability and search time were significantly affected by target range, increase in range from 1 to 3 miles resulting in a linear decrease in detection probability and a linear increase in search time.

There were significant differences between targets for each measure of performance. When the targets were ranked according to each of the performance measures significant correlations were found between the rankings. Targets for which the detection probability was high tended to be associated with relatively short search times and high confidence levels. Conversely, targets for which the detection probability was low tended to be associated with relatively long search times and low confidence levels.

The performance of skilled subjects was very similar to that of unskilled subjects, but the former took significantly less time in map-briefing and in searching for the targets.

In the discussion sections the general suitability of the experimental technique is assessed and the results considered in relation to further work at present in progress.

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ILLUSTRATIONS

1. INTRODUCTION

In spite of the development of sophisticated navigational aids visual means of obtaining information about the position of an aircraft or missile in relation to the terrain remain of vital importance. The recognition of terrain features is essential both for updating navigational systems and in the acquisition of military targets. Strategic considerations frequently necessitate flight operations at very low altitudes and high speeds. This requirement has changed the nature of the visual task from what was, in effect, a quasi-static one to one with complex dynamic characteristics which impose severe demands on the observer. The situation is further complicated if the target acquisition task is carried out by means of a television viewing system rather than by direct view of the terrain.

Under high-speed, low-level conditions target acquisition performance depends on a wide range of factors relating to the aircraft speed and altitude and the navigational uncertainty, to the type of target and terrain, and to the quality of the briefing information available. If a television viewing system is used other factors such as field of view, resolution, display size and viewing distance must also be taken into consideration.

Research has been carried out into various aspects of target acquisition performance for many years but the relationship between laboratory findings and operational criteria has never been well defined. One reason for this is that the degree of control that can be exerted over field trials carried out under operational conditions is relatively low, whereas in laboratory experiments which are amenable to a high degree of control realism is proportionately lacking. This problem can be illustrated by means of a three-dimensional diagram in the form of a cube, the three axes of which relate respectively to visual complexity, dynamic complexity and experimental control (Greening, 1964). Within this cube various types of target detection experiment may be represented according to the extent to which the true visual and dynamic complexity of the operational situation is reproduced, and the degree of experimental control exerted.

The eventual aim of such research is to derive data approximating as closely as possible to a situation in which all the relevant parameters are closely controlled without losing the visual and dynamic complexity of the airborne environment. Data of this type is vital in the formulation of a model which would enable performance to be predicted for any particular combination of parameters. However, owing to the number and complexity of the effects involved, and the likelihood of interactions between them, the formulation of such a model is an extremely difficult task and one that is as yet far from completion. There are three basic methods by which the necessary data may be obtained:

(a) Analytical evaluation of laboratory experiments

Laboratory experiments carried out under highly-controlled conditions tend to lead to over-optimistic estimates of detection performance since such experiments are in general not directly applicable to airborne situations. Thus, although the effect of both static factors such as target size, contrast and illumination, and dynamic factors such as angular velocity, can be analytically evaluated, the visual and dynamic complexity of the real world is not adequately represented. Work of this type, whether static or dynamic, (see, for instance, Blackwell, 1946, Boynton and Bush, 1957, Miller, 1958 and Erickson, 1963), although useful in determining upper limits of performance, is thus of little help in predicting typical behaviour in the airborne situation.

(b) Flight trials

Flight trials provide the most realistic method of obtaining target acquisition data since all the visual and dynamic characteristics of the operational situation are present. However, the difficulty of controlling and measuring the many parameters involved and in carrying out enough trials for reliable statistical analysis is considerable. The main problems are (i) the difficulty of flying an aircraft repeatedly over exactly the same track; (ii) seasonal and diurnal changes in the character of foliage and other natural features; (iii) changes in illumination and atmospheric transmission; and (iv) the difficulty of introducing systematic changes of size, colour, location and orientation with targets such as bridges and buildings.

In spite of these difficulties partially controlled flight test programmes have been carried out and valuable data on acquisition probabilities and ranges has been obtained. However, the lack of experimental control inherent in such trials makes it difficult to relate the flight data to data from laboratory studies.

(c) Simulation studies

Simulation studies provide a means of establishing a link between theoretical laboratory data and flight trials. The parameters of interest can be carefully controlled although realism, in terms of the visual and dynamic characteristics of the operational situation, tends to be correspondingly reduced. The method of simulation may be very simple and relate only to particular aspects of the task, or extremely complex methods of simulation with provision for systematically varying many visual and dynamic parameters, may be used. One particular advantage of simulation techniques is that interactions between parameters can be conveniently investigated. However, it has been found that the data obtained from high-fidelity terrain simulators, which can almost exactly reproduce the visual characteristics of the real world, may differ from those found in flight trials by a factor of two (Blackwell et al, 1959).

Each of these approaches, particularly high-fidelity simulation studies, are represented in recent work carried out in the United States. Work reported includes an investigation of the effects of altitude, target off-set, background type, contrast, field of view and other variables using a terrain simulator, (Wyman et al, 1965); dynamic studies of geographic orientation in aircraft pilots and the effectiveness of various types of maps and charts, (Osterhoff and McGrath, 1963-66); the effect of T V. camera field of view and target size on detection performance, (Rusis and Snyder, 1965) and simulation studies using aerial film to investigate the effect of various conditions of altitude and speed on acquisition probability and acquisition range for a series of ten targets, (Gilmour, 1964).

This last investigation is of particular relevance to the work described in this report since it involved a comparison between the performance of skilled and unskilled subjects. It was found that on first exposure to the series of targets the skilled group showed a higher probability of acquiring the assigned targets, but there was no significant difference between the skilled and unskilled groups in the range at which acquisition occurred. On second exposure to the same series of targets the skilled group showed significant improvement in both acquisition probability and acquisition range. The effect of second exposure on the unskilled group was not tested in this experiment but in some later work unskilled subjects also showed significantly improved performance on second exposure, (Gilmour and Iuliano, 1964).

The use of aerial photographs as a static simulation technique has been relatively little reported. Such experiments can be carried out more simply than high-fidelity simulations and the visual complexity of the operational situation is retained although dynamic realism is completely lost. In a study of aerial terrain orientation by means of television display the effect of field of view size was investigated by a static simulation method, (Leininger, 1963). The simulation was that of a vertical, 90-degree terminal phase of an air-to-surface missile with no range closure during the orientation period. The data, obtained from twelve skilled subjects, indicated that the size of the field of view, which ranged from 3750 x 5000 feet to 40,000 x 30,000 feet, affected the mean time to orient the centre of the displayed area to a pre-established target area, but no clear indication of an optimum field of view was found.

Research at present being carried out in this country into target acquisition problems includes fundamental investigations into detection thresholds, laboratory simulation studies on the effects of photographic degradation on detection performance, and flight trials. Within this general framework there is a further need to attempt to relate theoretical data to operational data and to investigate the effect of various parameters e.g. resolution, field of view, display size, which cannot be conveniently studied in the airborne situation. This report describes some preliminary studies which were intended to indicate the relative importance of various parameters so that more detailed investigations could be carried out at a later stage.

The need for visual detection of targets or fix-points arises directly from the fact that even the most advanced navigational aids are not completely accurate, and therefore determination of the exact position of the aircraft must be done by visual means. The degree of search involved in the target acquisition task depends on the uncertainty in the aircraft position, both in range and off-set, as it approaches the vicinity of the target. The greater this uncertainty the larger the area of terrain that has to be searched to locate the target and thus the greater the difficulty of the task. Navigational uncertainty was therefore a primary factor to be studied in this preliminary investigation. Closely related to this factor was the range at which detection was possible, which in turn depends on target conspicuity. Before an experiment to study the effect of these factors could be finally planned in detail a number of decisions had to be made relating to the nature of the experimental task and the method of simulation. The remainder of this section is concerned with the various possibilities involved considered under separate headings.

1.1 The nature of the task to be simulated

In planning the initial experiments to be carried out in this programme the exact nature of the task to be simulated had first to be specified. Basically, the task of a navigator is to ensure that the aircraft is maintained on the correct course in spite of any inaccuracy in his navigational aids. There are two methods of approach to this task. The first method, which may be regarded as 'map to terrain' navigation, consists of navigating from fix-point to fix-point by dead reckoning and searching the terrain only when the fix-point is expected to appear. Acquisition of this fix-point determines the exact position of the aircraft which then proceeds in a similar manner to a succession of fix-points before reaching its destination.

The second method of navigation is 'terrain to map' navigation which requires the navigator to keep continuous visual contact with the terrain whilst referring back to the map to check his position. Which of these two methods is adopted depends upon several factors, including the speed of the aircraft. At high speeds the first method must be used since the navigator has little time to look for anything but the pre-determined fix-points and most certainly has not time to search his map for other indications of his position. On the other hand, at low speeds a navigator may prefer to use either the second method, maintaining continuous visual contact with the terrain and referring to his map only to identify the prominent features he observes, or a combination of the two. It is important to note that if an aircraft becomes lost the 'terrain to map' method of navigation must be adopted whatever the aircraft speed since the navigator has no exact means of predetermining his fix points.

These two methods of navigation lend themselves to two very different types of simulation experiment in which:

(a) The subject is told what his fix point is and allowed to study the map. He is then shown a display and asked to locate the fix-point.

(b) The subject is shown a display and then asked to match it with his position on a map. This is a more difficult task since large areas of terrain may have no significant features, and in the airborne situation the navigator would not attempt to orientate himself until some prominent feature occurred.

Therefore it was important to decide which type of navigation was to be simulated before the experimental technique was considered.

As indicated earlier, in the airborne situation the complexity of the navigator's task is related to the uncertainty inherent in his navigational aids since this will determine the area of terrain that has to be searched when the aircraft approaches the vicinity of the target. If there was no navigational uncertainty then visual means of target detection would not be required. Navigational uncertainty was therefore a factor which could not be neglected in this investigation.

1.2 Method of simulation

Although a dynamic visual display is inherent in airborne navigation many parameters which affect target detection performance can be studied more conveniently and more rapidly in experiments using static displays. It was decided therefore that as a prelude to the use of dynamic material the present experiment would be carried out with static material. The possibility of displaying synthetic material rather than views of real targets and terrain was considered. The main advantage of using synthetic material would have been that the exact nature of targets and the density of other features in the terrain e.g. rivers, woods, etc., could be closely controlled and manipulated, and thus the difficulty of the task systematically varied. However, this idea was rejected as being outside the scope of the present experiment for which actual aerial photographs of selected targets would be used. Three possible methods of presenting the static display were considered:

(a) Full size transparencies

(b) Slides

(c) Photographs

The use of full-size transparencies illuminated from the rear was rejected because of difficulties in processing transparencies of the size required (8" x 8"), under controlled conditions.

Although it seemed possible that 2" x 2" slides could be prepared under suitably controlled conditions and would provide adequate resolution for the requirements of this experiment difficulties arose when possible projection apparatus for these slides was investigated. Even if the best equipment available was used the non-uniformity of the illumination over the visual field was a serious problem. A higher level of illumination in the centre of the field would render invalid any target detection experiments since it is thought that the eye is automatically drawn towards an area of high illumination and thus the non-central area of the display would tend to be neglected. Even the use of a neutral density filter designed to counteract this non-uniformity would not completely overcome the problem since filter characteristics must be matched to the particular light or bulb being used. The only solution appeared to be the design and construction of a projector specifically to meet the requirements of the project. Although this was possible it would have been unnecessarily expensive and would also have delayed the start of the work. It was decided therefore that the present experiment would be carried out with photographs and more sophisticated projection equipment for slides developed at a later stage if required.

Since, to obtain the required number of still photographs, exposed and processed under controlled conditions, would take approximately six months, it was decided that, although work would be started to prepare a library of these controlled photographs, the present experiments would go ahead using less rigorously controlled material. This would obviously result in some loss of precision but nevertheless the information obtained would be of value, particularly in planning future experiments.

It was decided that these preliminary photographs would be taken at the specified ranges from the target, and at an altitude of 2,000 ft, using a camera lens giving a 50° field of view, inclined at approximately 10° to the horizontal. The size of the camera field of view was chosen so that different portions of the total field could be sampled, representing a smaller field of view. These smaller fields of view could be obtained either by masking the 50° photograph and displaying only the portion required, or by reprinting the portion magnified to the original size. It was intended that in these initial experiments a horizontal field of view of 30° would be presented. This would allow for either a central portion, or a portion off-set by up to 10°, to be displayed. To avoid the need for reprinting, which would introduce further variability into the material, it was decided to display this field of view by appropriate masking of the 50° photograph. This resulted in a display size of approximately 4½" x 3½" which was closely comparable to that proposed for the operational situation. It was further decided that in this experiment the viewing distance, which obviously had to be closely related to display size, would be selected so as to establish a base-line of performance. A value of 13" was chosen. This distance is greater than that of the near-point for young subjects, so that there was unlikely to be accommodation strain in tasks of short duration. In later experiments the viewing distance would be increased to a maximum of 30" thus reducing the size of the angle subtended by the display at eye from 21° x 15¾° to 9° x 7¾°.

Simulating an essentially dynamic situation by means of static photographs would necessarily introduce a highly unrealistic element into the experimental task. The possibility of displaying the photograph to the subject for a limited time (comparable with that during which the target would be visible in the airborne situation) was considered. This would undoubtedly introduce greater realism into the experimental task but it was felt that much information would be lost about longer detection times required for difficult targets and conditions. Therefore it was decided that no time limits should be introduced into the experiment at this stage but that the importance of rapid detection would be strongly emphasised to the subjects.

1.3 Briefing procedure.

Having decided how the photographic display was to be presented, it was then important to consider the type of briefing necessary. The subjects required a map of the target area and for this initial experiment the 1" = 1 mile Ordnance Survey map seemed the most suitable. Exactly what further information should be given to each subject was open to some discussion but it was eventually decided that he should be told the nominal range to his target, and the navigational uncertainty involved. It was further decided that some indication of the extent of this uncertainty should be presented on the map either (a) by outlining the area of terrain that might be seen in the visual display or (b) by outlining the limits of the possible position of the aircraft. Alternative (b) was chosen since this was the information that would in fact be available to the airborne navigator.

The procedure to be adopted in briefing the observer before the presentation of each of the target photographs was therefore finalised as follows. The subject would be given an appropriate map section on which the uncertainty in the aircraft position would be marked. Since the time required to locate a target position on the map given its grid reference was not relevant to this investigation, the actual target position would be pointed out to him. He would then be allowed to study the map for as long as he required and memorise features which might appear in the photographic display. Once he had finished briefing himself the observer would not be allowed to refer back to the map while looking at the display, since in the airborne situation there would be no time for this.

It seemed likely that since inexperienced subjects were to be used in this experiment some form of detailed training would be required to enable them to search a map area appropriate to the navigational and photographic parameters involved and to memorise suitable features within this area. Furthermore they would need to learn how to judge distance on the photographs. Various aids to help them to do this were considered e.g. superimposing a grid showing the level of points on the photograph 1 mile, 2 miles, 3 miles etc. distant from the aircraft. This idea was rejected since, owing to variation in the position of the horizon on the photographs, a separate grid would be needed for each. It was decided that suitable training and practice should enable subjects to carry out the task and that some exploratory experiments would be carried out to indicate the type of instruction required.

1.4 Subjects

Since relatively few pilots and navigators experienced in high-speed low-level flight would be available to take part in these experiments a high proportion of subjects used would be unskilled. This provided an opportunity to investigate performance differences, if any, between skilled and unskilled subjects. It was decided therefore that unskilled subjects would be tested initially and their results compared with those from experienced pilots and navigators. It was thought that students would be the most suitable people to act as unskilled subjects.

1.5 Collateral tests

Since both skilled and unskilled subjects were to be used it was important to know whether, if performance differences were found, these could be solely attributed to experience, or lack of it, or whether there were other significant differences e.g. in personality, intelligence, visual acuity, etc. between the two groups. It was therefore decided that all subjects should undergo certain preliminary tests which would provide the necessary background data for comparison purposes. Measures of the following factors were thought to be most suitable in view of the nature of the experimental task:

(a) Extraversion - intraversion

(b) Neuroticism

(c) Intelligence

(d) Short-term memory

(e) Visual acuity

A number of methods available for assessing these factors were considered, bearing in mind the need for tests which were reliable without being unduly time-consuming to administer. The following tests were chosen:

(a) and (b) Extraversion-intraversion, neuroticism

The Eysenck personality inventory which provides a numerical measure of these factors, consists of a series of 56 questions against which the subject records a 'yes' or 'no' answer. This test has been standardised on 2,000 normal people and norms are given in the manual for various population groups including students and army personnel,(Eysenck, 1964).

(c) Intelligence:

Since both student and aircrew subjects were likely to be well above average in intelligence the A.H.5. intelligence test, devised and standardised by A.W. Heim, was thought to be the most suitable. This test is intended to differentiate between subjects of high intelligence who would be closely bunched at the top end of an intelligence test intended for a cross-section of the population. The test was standardised on groups including university lecturers and research workers, students, R.A.F. cadets and engineering apprentices. Norms are given for these groups in the test manual. (Heim, undated).

(d) Short-term memory:

The digit-span test, a standard psychological test included in the Wechsler adult intelligence scale, was chosen to assess short-term memory.

(e) Visual acuity:

Standard tests e.g. Snellen charts and the Jaeger test type were available for testing visual acuity.

The possibility of recording eye movements while the subject was searching the photographic display was investigated. Apparatus available was only accurate to $\pm\ 1\frac{1}{2}^{\circ}$ and since the angular display size at a viewing distance of 13" was $21^{\circ} \times 15\frac{3}{4}^{\circ}$ it would have been possible using this apparatus to divide the display into only 35 areas. This was not thought to be sufficiently accurate since in these experiments search was likely to be confined to a limited area of the display. It was decided that eye movement studies would not be included in the present investigations but would be reconsidered at a later stage in the programme.

1.6 Experimental conditions

At this stage in the planning of these experiments the general method of approach had been settled and it was necessary to consider the number of levels at which the various navigational factors involved could be investigated. Initially it was intended that three levels of navigational uncertainty (± 1, ± 2, ± 3 miles) should be studied and four nominal ranges to the target (1, 2, 3, and 4, miles) giving rise to true distances from the target ranging from 0 - 7 miles and a total of more than 50 experimental conditions. However it was soon realised that this would involve many hundreds of subjects and could not be attempted at this stage. Even if the navigational uncertainty was reduced to two levels and nominal range to the target to three levels there would still be 20 conditions and this again was thought to be excessive.

The experiment was therefore drastically reduced to include only two levels of navigational uncertainty (± 1 and ± 2 miles) and one nominal range of 2 miles. This gave rise to 4 true ranges to the target (1, 2, 3 and 4 miles, 0 mile case excluded) and a total of 7 experimental conditions. This plan required only 4 photographs of each target and, provided that off-set errors were not studied in the same experiment, a statistically designed experiment using a realistic number of subjects was possible, (see section on Experimental Design).

1.7 Exploratory studies

Before the final details of the experiment were decided two preparatory studies were carried out. These involved (a) unskilled subjects and (b) skilled subjects.

(a) Five unskilled subjects, students and technicians, were tested on four target photographs, one at each of the four ranges. The task was explained to them before they started. The map was displayed on a table and the photograph in a simple viewing box. The time spent studying the maps and subsequent target detection times were recorded by stop-watch. The results showed a high proportion of incorrect identifications and excessively long search times. Although it was possible that the importance of speed in detection had not been adequately stressed, these results also indicated that a period of detailed training and practice for each individual subject would be necessary to obtain results comparable with those of professional subjects.

Difficulties encountered by the subjects in attempting this task were discussed and a detailed training programme was devised to overcome these problems. This method of training is outlined in 'Experimental procedure'.

(b) Two navigators experienced in low-level high-speed flight were tested on seven representative targets one under each condition of uncertainty and range. These targets were presented using the complete display and recording apparatus described in Section 4. In view of the results obtained, (relatively slow search times and approximately 33% incorrect identifications) minor modifications were madeto the display apparatus, to emphasise the importance of speed in the detection task. It was also decided to exclude certain targets from the test sequence, particularly those in which the target required could be easily confused with similar targets nearby.

The navigators were then presented with each of the four photographs of the eighteen targets displayed on a table together with the appropriate maps. They were asked to rate each photograph on a seven-point scale according to how difficult the target was to detect in that particular photograph, relative to other views of that target and all the other targets. They were then asked to give an overall ranking to each target i.e. to look at the four views of each target and assess its overall difficulty. In making these judgements they were told to take into account a number of factors including quality of photograph, weather conditions, type of target, type of terrain and 'lead in' features. It was not intended to obtain exact information from these rankings but simply a general indication of the relative difficulty of detecting these targets as assessed by experienced navigators. Inspection showed that there was a considerable measure of agreement between the navigators both on the individual photographs and the overall judgements given to each target. The targets were then listed in seven categories according to the judgements made. In cases where the judgements of the two navigators did not agree a representative value was taken. The ranking data and the seven categories of targets are shown in Appendix II.

2. PURPOSE OF THE EXPERIMENT.

The main aims of this experiment were:

(a) to investigate the effect of navigational uncertainty on target detection performance, in terms of accuracy and speed of detection;

(b) to investigate the effect of range on target detection performance;

(c) to determine the extent of the variation in detection difficulty between different targets;

(d) to investigate differences, if any, between the performance of skilled subjects (professional pilots and navigators) and unskilled subjects (students), of comparable age and ability.

It was recognised that in view of the limited amount of experimental material available and the fact that the photographs had not been either exposed or processed under controlled conditions the results could only be expected to indicate the relative importance of the various factors involved, rather than to provide detailed and precise data. However, the information obtained would nevertheless be of considerable value in planning future experiments and for comparison purposes. It was particularly important to determine whether meaningful results could be obtained from unskilled subjects trained specifically to do the experimental task. This had significant implications for future experiments since there are relatively few aircrew experienced in high-speed low-level flight who are available to take part in this type of study.

Furthermore, the experiment was intended to provide information on the differences between individual subjects, both skilled and unskilled, and the extent to which these differences were related to other factors, e.g. personality variables, intelligence.

3. EXPERIMENTAL DESIGN

3.1 Factor levels

The primary factors chosen for study in this initial experiment were:

(a) Navigational uncertainty (2 levels)

(b) Range from target (4 levels)

The two levels of navigational uncertainty chosen as being representative of those encountered under operational conditions were ± 1 mile and ± 2 miles. The nominal distance of the aircraft from the target was fixed as 2 miles. Thus the actual ranges from the target were as shown in the following table:-

Nominal range	Navigational uncertainty	Actual ranges
2 miles	± 1 mile	1, 2, 3 miles
2 miles	± 2 miles	(O)1, 2, 3, 4 miles

It was decided to exclude the zero range case since the target would be out of the field of view of the camera. Thus there were a total of seven experimental conditions, three for the ± 1 mile uncertainty and four for the ± 2 miles uncertainty.

3.2 Statistical design of experiment.

In considering the design of an experiment to test the effect of the seven conditions on target detection performance a number of problems arose:-

(i) The experimental material was severely limited since R.A.E. could only provide photographs of eighteen targets and some of these would be required for training purposes. In addition, each target could be presented to a subject on one occasion only, since having seen a view of the target at one range would obviously have considerable effect on his ability to locate it at another range. Thus the limitation on the number of targets for testing purposes was a critical factor in the experimental design.

(ii) Since the task was a complex one there was likely to be a considerable learning effect during the course of the experiment. This could be minimised by training and practice before the test but relatively few targets were available for this.

(iii) In the operational situation a navigator would be working to one condition of navigational uncertainty with which he would be familiar. However, in this experiment there were three ranges associated with the $\pm$ 1 mile navigational uncertainty and four associated with the $\pm$ 2 mile uncertainty. Thus to assign each subject to a single uncertainty condition would result in an imbalance in the experiment.

Various experimental designs were discussed bearing in mind these considerations. Several possibilities emerged:-

(a) A group of n subjects (say 10) would be allocated to each of the seven experimental conditions and each target presented in that condition. The order of targets presented within a condition would be systematically varied to control learning effects. The groups of subjects could be matched on the basis of a pre-test to overcome the confounding of subject differences with differences between experimental conditions.

The major disadvantage of this design was that since a subject would only be exposed to one condition the target he would be required to locate would appear in approximately the same position on each photograph and he would learn to expect this. The detection task would thus be considerably simplified. This experimental design was therefore rejected.

(b) A second possible experimental design was based on a matrix of seven targets and seven conditions. This matrix could be filled with seven subjects, given the restrictions that:-

(i) A subject may not experience more than one experimental condition for a given target.

(ii) A subject may not experience more than one target for a given experimental condition.

However, as mentioned previously, it was thought more realistic that a subject should be exposed to only one condition of navigational uncertainty. This led to the possibility of two separate matrices, one for each uncertainty. The imbalance arising from having three ranges associated with $\pm$ 1 mile uncertainty and four with the $\pm$ 2 mile one could possibly be overcome by including an extra target at suitable range in the sequence for the $\pm$ 1 mile uncertainty condition. This would ensure that each subject saw the same number of targets, but the extra one would not be included when analysing the results.

However, even if the problem of imbalance between the conditions could be overcome satisfactorily, a further problem remained. In such small matrices, i.e. 4 targets x 4 conditions, it was likely that the order in which any subject received a particular sequence of 4 targets and condition combinations from a Latin square arrangement would influence his performance. To control this would necessitate the presentation of each sequence in all possible orders, i.e. 24, (4 x 3 x 2 x 1), orders of presentation for each sequence. Thus, since there would be four sequences in each matrix, the only way in which order effects could be controlled would be to use 4 x 24 subjects in each matrix. Even if this were done it was thought that the results might be influenced by the particular Latin square arrangement chosen out of the several different ones possible. Therefore, using a realistic number of subjects, it was impossible to completely control order effects.

(c) In view of these difficulties, the best experimental design seemed to be that in which each cell in a target x conditions matrix would be filled by a different subject, each subject having been previously trained to an acceptable level of performance. Thus independent values would be obtained in each cell and all the difficulties previously discussed, i.e. learning effects, order effects and imbalance between the two uncertainty conditions would be overcome. In addition, since only one target and condition combination would be required for test purposes there would be enough photographs for thorough training and for pre-testing to ensure that an arbitrary performance criterion had been achieved before the test target was presented.

However, it was decided that the number of subjects required (7 x number of targets tested x number of values required in each cell) was too great in view of the time required for training and carrying out preliminary tests. This experimental design was therefore abandoned in favour of one which, though less rigorous statistically, was considerably more economical in subjects.

(d) The experimental design eventually decided on was based on the matrix of 7 targets and 7 conditions. Seven subjects were assigned to this matrix in a Latin square arrangement, with each subject appearing once in each row and once in each column, i.e. each subject was presented with each target once only and each combination of range and uncertainty condition once only. No attempt was made to restrict a subject to a single uncertainty.

The order of presentation of the particular series of targets and conditions for a given subject was then randomised, (see Appendix III for detailed schedules). This ensured that effects due to learning or to particular orders of targets and conditions would be random. The effect of learning during the presentation of the seven test targets was minimised by a period of detailed training and practice beforehand. During this training the difference between the two uncertainty conditions and the fact that both conditions would be presented randomly during the test run was stressed.

The seven test targets used in the matrix were chosen on the basis of the overall judgements of difficulty made by the professional navigators during the exploratory studies. One target from each of the seven difficulty categories was chosen for the test matrix. The remaining eleven targets were used for training and practice purposes.

The unskilled subjects used in this experiment were students of age and intelligence comparable with that of professional aircrew. A few of the former had had some flying experience but, with one exception, this was less than 10 hours. In general they showed a considerable degree of interest in the experiment and it was possible that payment further increased their motivation.

The original intention was that only subjects who achieved 5, or more, correct detections out of the 7 test targets would be included in the matrix of detection times. However, it soon became apparent that, even after a considerable period of training, only about 25% of the unskilled subjects could achieve this level of performance. Thus, in rejecting subjects correctly detecting 4 or less out of 7 targets much data was being wasted. Therefore, it was decided that each subject would be allocated to one of three matrices according to whether he achieved a high score (5 or more correct), an average score (4 correct) or a low score (3 or less correct). Since it was not possible to anticipate the score a subject would achieve (although there appeared to be some correlation with score on I.Q. test) in later stages of the experiment results were sometimes obtained which duplicated, in terms of score of correct detections in a particular sequence of targets and conditions, those already recorded. These subjects were rejected and testing continued until each of the three matrices were completed. Altogether, approximately 30 subjects were tested. The results for 21 of these were included in the three matrices, the remainder being rejected as they duplicated other results. In practice this introduced a slight bias into the selection of subjects used since this duplication only occurred with subjects scoring 4 or 3 correct detections.

Facilities for testing skilled subjects, i.e. R.A.F. pilots and navigators experienced in high-speed low-level flight, were arranged by R.A.E. at Farnborough. Seven skilled subjects were tested using the same targets and conditions matrix as for the unskilled subjects. It would have been preferable to test equal numbers of skilled and unskilled subjects, but this was not possible since there were not enough skilled subjects available. The seven skilled subjects tested were therefore assigned to one matrix regardless of number of correct detections achieved.

This experimental design enabled the effect of navigational uncertainty, range from target, and experience to be assessed. It also gave some indication as to the extent of the variations in detection difficulty between the test targets and the variations of performance between individual subjects.

4. DISPLAY AND RECORDING APPARATUS

In designing the apparatus for use in this experiment the main aim was to make it as simple and flexible as possible, since the exact nature of subsequent experiments and the experimental material to be used was not fully decided.

The main apparatus consisted of:-

(a) Display box for map.

(b) Illuminated box for the photographic display with provision for varying the viewing distance.

(c) A Labgear decatron timing unit linked to an automatic print-out.

This recorded the time a subject spent studying the map, the time he took to locate the target and the confidence level of his judgement as indicated by his choice of one of seven switches.

A plan diagram of the experimental area is shown in Figure 4.0.1.

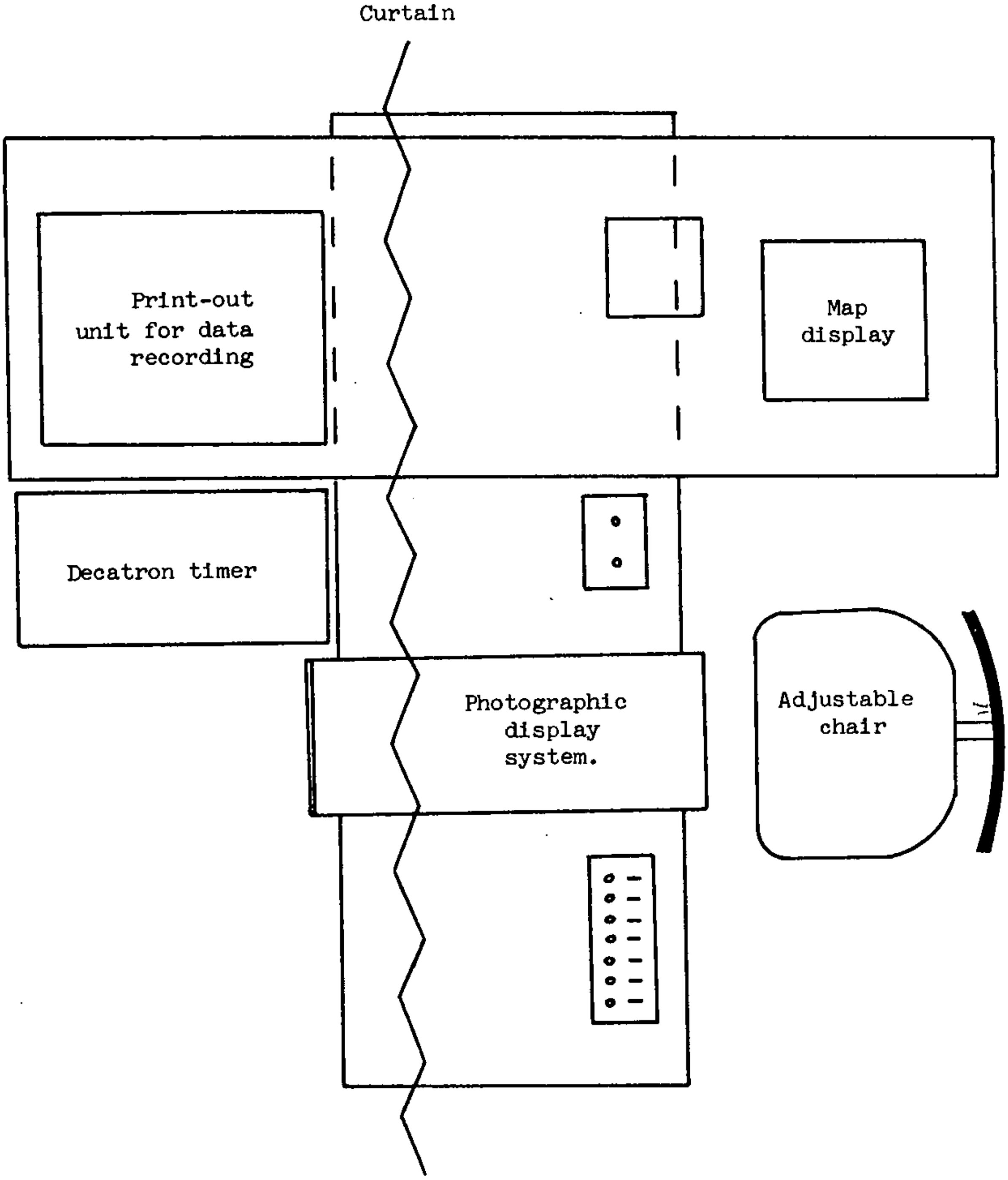
4.1 Map Display

The map display box was designed so that the section of map could be displayed at angles ranging between 30° and 60° to the vertical, although in this experiment only the 30° to the vertical position was used. The background against which the map was displayed was painted matt grey. The lower edge of the map was positioned in a wooden groove and the upper edge held by two small catches. Above the map was a slot for the label giving the name of the target. (See Figure 4.1.1.)

The display box had a hinged lid incorporating a micro-switch so that as soon as the box was opened the switch was released and the timer started. As the box was closed the timer was stopped and the time the subject had spent studying the map was recorded on the print-out. After each presentation the map was changed, the lid of the box being held half closed so that the subject did not get a preview of the map before the start of the cycle.

FIGURE 4.0.1

Plan view of experimental area



Scale 1 : 10

FIGURE 4.1.1
General view of experimental area

4.2 Photographic display.

The display apparatus for the photographs was designed to fulfill three basic requirements as simply as possible. These requirements were:-

(i) Adequate illumination which did not cause light to be reflected off the glossy photographs into the subject's eyes.

(ii) A method of displaying either the whole photograph, measuring 8" x 8" or any portion of it, centrally in the subject's field of view, at an angle of 30° to the vertical.

(iii) A viewing distance which could be varied between 13" and 30".

Display apparatus designed to incorporate these features is shown in Figures 4.2.1 and 4.2.2.

The optimum arrangement of the lighting relative to the photograph and the possible positions of the subject's eyes, allowing for the range of variation in viewing distance, was calculated so as to eliminate specular reflection. Two incandescent 60 watt tubular lights 8" long were positioned vertically one to each side of the slide on which the photograph was mounted and approximately 4" in front of it. The tubes were positioned in recesses out of the main viewing tunnel to prevent light falling directly into the subject's eyes. This arrangement gave an even level of illumination over the display. The illumination could be varied by means of a rheostat but in this experiment it was kept constant at 200 lumens/sq.ft., giving an average brightness of 100 ft. lamberts over the photograph. These values are in accordance with those recommended for work involving close attention to detail. (Weston, 1962).

Flexibility in displaying the photographs was achieved by a magnetic mounting device. Since the size of the display required was 4.8" x 3.6", the longer side being horizontal, an aperture of this

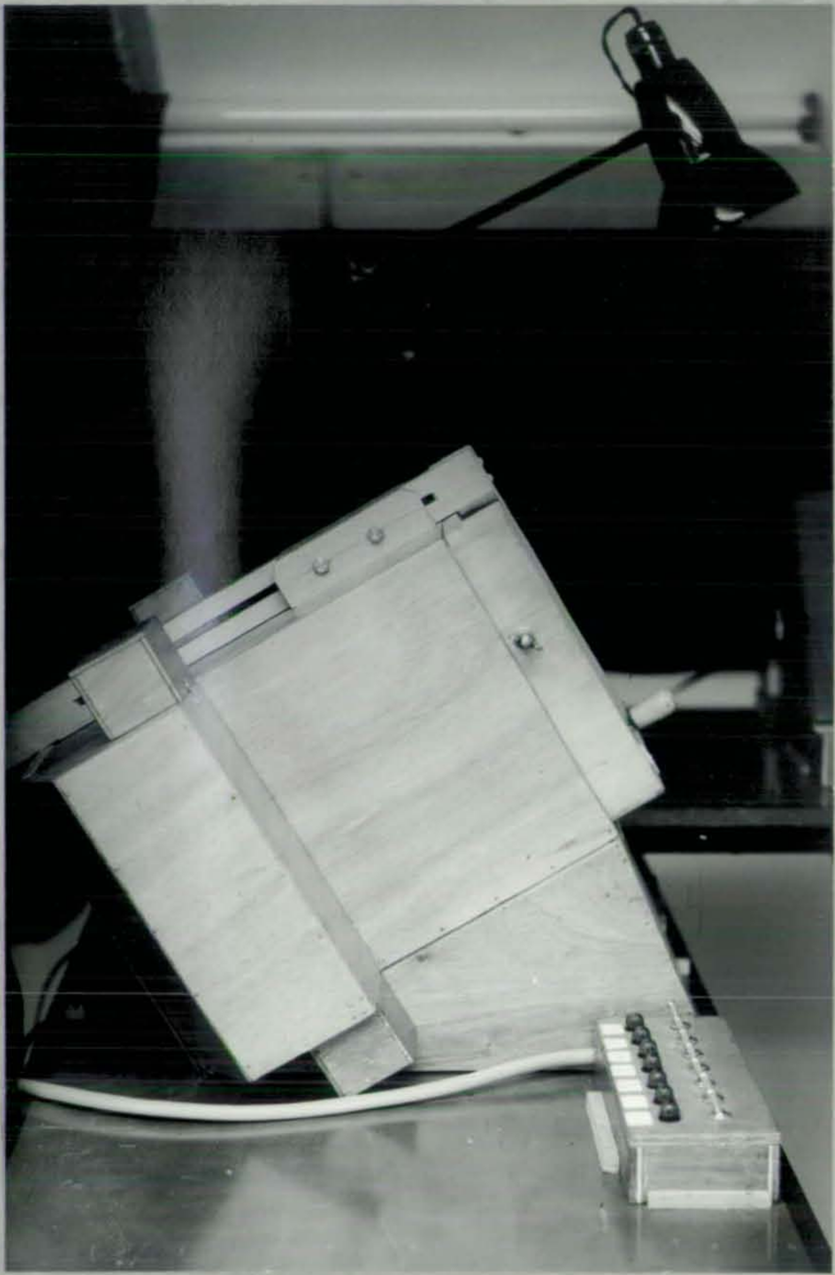
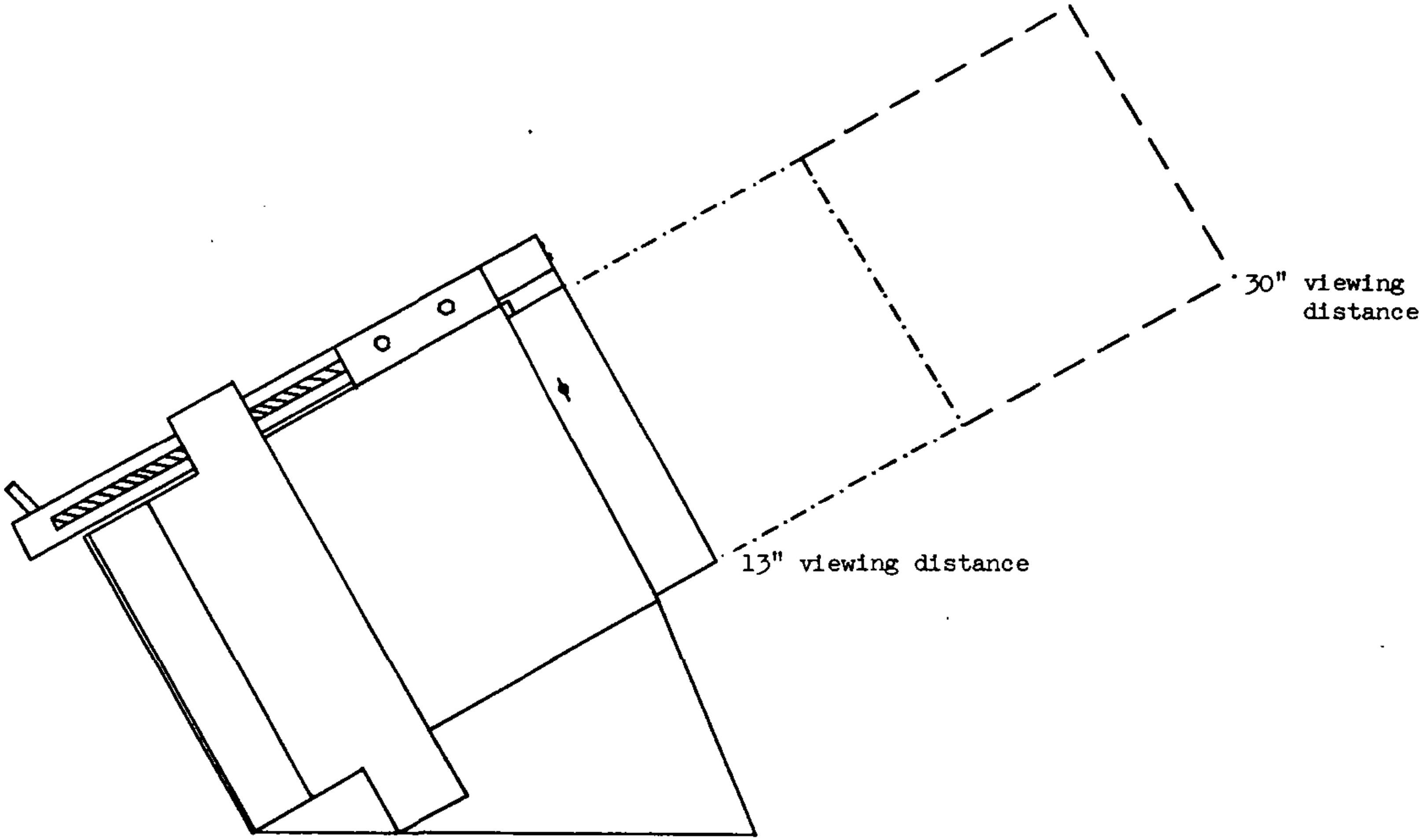


FIGURE 4.2.1
Display box adjusted for
the 13" viewing distance

FIGURE 4.2.2

Side view of photographic display system



Scale 1 : 5

Dotted lines show position of viewing tunnel when fully extended.

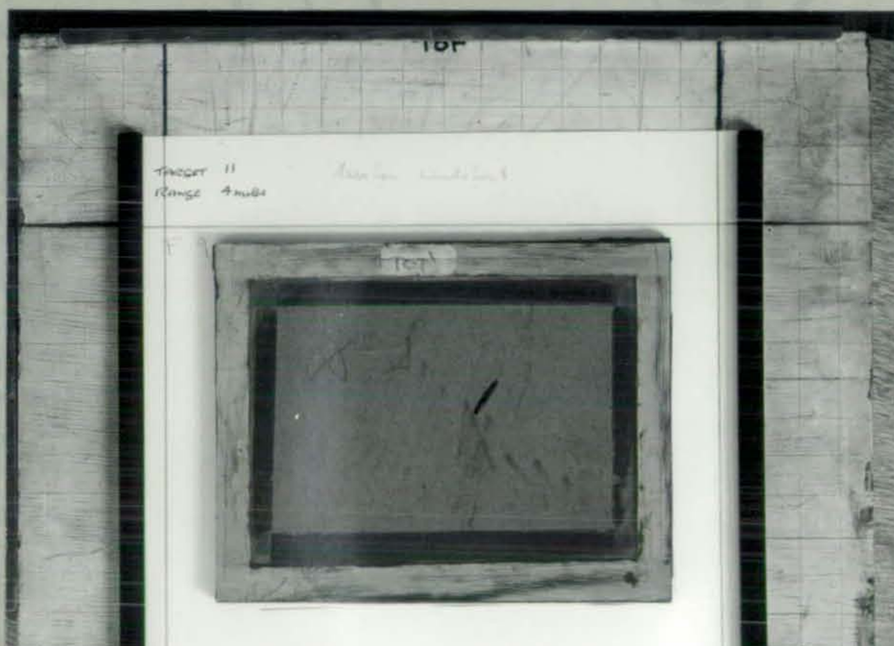
size was cut in the centre of a sheet of aluminium, size $10^3/4$ x 10". This sheet acted as a masking slide for the photograph enabling any portion of it to be displayed through the aperture. Thus, regardless of which portion of the photograph was shown to the observer, the position of the display remained constant. The front of the masking slide was painted a matt grey, the colour being as close as possible to the average shade of grey in the photographs, so that the degree of contrast between the photograph and the surface of the masking slide was minimised.

The back of the slide was marked in ½" squares so that the photograph could be accurately positioned. It was held firm by means of a rectangle formed of magnetic strip which was placed on the back of the photograph. The whole assembly fitted into two horizontal grooves at the back of the display box. (See Figure 4.2.3.)

Variation in viewing distance was allowed for by a telescopic viewing tunnel, of 8" x 8½" internal cross section, which could be extended to allow the viewing distance to be increased from 13" to 21". An extra section could be added to the viewing tunnel to further increase the viewing distance to a maximum of 30". The inside of the whole tunnel was painted the same shade of grey as the masking slide. A fixed head position was achieved by means of a chin-rest and adjustable forehead-rest as shown in Figure 4.2.4. In this experiment only the minimum viewing distance 13" was used. Figure 4.2.5. shows a subject viewing the display.

Alongside the display apparatus were two control panels. The first had a 'start' button which illuminated the display when the subject was ready to begin the detection task and a 'stop' button, which the subject operated as soon as he located the target. This caused the detection time to be recorded on the print-out. The second control panel had a row of seven numbered switches with associated

FIGURE 4.2.3
Method of mounting photographs in display box.



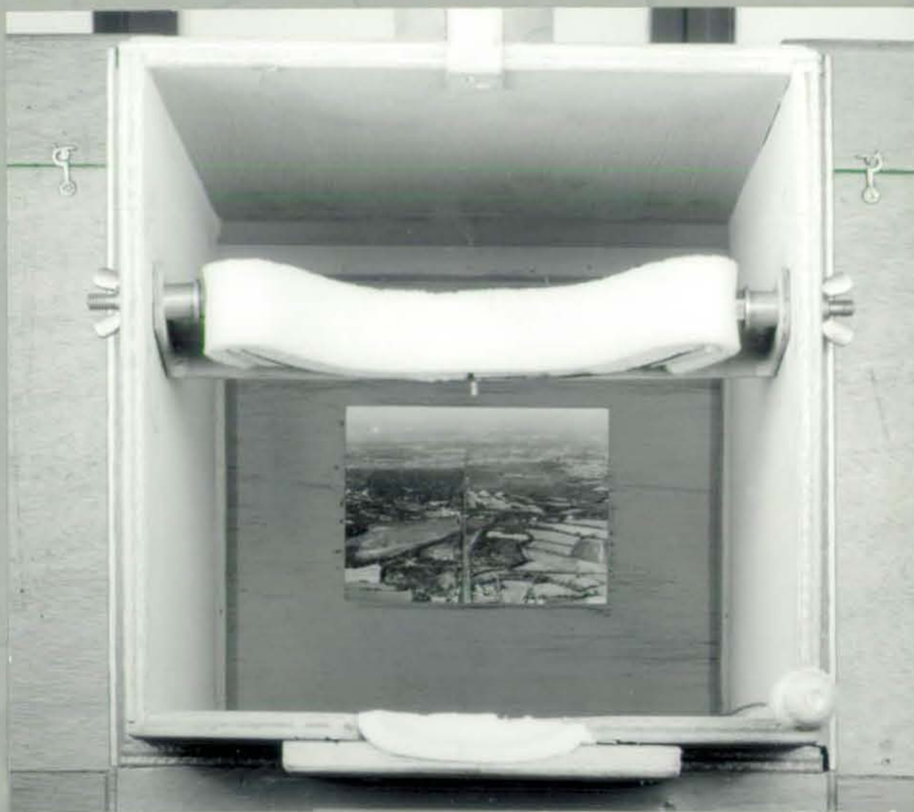


FIGURE 4.2.4
Front view of display box

FIGURE 4.2.5
A subject viewing the display

lights. The subject used this to indicate by depressing one particular switch how confident he was in his judgement.

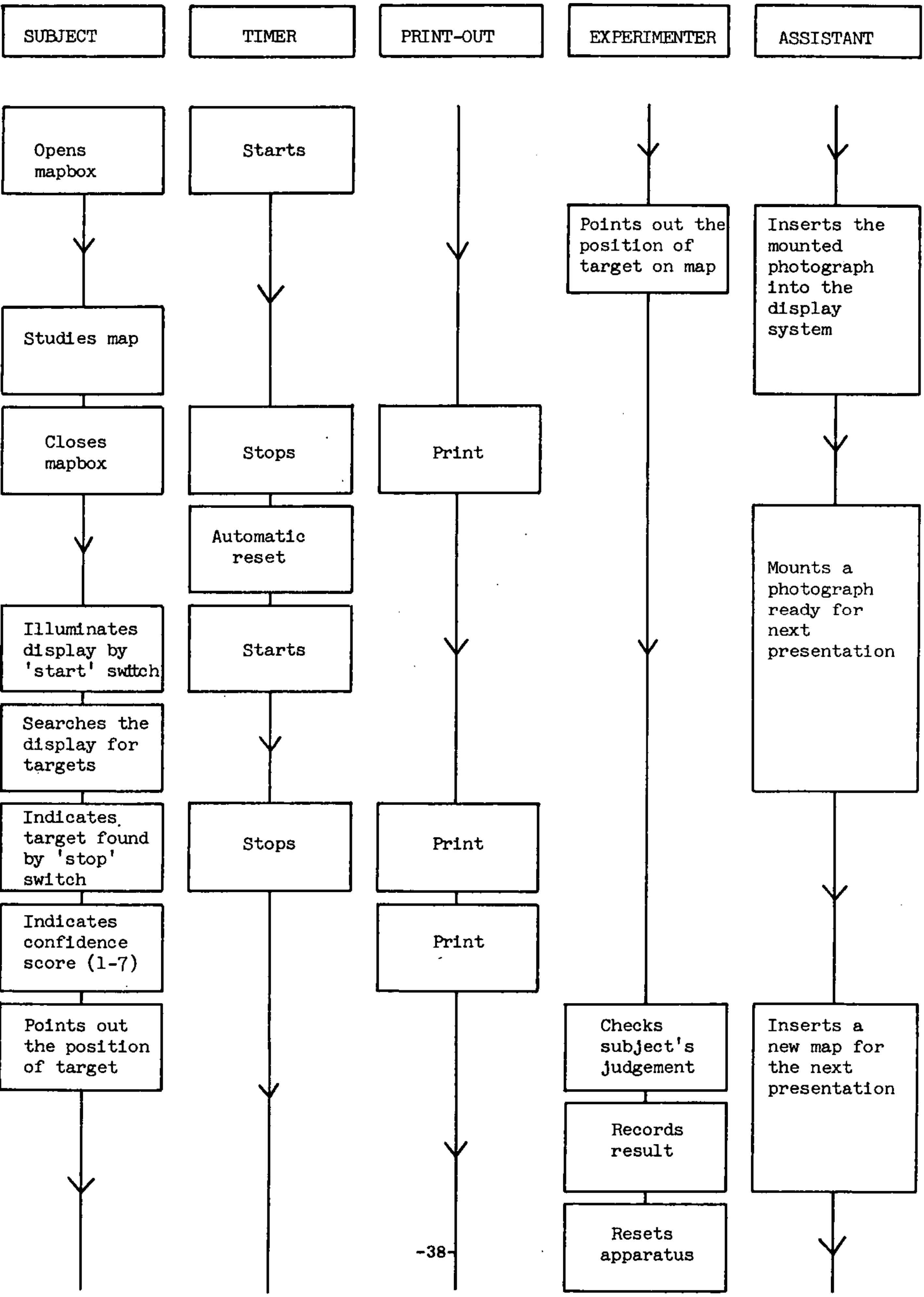
4.3 Timing and recording apparatus

The time the subject spent studying the map and the search time were measured by the Decatron timer (see Figure 4.3.1.) and automatically recorded on the print-out. The confidence level indicated by the subject was also recorded. Thus the only information which the experimenter had to record was whether the subject had located the target correctly or incorrectly. A block diagram of the operational sequence of the apparatus is shown in Figure 4.3.2.

FIGURE 4.3.1
Recording and timing apparatus.

FIGURE 4.3.2

Block diagram of operational sequence



5. PREPARATION OF EXPERIMENTAL MATERIAL.

5.1 Photographs

The photographic material provided by R.A.E. consisted of four photographs of each of eighteen targets. The four photographs of each target were taken from an altitude of 2,000 ft. and at distances from the target of 1, 2, 3 and 4 miles respectively. The photographs were approximately 8" square and the camera angle of view was 50°. A list of grid references indicating the exact target positions and the position from which each photograph had been taken along the approach line was also provided. These references all related to points on the 1" = 1 mile Ordnance Survey map of the Aldershot area, (Sheet 169). The detailed list of targets and grid references is shown in Appendix 1.

The required size of the display in this experiment was equivalent to a camera angle of $30^{\circ} \times 22\frac{1}{2}^{\circ}$, i.e. 4.8" x 3.6", the longer side being horizontal. Guide lines were drawn on the back of the photographs so that they could be positioned accurately on the masking slide to show the central part of the photograph laterally, and to show the horizon $^{1}/4$" from the top of the display vertically.

Although it had been specified that the target should be in the lateral centre of the field of view in many cases the target appeared slightly off centre. By suitable masking of the photograph it would have been possible to display a portion showing the target in the centre of the field of view but it was decided that if this was done the subjects would soon learn to expect the target to be central, thus simplifying the search task. Therefore the central portion of the photograph was displayed in each case regardless of the exact position of the target.

For reference purposes, the position of the target on each photograph was recorded by means of a transparent grid, marked in $\frac{1}{2}$"

squares from which the vertical and horizontal co-ordinates of the target position could be determined.

5.2 Map Sections

Two similar map sections were prepared for each target area, one for each navigational uncertainty condition. The sections measured $6^1/4"$ x $6^1/4"$ (i.e. 10 x 10 grid squares) and were bounded by grid lines. Each section was cut in such a way as to include the target, the four mile approach to the target, as indicated by the grid references given, and as much of the area beyond the target as possible. In some cases this was limited by the proximity of the target to the edge of the original map, (O.S. sheet 169, 1" = 1 mile, Aldershot area). Since many of the map sections over-lapped it was necessary to use several copies of the map to cut the two duplicate sections needed for each target.

The rectangular areas representing the uncertainty in the aircraft position, 2" x ½" for the $\pm$ 1 mile uncertainty and 4" x ½" for the $\pm$ 2 mile uncertainty, were reproduced photographically on to transparent plastic film. Eighteen copies of each were prepared. These were used to cover the map sections in such a way as to indicate the appropriate uncertainty area relative to the target and the line of approach. The plastic film also served to protect the map sections, which were backed with thin card. Figures 5.2.1. and 5.2.2. show the way in which the uncertainty areas were marked relative to the target.

During the preparation of these map sections it became apparent that the points from which the photographs had been taken, as indicated by the grid references given, were not always co-linear. This was allowed for by the $\pm$ $^1/4$ mile off-track error introduced into this experiment and the uncertainty area was always marked in such a way as to include the specified grid points.

FIGURE 5.2.1

Target 17 - Charterhouse School

Sample map showing the smaller area of navigational uncertainty (± 1 mile x ± ¼ mile) and the position of the target, indicated by an arrow.

FIGURE 5.2.2

Target 17 - Charterhouse School

Sample map showing the larger area of navigational uncertainty ($\pm$ 2 miles x $\pm \frac{1}{4}$ mile) and the position of the target, indicated by an arrow.

6. EXPERIMENTAL PROCEDURE

6.1 Testing of unskilled subjects

The procedure outlined in this section was carried out for each of the unskilled subjects taking part in this experiment. The nature of the apparatus necessitated individual testing of subjects and each experimental session lasted approximately 2½ - 3 hours.

Before the start of the session the various forms required for preliminary testing and recording purposes were put ready and the experimental material assembled for presentation in the appropriate sequences.

On arrival the subject's name, age and occupation, and the number of the particular test schedule to be used were recorded on the result sheet. If the subject had had any flying experience, other than commercial flights, the number of hours was recorded.

After these details had been noted the subject was given a general explanation of the main aims of the experiment and what he would be required to do. The following programme was then carried out, the approximate times required for each part being shown in brackets:

(a) Preliminary tests

(i) Personality assessment using the Eysenck questionnaire to measure extraversion-intraversion and neuroticism (10 minutes).

(ii) Intelligence test using Heim's A.H.5. test of high grade intelligence. (60 minutes).

(iii) Short-term memory measured by digit span test, forwards and backwards (5 minutes).

(iv) Visual acuity test using a Snellen Chart, a Landolt C chart and Jaeger test type (5 minutes).

(b) <u>Training and practice at the detection task</u>. (30 minutes)

The main points covered during this training period were:

(i) Map reading, with particular reference to terrain features of importance in aerial observation.

(ii) Navigational uncertainty. The difference between the ± 1 mile and the ± 2 mile error conditions was emphasised. The subject was told that the appropriate rectangular area of uncertainty would be marked on each map, (see Figures 5.2.1 and 5.2.2).

(iii) The shape and size of the search areas associated with each uncertainty level, and the way in which these map areas were related to the camera field of view, the inclination of the camera and the maximum possible range of the target for each uncertainty condition, were explained. The difference in the size of the two search areas was stressed by means of transparent overlays, and the fact that there was an approximately 1 mile 'dead space', i.e. terrain in front of the aircraft that was out of the field of view of the camera, was pointed out. (see Figures 6.1.1 and 6.1.2).

(iv) Practice with three sample maps and corresponding photographs. On each map the subject was asked to indicate the appropriate search area and the terrain features of importance. He was then shown an appropriate photograph and asked to point out the target and the 'lead-in' features. Photographs showing the same target at other ranges were then shown to him to indicate how the position of the target in the photograph changed according to range. The subject was not told that only four views of each target taken at specific ranges of 1,2, 3 or 4 miles were available. He was simply informed that he might be presented with a photograph from anywhere inside the uncertainty areas.

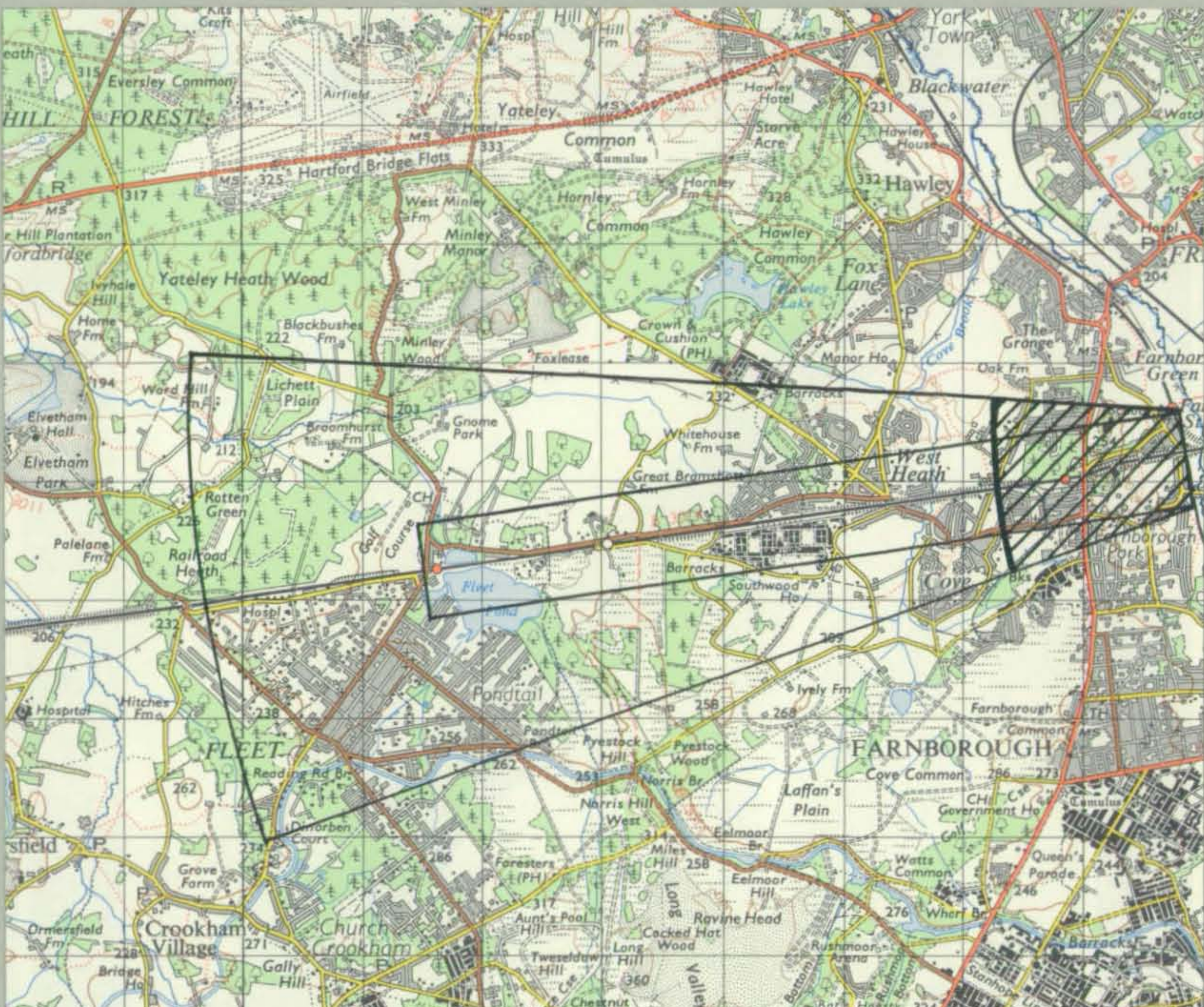
FIGURE 6.1.1

Target 3 - Fleet Station

Sample map showing the rectangular area of navigational uncertainty (± 1 mile x ± ½ mile), and the corresponding search area as indicated to the subjects by means of a transparent overlay during the preliminary training The shaded area represents the 'dead space'.

FIGURE 6.1.2

Target 3 - Fleet Station



Sample map showing the rectangular area of navigational uncertainty (± 2 miles x ± ½ mile), and the corresponding search area as indicated to the subjects by means of a transparent overlay during the preliminary training. The shaded area represents the 'dead space'.

The search technique suggested to him was that, if the target was not immediately apparent, he should search the foreground for conspicuous features which, from his study of the map, should indicate the position of the aircraft relative to the target and thus suggest where the target was most likely to appear in the photograph. It was emphasised that he would have as long as he required to study the map but that speed in locating the target was extremely important.

Throughout the training period the subject was encouraged to ask questions if any of the points explained were not clear.

(c) Experimental run (45 minutes)

Before the experimental run was started the windows were blacked out and the lights turned on to ensure that there was a constant level of illumination regardless of weather conditions. The working of the apparatus and print-out was checked and the chair and/or apparatus table adjusted so that the subject was comfortably seated.

The procedure for the experimental run during which the experimenter was assisted by a technician was as follows:-

(i) The subject was shown how to operate the apparatus and it was emphasised again that although he could study the map for as long as he felt necessary, speed was essential in detecting the targets.

(ii) The subject was presented with a series of four practice targets, one at each range. At the end of each presentation he was told whether or not he had correctly located the target and, if he had not, was given a further opportunity to do so, with guidance if necessary. These practice targets served to familiarise the subject with the conditions of presentation, e.g. viewing distance, illumination etc. and with the operation of the apparatus.

(iii) The subject was presented with a further four practice targets. During these presentations no information was given to the subject as to whether or not he had correctly located the target. The same series of practice targets was presented to every subject.

(iv) The final sequence of seven presentations consisted of the test targets shown in the pre-determined order, under the particular conditions of uncertainty and range assigned to the subject. (See experimental schedules in Appendix III) Again, no information was given to the subject as to the accuracy of his responses.

Thus a total of 15 targets was presented to each subject. During the presentation of each target the operational procedure was as follows:-

(i) When the subject was ready to begin he opened the map box, thus starting the timer. The experimenter told him what the target was and pointed out where it was on the map. The subject was then allowed as long as he wished to study the map and when he had finished he closed the lid of the box. This activated the switch which stopped the timer and the time he had taken was recorded on the print-out.

(ii) The subject turned to the photographic display box, placed his chin and forehead in position and immediately depressed the 'start' button which illuminated the display and re-started the timer. As soon as he had located the target he depressed the 'stop' button which stopped the timer and printed out the search time.

(iii) The subject then removed his head from the display box and depressed one of a series of seven switches, labelled 0 - 6, to indicate how confident he was that he had correctly located the target. He had previously been instructed that if he was completely certain of his judgement he should depress switch No. 6, if he was only fairly certain No.4 and if he was very uncertain No. 1. Intermediate degrees of confidence within this general structure could be indicated by the remaining switches. The switch number 0 was only used if the subject could make no judgement at all after a reasonable time.

(iv) Finally, the subject used the pointer to indicate to the experimenter the position of the target on the photograph. The experimenter recorded on the result sheet whether the judgement was correct or incorrect. The exact position of the target could not always be clearly seen, but only deduced. In these cases judgements were counted as correct provided they fell within ¼" of the exact position.

(v) After the target position had been indicated the map was changed. Since this involved opening the map box the apparatus could not be reset until this had been done. When the new map was in position and the box closed the experimenter reset the apparatus by switching back the confidence level switch, which also extinguished the illumination of the photograph.

The new photograph was then inserted and the apparatus was ready for the next presentation. To reduce delay between presentations two magnetic mounting slides were available so that while one photograph was being displayed the next could be prepared.

Throughout the experimental run noise and other distractions were reduced to a minimum although it was not possible to silence the timing apparatus which clicked continuously. However, the majority of subjects were not disturbed by this although a few mentioned that they found it distracting. All subjects were asked to comment on any particular difficulties and these comments were noted on their result sheets.

At the end of each experimental session details of the targets, ranges and uncertainty conditions presented were recorded together with the map study times, the detection times and the confidence level of each judgement obtained from the print-out. The scores obtained on the preliminary tests were also recorded on the result sheets, a sample of which is shown in Appendix IV.

Detection times for the sequence of seven test targets were also recorded on one of the three replications of the test matrix according to the score of correct judgements achieved. (See Section 3, Experimental Design). Testing of any particular schedule was discontinued when results had been obtained in each matrix.

6.2 Testing of skilled subjects.

The procedure used for testing skilled subjects at R.A.E., Farnborough was exactly the same as that outlined for the unskilled subjects except that training in map reading and detailed explanation of the navigational uncertainty conditions was obviously unnecessary. However, it was thought that the experience of the skilled subjects would be of value in devising more effective methods of training for the unskilled subjects. The training material used was therefore explained to them and any suggestions or improvements noted. They were shown the same three targets as the unskilled subjects for practice purposes before starting the apparatus trials.

7. EXPERIMENTAL RESULTS

In the analysis of the results obtained from this experiment each of the main factors tested is considered in relation to the four measures of performance recorded, i.e. probability of correct detection, search time, confidence level and map-briefing time. A separate section is given to each performance measure and the effect of each of the main factors systematically considered. For convenience a cross-referenced summary table is given in the final section, (page 106).

In each case data from the 21 unskilled subjects are considered separately from the data relating to the 7 skilled subjects. The latter have been analysed in less detail and used mainly for comparison purposes since the small size of the sample precluded more detailed analysis.

In the statistical treatment of the results the raw data were treated as if each value in a 7 x 7 (targets x conditions) matrix were independent. As discussed in Section 3, Experimental Design, this assumption was thought to be reasonable although each subject contributed seven values to a matrix. In the following section all tests of statistical significance are two-tail unless otherwise stated. The data from the 4 miles range condition which relates only to one of the navigational uncertainty conditions ($\pm$ 2 miles) was excluded in cases where it would have caused imbalance in the analysis.

7.1 Detection probability

The raw data obtained from the unskilled subjects are shown in Table 7.1.1 and those from the skilled subjects in Table 7.1.2. The overall detection probability for the unskilled subjects was very close to that for the skilled subjects, the values being 0.59 and 0.61 respectively.

It can be seen in Tables 7.1.1 and 7.1.2 that the value in each cell is restricted to either 0, indicating incorrect detection, or 1, representing correct detection. In spite of this restraint on the data, conventional analyses of variance were carried out on each set of data. The results of the analysis for unskilled subjects were then compared with those obtained from a more sophisticated technique, Logit analysis. This is considered in a later section.

In carrying out the analyses of variance on the data in Tables 7.1.1 and 7.1.2 the values relating to the 'Range 4 miles' condition were excluded since these occurred under only one of the two conditions of navigational uncertainty.

In Table 7.1.3, which relates to unskilled subjects, it can be seen that two of the main factors tested have a significant effect on detection performance. These are the effect of target differences, which is highly significant, and the effect of range, significant at the 5% level. The effect of groups, shown to be highly significant, was pre-arranged in the design of the experiment and need not be considered further. In this analysis the effect of navigational uncertainty is shown to be totally non-significant. None of the interactions between the main factors reach the 5% significance level.

Table 7.1.4 shows the corresponding analysis of variance on the data obtained from skilled subjects. This sample was much smaller than that of unskilled and the results do not reach such a high level of significance. The only significant effect is that due to targets. Ranges are not shown to be significant.

The main factors tested (a) navigational uncertainty, (b) range, and (c) target differences are considered in greater detail below.

TABLE 7.1.1.

Correct and incorrect identification by three groups of unskilled subjects.

Correct identifications per subject in Groups A, B and C were 5 or better, 4 and 3 respectively.

	Group A							Group B							Group C						
	Uncertainty 1			Uncertainty 2				Uncertainty 1			Uncertainty 2				Uncertainty 1			Uncertainty 2			
	Range			Range				Range			Range				Range			Range			
TARGETS	1	2	3	1	2	3	4	1	2	3	1	2	3	4	1	2	3	1	2	3	4
3	1	1	0	1	1	1	0	0	1	0	1	1	1	1	1	1	0	1	0	0	1
14	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
17	1	1	1	1	0	0	0	1	1	1	1	0	0	0	1	0	1	1	1	0	0
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0
15	1	1	0	1	0	1	1	1	0	0	0	1	0	1	0	0	0	0	0	0	0
13	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0
1	0	1	0	1	1	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0

Overall probability of detection: 0.59

1 = correct detection

0 = incorrect detection

The range values are given in miles.

TABLE 7.1.2.

Correct and incorrect identifications by skilled subjects

		Uncertainty 1			Uncertainty 2			
		Range			Range			
		1	2	3	1	2	3	4
TARGETS	3	1	1	1	1	1	0	1
	14	1	1	1	1	1	1	1
	17	1	1	0	1	0	1	0
	16	1	1	1	1	1	1	0
	15	0	0	0	0	1	1	1
	13	1	0	1	1	0	0	0
	1	0	0	0	0	1	0	0

Overall probability of detection: 0.61

1 = correct detection

0 = incorrect detection

The range values are given in miles.

TABLE 7.1.3.

Analysis of variance on detection probability data for unskilled subjects shown in Table 7.1.1 *

Source	D.F.	S.S.	M.S.	V.R.	Significance
Uncertainty (U)	1	0.01	0.01	-	N.S.
Ranges (R)	2	0.97	0.48	3.12	$p < 0.05$
Targets (T)	6	8.41	1.40	9.04	$p < 0.001$
Groups (G)	2	2.40	1.20	7.74	$p < 0.001$
U x R	2	0.11	0.06	-	N.S.
U x T	6	1.71	0.29	1.95	N.S.
U x G	2	0.11	0.06	-	N.S.
R x T	12	1.92	0.16	1.09	N.S.
R x G	4	0.17	0.04	-	N.S.
G x T	12	2.49	0.21	1.41	N.S.
U x R x T	12	2.33	0.19	1.17	N.S.
R x T x G	24	2.61	0.11	-	N.S.
T x G x U	12	1.67	0.14	-	N.S.
G x U x R	4	0.56	0.14	-	N.S.
Residual (a)	24	4.00	0.17		
Pooled residual (b) (Residual (a) + URT, RTG, TGU, GUR).	76	11.16	0.15		
Pooled residual (c) (Pooled residual (b) + UR, UT, UG, RT, RG, GT)	114	17.68	0.16		
TOTAL	125	29.47			

* Data relating to Uncertainty 2, Range 4 miles, have not been included in the analysis since there are no corresponding values for Uncertainty 1.

TABLE 7.1.4

Analysis of variance on detection probability data for skilled subjects shown in Table 7.1.2 *

Source	D.F.	S.S.	M.S.	V.R.	Significance
Uncertainties (U)	1	0.02	0.02	-	N.S.
Ranges (R)	2	0.14	0.07	-	N.S.
Targets (T)	6	3.81	0.64	3.59	$p < 0.01$
U x R	2	0.05	0.02	-	N.S.
U x T	6	1.14	0.19	1.00	N.S.
R x T	12	2.19	0.18	-	N.S.
Residual (a)	12	2.29	0.19		
Pooled residual (b) (Residual (a) + UR, UT, RT)	32	5.67	0.17		
TOTAL	41	9.64			

* Data relating to Uncertainty 2, Range 4 miles have not been included in the analysis since there are no corresponding values for Uncertainty 1.

(a) Navigational uncertainty

Differences in detection performance between the two conditions of navigational uncertainty tested, ± 1 mile and ± 2 miles, were small. Table 7.1.5 shows the overall detection probability for unskilled and skilled subjects under each uncertainty condition.

TABLE 7.1.5

Detection probabilities under each uncertainty condition.

Uncertainty condition	Detection probability	
	Unskilled	Skilled
± 1 mile	0.63	0.62
± 2 miles	0.62	0.67

T-tests confirmed that differences between these values were non-significant, as indicated by the analyses of variance.

(b) Ranges

Table 7.1.6 shows the overall detection probability for each range.

TABLE 7.1.6

Detection probabilities under each range condition.

Range (miles)	1	2	3	4*
Unskilled	0.74	0.62	0.52	0.38
Skilled	0.71	0.64	0.57	0.43

* Values for range 4 miles are based on only half as many readings as the other values.

The general trend towards lower detection probabilities at greater ranges is in accordance with the results of the analyses of variance which showed range to be a significant factor for unskilled subjects. The deterioration in performances at longer ranges is less marked for the skilled subjects than for the unskilled ones. This is to be expected since professional pilots and navigators are experienced at detecting targets, or fix points, at ranges of approximately 3 miles, whereas this task apparently presented greater difficulty to the unskilled subjects.

The total variance due to range as shown in Table 7.1.3 was further analysed into linear and deviation components. This analysis which relates to unskilled subjects is shown in Table 7.1.7.

TABLE 7.1.7

Analysis of range variation

Source	DF	S.S.	M.S.	V.R.	Sig.
Ranges	2	0.968			
Linear regression	1	0.964	0.964	0.219	$p. < 0.05$
Deviation about linear regression	1	0.004	0.004	-	-
Residual	114	17.681	0.155		

It can be seen that the linear component is significant at the 5% level and accounts for almost the whole of the total variance. This indicates that there is a significant linear regression of detection performance on range for unskilled subjects but there is no evidence of a non-linear effect.

From the equation:

$$Y = 0.841 - 0.107 (X)$$

where Y is the expected detection probability for any given range X, it is possible to calculate the expected values for each of the ranges 1 - 3 miles and compare them with actual values obtained. Table 7.1.8 shows these comparisons.

TABLE 7.1.8

Comparison of calculated and actual detection probabilities

Range	Calculated probability	Actual probability
1	0.73	0.74
2	0.63	0.62
3	0.52	0.52

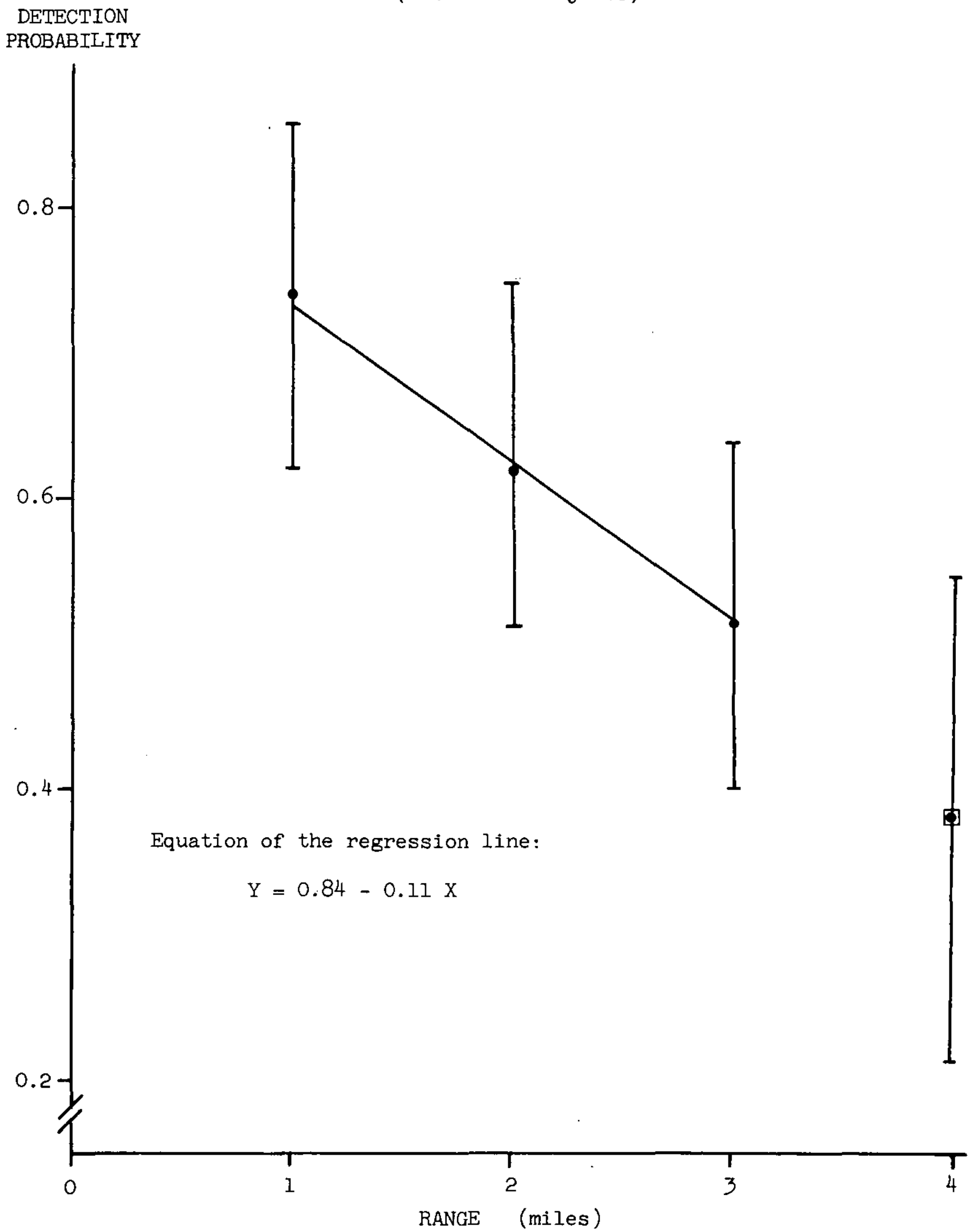
The regression line is shown in Figure 7.1.1 together with the observed mean probability of detection for each range and the associated 95% confidence limits.

The significance of the differences between the means shown in Table 7.1.6 for unskilled subjects was calculated, as shown in Table 7.1.9. It can be seen that there is a significant difference between detection performance at 1 mile and 3 miles but that differences between 1 mile and 2 miles, and 2 miles and 3 miles are non-significant although consistent with the general trend.

FIGURE 7.1.1

The effect of range on detection probability.

(Unskilled subjects)



NOTES The vertical lines represent the 95% confidence limits of the mean detection probability values.

The mean detection probability for range 4 miles was based on only half as many readings as the other values and the data were therefore not included in the calculation of the regression line.

TABLE 7.1.9

Significance of differences in range means for unskilled subjects

Ranges	Differences between means	Significance
1, 2.	0.12	N.S. (only reaches 0.20 level)
1, 3	0.22	Significant 0.02 level
2, 3	0.10	N.S. (only reaches 0.20 level)

Difference between means in this table must exceed 0.17 to be significant at the 5% level, and exceed 0.20 to be significant at the 2% level.

(c) Target differences

Table 7.1.10 shows the overall detection probabilities for each of the seven targets, arranged in rank order. The preliminary rankings carried out before the main experiment was started are also shown.

TABLE 7.1.10

Detection probabilities for each target.

Target	Detection probability		Rankings		
	Unskilled	Skilled	Unskilled	Skilled	Preliminary
14	1.00	1.00	1	1½	2
16	0.94	1.00	2	1½	4
3	0.67	0.83	3½	3	1
17	0.67	0.67	3½	4	3
13	0.50	0.50	5	5	6
15	0.33	0.33	6	6	5
1	0.28	0.17	7	7	7

It can be seen from this table that there is a wide variation in detection probability for the seven targets, but that there is very close agreement between unskilled and skilled subjects. The significance of the correlations between the rankings for skilled and unskilled subjects, and between the preliminary rankings carried out by two navigators and the skilled subjects, was evaluated by the Kendall rank correlation coefficient, tau. The values of tau and their significance are shown below:

	tau	Significance
Skilled/unskilled	0.95	p = 0.002
Skilled/preliminary	0.59	p = 0.070

The values shown in the second column of Table 7.1.10 i.e., the mean detection probability for each target as obtained from the results for unskilled subjects, were further analysed to determine the significance of differences between these means. The standard error of the difference between pairs of the means was calculated and thus the significance of the difference could be determined for each pair. Table 7.1.11 shows these differences in detection probability means and the level of significance reached.

TABLE 7.1.11

Differences between target detection probability means

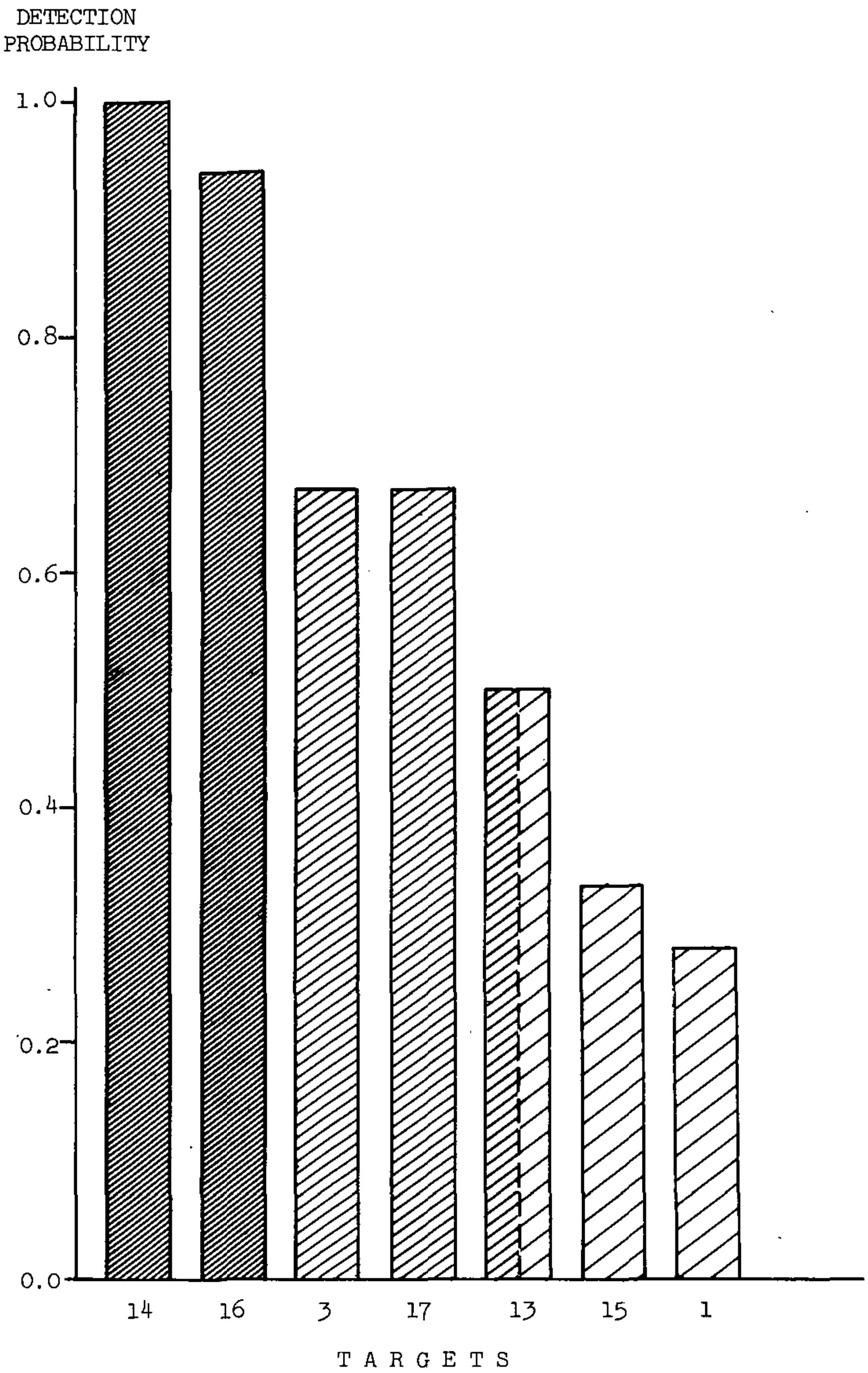
Targets	14	16	3	17	13	15	1
14	-	0.06	0.33	0.33	0.50	0.67	0.72
16		-	0.27	0.27	0.44	0.61	0.66
3			-	0.00	0.17	0.34	0.39
17				-	0.17	0.34	0.39
13					-	0.17	0.22
15						-	0.05
1							-

Differences between means must exceed 0.26 to be significant at the 5% level and must exceed 0.34 to be significant at the 1% level. In this table 5% significance is indicated by single underlining, 1% by double underlining.

FIGURE 7.1.2

Mean detection probabilities for each of the seven targets

(Unskilled subjects)



NOTE The three different types of shading represent statistically significant differences between the detection probabilities. The combination of two shadings indicates that the target, Number 13, is not significantly different from targets shaded with either of the component shadings.

Inspection of the results in Tables 7.1.10 and 7.1.11 indicates that the targets can be divided into three pairs. Between these pairs differences in detection probability are significant, but the difference within each pair is non-significant. Targets 14 and 16 are the most readily detectable, Targets 3 and 17 less so, and Targets 15 and 1 the most difficult. The remaining target No.13 is statistically different only from Nos. 14 and 16, its detection probability being approximately mid-way between the other two pairs. (See figure 7.1.2).

(d) Logit analysis of detection probability data

The raw data on detection probabilities, shown in Tables 7.1.1 and 7.1.2, being of a quantal nature, was not altogether suited to the conventional analysis of variance techniques used. The results obtained from the conventional analysis were therefore compared with those obtained from a more sophisticated technique, Logit analysis.

The model used in this method was that the probability, P of a correct detection is related to the factors tested by the following multiple regression equation:

$$Y = \text{Logit } P = \tfrac{1}{2} \ln. \frac{P}{1 - P} = \sum b_i x_i$$

In this equation the x values are constants relating to the experimental conditions and the b values are the corresponding regression coefficients, derived by successive approximations. The analysis, which was carried out by Professor P. Armitage of the London School of Hygiene and Tropical Medicine, is shown in full in Appendix V.

The results obtained from the Logit analysis on the data for unskilled subjects agree closely with those obtained by conventional methods. Both techniques of analysis show evidence of significant differences in detection probability between targets and between ranges, but no difference between uncertainty conditions.

It was not possible to analyse the limited amount of data from the skilled subjects by the Logit method but it is reasonable to assume that the conventional methods of analysis used gave substantially similar results.

7.2 Search time.

In this experiment the search time was taken to be the time required, in seconds, by a subject to view the display before making a response indicating that he had located the target, whether correctly or incorrectly. Since a static mode of simulation was used these search times are not directly applicable to the airborne situation in which the aircraft is moving rapidly over the terrain, except possibly in the particular case of a television display 'frozen' to enable the navigator to search a still display. However, the analysis of these times is of interest in indicating under which conditions a longer search time is necessary and whether longer search times result in a higher proportion of correct or incorrect decisions.

Tables 7.2.1 and 7.2.2 show the search times for unskilled and skilled subjects respectively. A standard analysis of variance was carried out on each of these sets of data and the results are shown in Tables 7.2.3 and 7.2.4. In Table 7.2.3 which relates to unskilled subjects, it can be seen that only target differences have an overall significant effect on search times, but that when the total range variance is subdivided into a linear and a deviation component the linear variance reaches the 5% significance level. The effect of navigational uncertainty is non-significant. These results are similar to those obtained in analysing the detection probability data, (see Table 7.1.3). Differences between subject groups, which were arranged according to number of targets correctly detected, were non-significant. This suggests that better detection performance by a group of subjects is not associated with either longer or shorter search times.

In Table 7.2.4, which relates to skilled subjects, none of the main factors are shown to be significant and, as for the unskilled subjects, factor interactions are all non-significant.

TABLE 7.2.1

Search times for target identification by three groups of inexperienced subjects

	Group A							Group B							Group C						
	Uncertainty 1			Uncertainty 2				Uncertainty 1			Uncertainty 2				Uncertainty 1			Uncertainty 2			
	Range			Range				Range			Range				Range			Range			
	1	2	3	1	2	3	4	1	2	3	1	2	3	4	1	2	3	1	2	3	4
3	4.2	7.4	<u>7.2</u>	10.8	7.6	1.4	<u>2.2</u>	<u>9.2</u>	4.2	<u>12.0</u>	10.6	2.8	13.2	14.0	4.0	2.0	<u>11.6</u>	19.8	<u>4.0</u>	<u>11.0</u>	4.0
14	2.6	8.8	11.8	1.2	4.6	3.6	5.8	2.2	4.0	4.8	9.4	1.8	1.4	<u>7.8</u>	2.0	1.2	1.2	2.8	2.4	14.0	<u>11.6</u>
17	2.0	4.4	4.4	2.6	<u>23.8</u>	<u>38.4</u>	<u>32.2</u>	21.4	23.2	12.2	2.2	<u>22.4</u>	<u>11.0</u>	<u>5.0</u>	6.0	<u>17.6</u>	18.8	2.4	5.2	<u>23.2</u>	<u>6.2</u>
16	9.6	2.4	6.0	5.2	12.4	20.0	15.6	4.4	15.4	7.6	4.0	4.8	8.8	8.6	1.8	12.8	16.2	<u>21.2</u>	4.6	12.0	<u>30.4</u>
15	15.4	20.6	<u>6.8</u>	8.6	<u>12.4</u>	25.2	7.8	13.0	<u>34.4</u>	<u>42.2</u>	<u>13.0</u>	41.6	<u>4.6</u>	9.2	<u>4.4</u>	<u>12.6</u>	<u>13.2</u>	<u>4.6</u>	<u>22.0</u>	<u>30.6</u>	<u>12.2</u>
13	13.2	14.0	26.0	13.4	2.2	12.2	<u>16.6</u>	4.4	<u>10.0</u>	<u>9.0</u>	<u>2.6</u>	<u>11.2</u>	<u>11.0</u>	<u>17.2</u>	<u>55.6</u>	<u>16.0</u>	11.0	3.8	<u>11.0</u>	<u>12.6</u>	<u>20.6</u>
1	<u>12.2</u>	7.8	<u>27.8</u>	23.8	12.4	<u>43.0</u>	4.8	<u>16.0</u>	<u>28.2</u>	<u>7.8</u>	17.4	<u>14.8</u>	7.6	<u>24.8</u>	<u>4.0</u>	<u>13.0</u>	<u>14.0</u>	<u>18.6</u>	<u>22.6</u>	<u>12.4</u>	<u>11.6</u>

All times given in seconds.

Search times for targets which were incorrectly identified have been underlined.

The range values are given in miles.

TABLE 7.2.2

Search times for target identification by experienced subjects

	Group D						
	Uncertainty 1			Uncertainty 2			
	Range			Range			
	1	2	3	1	2	3	4
TARGETS 3	7.6	1.6	9.8	2.8	1.6	13.2	3.4
14	2.2	0.8	1.0	3.0	0.8	1.6	6.6
17	2.8	9.0	19.8	4.2	14.6	10.8	15.0
16	6.0	3.8	4.2	10.0	8.0	10.8	29.8
15	13.0	13.8	2.8	7.8	8.0	12.8	14.0
13	16.4	6.0	14.4	1.8	5.4	12.0	10.2
1	3.2	7.4	15.0	6.6	12.6	30.8	6.0

All times given in seconds.

Search times for targets which were incorrectly identified have been underlined.

The range values are given in miles.

TABLE 7.2.3

Analysis of variance on search time data for unskilled subjects shown in Table 7.2.1 *

Source	D.F.	S.S.	M.S.	V.R.	Significance
Uncertainties (U)	1	4.05	4.05	- (c)	N.S.
Ranges (R)	2	400.95	200.48	2.48 (c)	N.S.
Targets (T)	6	2599.39	433.23	5.35 (c)	$p < 0.01$
Groups (G)	2	0.08	0.04	- (c)	N.S.
U x R	2	52.20	26.10	- (b)	N.S.
U x T	6	503.43	83.91	1.09 (b)	N.S.
U x G	2	242.92	121.46	1.57 (b)	N.S.
R x T	12	1019.57	84.96	1.10 (b)	N.S.
R x G	4	531.37	132.84	1.72 (b)	N.S.
T x G	12	1011.05	84.25	1.09 (b)	N.S.
U x R x T	12	648.85	54.07	- (a)	N.S.
R x T x G	24	1730.24	72.09	- (a)	N.S.
T x G x U	12	1206.92	100.58	1.12 (a)	N.S.
G x U x R	4	124.41	31.10	- (a)	N.S.
Residual (a)	24	2153.16	89.72		
Pooled residual (b) (Residual (a) + URT, RTG, TGU, GUR)	76	5863.59	77.15		
Pooled residual (c) (Pooled residual (b) + UR, UT, UG, RT, RG, TG)	114	9224.12	80.91		
TOTAL	125	12228.60			
Subdivision of range variance					
Linear	1	399.55	399.55	4.94 (c)	$p < 0.05$
Other levels	1	1.40	1.40		N.S.
TOTAL (Ranges)	2	400.95			

* Search times relating to Uncertainty 2, Range 4 miles, have not been included in the analysis since there are no corresponding values for Uncertainty 1.

TABLE 7.2.4

Analysis of variance on search times data for skilled subjects shown in Table 7.2.2 *

Source	D.F.	S.S.	M.S.	V.R.	Significance
Uncertainties (U)	1	8.24	8.24	-	N.S.
Ranges (R)	2	225.38	112.69	-	N.S.
Targets (T)	6	458.16	76.36	-	N.S.
U x R	2	57.76	28.88	-	N.S.
U x T	6	180.60	30.10	-	N.S.
R x T	12	422.02	36.83	-	N.S.
Residual (a)	12	2950.20	245.85		
Pooled residual (b) (Residual (a) + UR, UT, RT)	32	3630.58	113.46		
TOTAL	41	4322.36			

* Search times data relating to Uncertainty 2, Range 4 miles has not been included in the analysis since there are no corresponding values for Uncertainty 1.

This apparent lack of any significant effect of the main factors tested on search time may be due to the small size of the sample of skilled subjects or may reflect the fact that pilots and navigators are trained to make rapid decisions and are less affected by the conditions. It can be seen in the following sections, in which the main factors are considered individually, that in general the skilled group worked more quickly than the unskilled, although the differences are not always significant.

(a) Navigational uncertainty

The overall mean search time for each condition of navigational uncertainty is shown in Table 7.2.5. (Range 4 miles excluded)

TABLE 7.2.5

Mean search times for each uncertainty condition.

	Uncertainty condition	
	± 1 mile	± 2 miles
Unskilled	11.7	12.1
Skilled	7.6 seconds	8.5 seconds

It can be seen that whereas there is very little difference in times between the two uncertainty conditions there are differences between the skilled and the unskilled groups. These differences do not however reach the 5% significance level.

(b) Ranges

Analysis of the search time data indicates that mean search times increase with increasing range, as shown in Table 7.2.6.

TABLE 7.2.6

Mean search times* for each range

	Range (miles)			Overall mean
	1	2	3	
Unskilled subjects	9.7	12.1	14.0	11.9
Skilled subjects	6.2	6.8	11.3	8.1

* The time values are given in seconds.

For the unskilled subjects there is a significant linear relationship between range and search time (see Table 7.2.3 and Figure 7.2.1). Differences between mean search times for the three ranges are non-significant, except for the difference between times for 1 mile and 3 miles which is significant at the 5% level (t = 2.20).

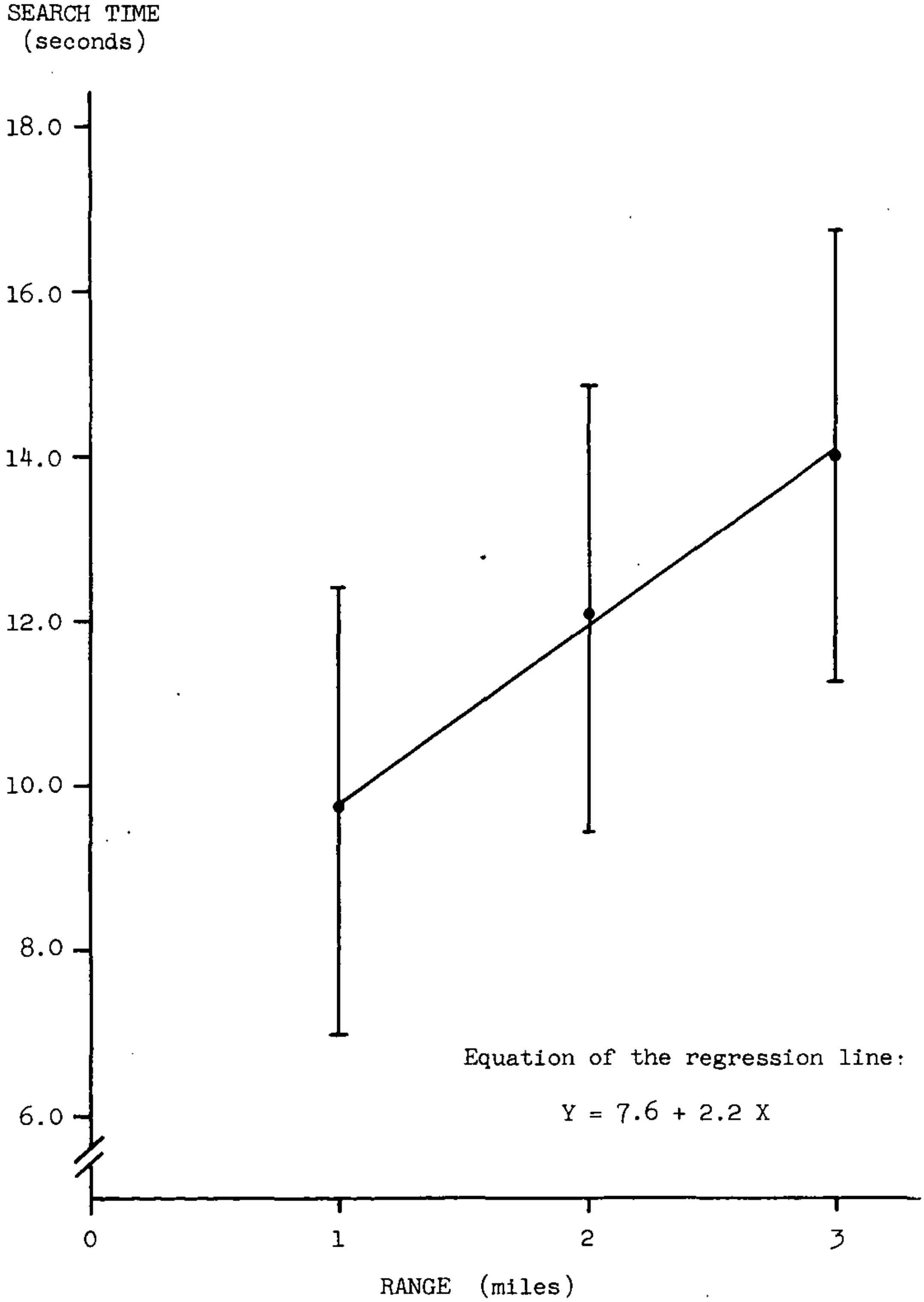
For the skilled subjects the trend of increasing search time with increasing range is also linear, (see Figure 7.2.2). Although there is some deviation about linearity this is not significant. Differences between the individual means do not reach the 5% significant level. Owing to the greater variance in the data for skilled subjects, and the smaller sample, the 95% confidence limits of the search time means are much wider for the skilled group than for the unskilled, as shown in Figure 7.2.2.

The difference between the overall mean search times for the skilled and unskilled groups, as shown in the last column of Table 7.2.6 is significant at the 5% level on a two-tail t-test.

FIGURE 7.2.1

The effect of range on search time.

(Unskilled subjects)

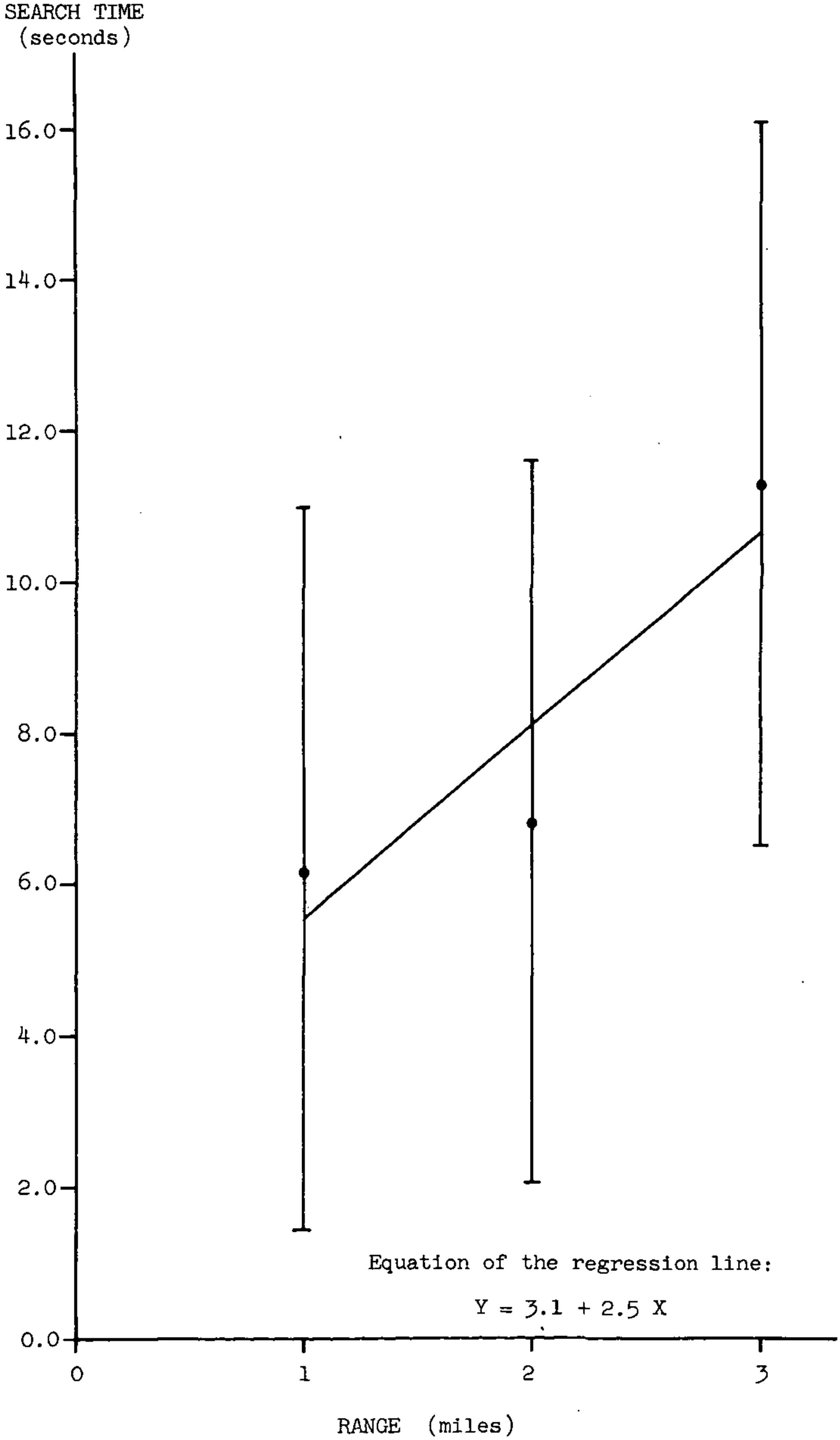


NOTE The vertical lines represent the 95% confidence limits of the mean search time values.

FIGURE 7.2.2

The effect of range on search time

(Skilled subjects)



NOTE The vertical lines represent the 95% confidence limits of the mean search time values.

(c) Target differences

Mean search times for each of the seven targets are shown in Table 7.2.7 together with the corresponding rank order for skilled and unskilled subjects.

TABLE 7.2.7

Mean search times for the seven targets.

Target	Mean search times		Search time rankings		Detection probability rankings	
	Unskilled	Skilled	Unskilled	Skilled	Unskilled	Skilled
14	4.4	1.6	1	1	1	1½
3	7.9	6.1	2	2	3½	3
16	9.3	7.1	3	3	2	1½
13	13.2	9.3	4	4	5	5
17	13.4	10.2	5	6	3½	4
1	16.9	12.6	6	7	7	7
15	18.1	9.7	7	5	6	6

This table shows that although mean search times range from 1.6 secs. to 12.6 secs. for the skilled group and from 4.4 secs to 18.1 secs. for the unskilled group the rank order of the targets, based on these mean search times, is very closely similar for the two groups. For comparison purposes, the rankings of the targets ordered according to their detection probabilities (see Table 7.110) have been included in Table 7.2.7. A significant correlation was found between the target rankings relating to the search time data for skilled and unskilled subjects, and between the search time and detection probability rankings for both groups of subjects. The values of the Kendall rank correlation coefficients and the corresponding significance levels are shown in Table 7.2.8.

TABLE 7.2.8

Significance levels of tau values for rank correlations.

	tau	Significance
Skilled/unskilled: search times	+0.81	p = 0.01
Skilled: search time/detection probability	-0.68	p = 0.044
Unskilled: search time/detection probability	-0.68	p = 0.044

The correspondence between the rankings on search time and detection probability indicates that in general those targets which were more likely to be detected correctly were also detected more quickly. This is reasonable since the more difficult targets would be likely to cause a subject to take longer in searching.

Target differences were further investigated by calculating the difference between mean search times for each pair of targets. These differences are shown in Table 7.2.9.

TABLE 7.2.9

Differences in mean search times for pairs of targets

Targets	14	3	16	13	17	1	15
14	--	3.52	4.97	8.86	8.97	12.42	13.63
3		--	1.45	5.34	5.45	8.90	10.11
16			--	3.89	4.00	7.45	8.66
13				--	0.11	3.56	4.77
17					--	3.45	4.66
1						--	1.21
15							--

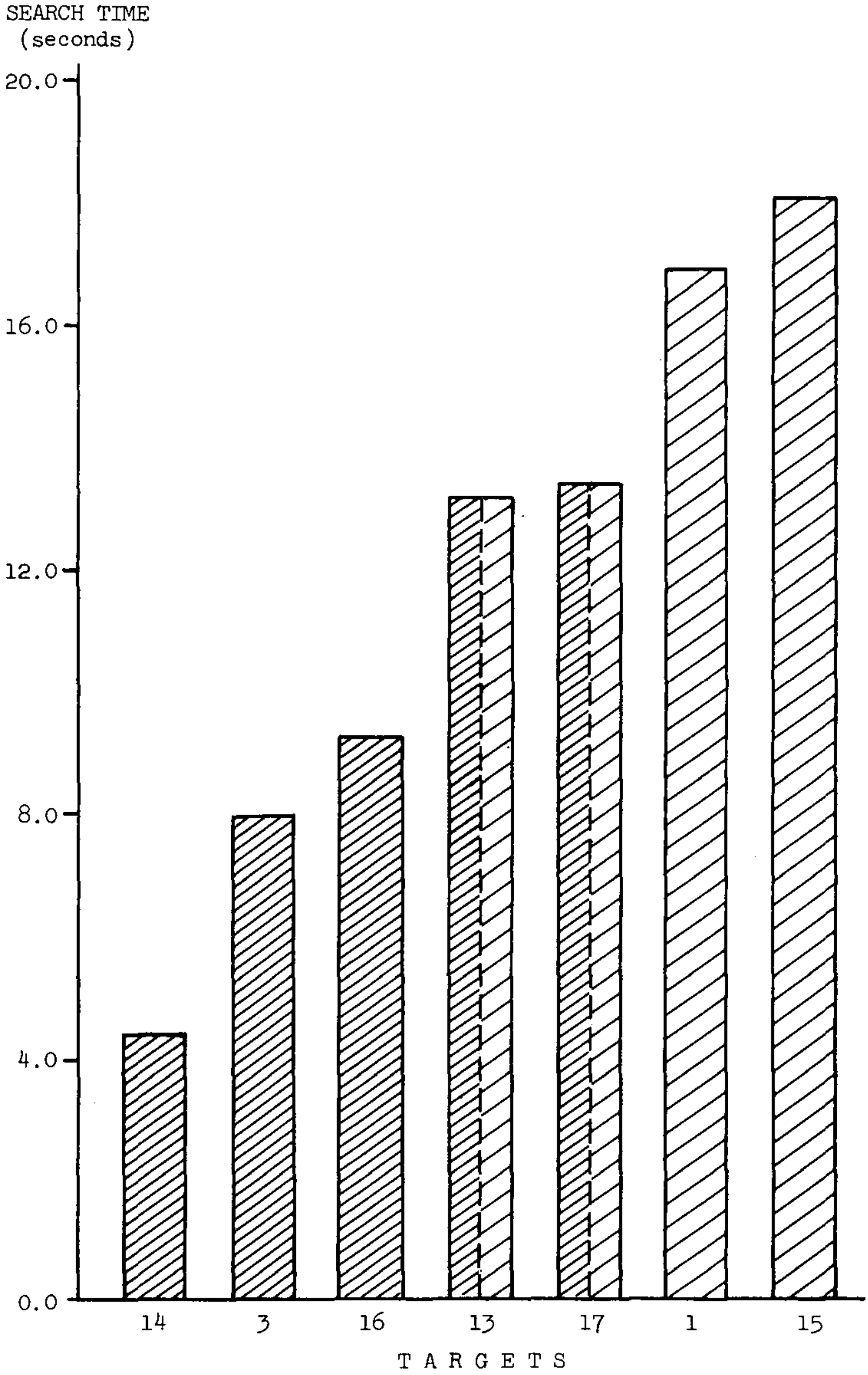
Significance at the 5% level is indicated by single underlining and at the 1% level by double underlining.

It can be seen from Table 7.2.9 that Targets 14, 3 and 16 required significantly shorter search times than Targets 1 and 15. The remaining two targets (17 and 13) are intermediate and significantly different only from Target 14. Mean search times are shown graphically in Figure 7.2.3 which can be compared with Figure 7.1.2. The inverse relationship between detection probability and search time is clearly shown.

FIGURE 7.2.3

Mean search time for each of the seven targets.

(Unskilled subjects)



NOTE The two different types of shading represent statistically significant differences between the mean search times. The combination of the two shadings indicates that these targets (Numbers 17 and 13) are not significantly different from either Targets 16 and 3 or Targets 15 and 1.

(d) Search time for correct and incorrect decisions

In carrying out the analyses of variance on the search time data no distinction was made between search times resulting in correct detections and those resulting in incorrect detections. To analyse the correct and incorrect decisions separately would have involved analysing an incomplete matrix. However, the mean search times associated with correct detections and those associated with incorrect detections were calculated for each of the main factors tested. In each case it was found that the mean search times were longer for the incorrect detections than for the correct ones. This is in agreement with the significant tau values shown in Table 7.2.8 which indicate a correlation between high detection probability and low search time.

Table 7.2.10 shows the mean overall search times, excluding range 4 miles, for correct decisions by unskilled and skilled subjects.

TABLE 7.2.10

Mean search times for correct and incorrect decisions

	Unskilled	N*	Skilled	N*
Correct decisions	9.0	79	6.2	27
Incorrect decisions	16.7	47	11.4	15
Overall	11.9	126	8.1	42

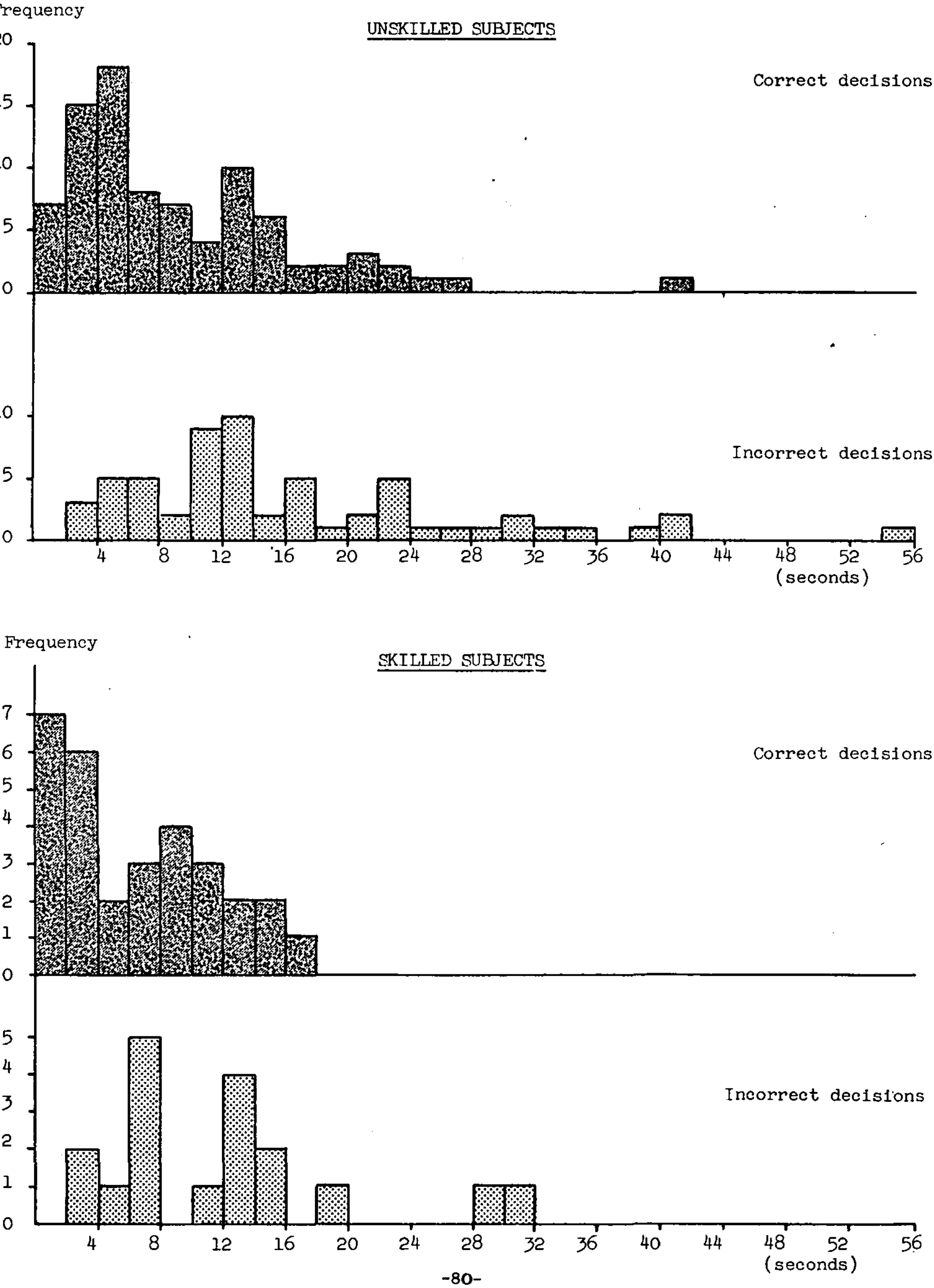
*N = number of readings on which the mean value is based.

The significance of the differences between the mean times for correct and incorrect decisions was determined by means of t-tests. For both skilled and unskilled subjects the differences were found to be highly significant, ($p < 0.001$). This confirms that correct decisions tend to be associated with shorter search times.

The time distributions of the correct and incorrect decisions are shown in Figure 7.2.4 for the unskilled and skilled subjects. These diagrams show that for both groups of subjects the incorrect decisions tend to occur after longer search times than the correct ones. Correct decisions, particularly for skilled subjects, are more tightly bunched and in both cases there are two clear-cut frequency peaks, although these occur at shorter search times for the skilled subjects.

FIGURE 7.2.4

Time distribution of correct and incorrect decisions



7.3 Confidence levels

After each target identification a confidence level judgement was recorded. This was a subjective measure on a seven-point scale of the degree to which the subject was certain of the correctness of his judgement. Complete certainty was indicated by 6, lesser degrees of confidence range from 5 to 1 and, in a few cases where the subject was unable to make a judgement this was indicated by 0.

The range 0 - 6 was chosen so that the zero confidence switch corresponded to a decision of 'no judgement', although these values appeared on the print-out as ranging from 1 - 7, i.e. one greater than the switch number. This difference did not affect the analysis which has been carried out on the 1 - 7 data.

The raw data on these confidence scores are shown in Tables 7.3.1 and 7.3.2 for unskilled and skilled subjects respectively. The corresponding analyses of variance are shown in Tables 7.3.3 and 7.3.4. For the unskilled subjects the significant factors are targets, ranges and groups. Navigational uncertainty and all interactions are non-significant. For the skilled subjects, only target differences reach the 5% significance level.

TABLE 7.3.1

Confidence levels associated with target identifications made by three groups of unskilled subjects

	Group A							Group B							Group C						
	Uncertainty 1			Uncertainty 2				Uncertainty 1			Uncertainty 2				Uncertainty 1			Uncertainty 2			
	Range			Range				Range			Range				Range			Range			
TARGETS	1	2	3	1	2	3	4	1	2	3	1	2	3	4	1	2	3	1	2	3	4
3	7	7	6	7	6	7	7	7	5	4	6	7	5	4	7	7	6	5	5	4	6
14	7	7	6	7	7	7	7	7	7	5	2	6	7	7	6	7	7	5	7	5	7
17	7	7	7	7	7	2	2	4	6	7	7	2	6	5	5	6	4	7	6	5	4
16	5	7	4	7	7	4	5	5	6	4	7	6	4	6	6	3	4	5	7	4	3
15	4	4	3	6	5	6	5	6	1	3	5	3	6	4	6	2	3	7	6	3	5
13	7	5	3	6	7	3	5	7	7	6	6	5	5	1	4	6	5	6	4	4	5
1	5	6	6	6	5	2	5	4	1	6	4	5	5	4	3	3	1	4	4	2	3

Confidence values range from 1 to 7, high values being associated with high confidence.

The range values are given in miles.

TABLE 7.3.2

Confidence levels associated with target identifications

made by skilled subjects

	Uncertainty 1			Uncertainty 2			
	Range			Range			
	1	2	3	1	2	3	4
3	7	6	7	7	7	5	7
14	7	7	7	7	7	7	7
17	7	7	4	7	5	5	5
16	5	7	7	3	6	7	5
15	5	6	5	5	5	3	7
13	2	6	4	7	7	2	6
1	5	3	2	6	3	2	6

Confidence level values range from 1 to 7, high values being associated with high confidence. The range values are given in miles.

TABLE 7.3.3

Analysis of variance on confidence level data for unskilled subjects shown in Table 7.3.1 *

Source	D.F.	S.S.	M.S.	V.R.	Significance
Uncertainties (U)	1	0.29	0.29	- (c)	N.S.
Ranges (R)	2	25.25	12.63	6.66(c)	$p < 0.005$
Targets (T)	6	71.83	11.97	6.31(c)	$p < 0.001$
Groups (G)	2	15.25	7.63	4.02(c)	$p < 0.025$
U x R	2	1.48	0.74	- (b)	N.S.
U x T	6	19.83	3.30	1.87(b)	N.S.
U x G	2	0.14	0.07	- (b)	N.S.
R x T	12	27.08	2.26	1.28(b)	N.S.
R x G	4	15.82	3.95	2.24(b)	N.S.
T x G	12	17.41	1.45	- (b)	N.S.
U x R x T	12	23.75	1.98	- (a)	N.S.
R x T x G	24	36.18	1.51	- (a)	N.S.
T x G x U	12	21.41	1.78	- (a)	N.S.
G x U x R	4	4.02	1.01	- (a)	N.S.
Residual (a)	24	49.09	2.05		
Pooled residual (b) (Residual (a) + URT, RTG, TGU, GUR)	76	134.45	1.77		
Pooled residual (c) (Pooled residual (b) + UR, UT, UG, RT, RG, TG)	114	216.21	1.90		
TOTAL	125	328.83			

* Confidence level data relating to Uncertainty 2, Range 4 miles have not been included in the analysis since there are no corresponding values for Uncertainty 1.

TABLE 7.3.4

Analysis of variance on confidence level data for skilled subjects shown in Table 7.3.2 *

Source	D.F.	S.S.	M.S.	V.R.	Significance
Uncertainties (U)	1	0.21	0.21	- (b)	N.S.
Ranges (R)	2	9.48	4.74	2.48(b)	N.S.
Targets (T)	6	51.57	8.60	6.31(b)	$p < 0.001$
U x R	2	3.00	1.50	1.10(a)	N.S.
U x T	6	5.95	0.99	- (a)	N.S.
R x T	12	35.86	2.99	2.20(a)	N.S.
Residual (a)	12	16.33	1.36		
Pooled residual (b) (Residual (a) + UR, UT, RT)	32	61.14	1.91		
TOTAL	41	122.40			

* Confidence level data relating to Uncertainty 2, Range 4 miles have not been included in the analysis since there are no corresponding values for Uncertainty 1.

(a) Navigational uncertainty

Table 7.3.5 shows the mean confidence scores recorded for each uncertainty condition for skilled and unskilled subjects, and the overall means.

TABLE 7.3.5

Mean confidence scores

	Uncertainty condition		Overall mean
	± 1 mile	± 2 miles	
Unskilled	5.2	5.3	5.25
Skilled	5.5	5.4	5.45

t-tests confirmed that there was no significant difference between the scores for the two uncertainty conditions for either group of subjects. The difference between the overall means for the unskilled and skilled subjects was also non-significant.

(b) Ranges

Mean confidence scores decreased with increasing range for unskilled subjects, but the trend was less consistent for the skilled subjects, as shown in Table 7.3.6.

TABLE 7.3.6

Confidence scores for each range.

	Range (miles)		
	1	2	3
Unskilled subjects	5.7	5.4	4.7
Skilled subjects	5.7	5.8	4.8

T-tests were carried out to determine the significance of the difference between the means for the three ranges. Table 7.3.7 shows the significance levels reached by the t-values.

TABLE 7.3.7

Significance of differences between range means.

	Range differences		
	1 - 2	2 - 3	1 - 3
Unskilled subjects	N.S.	$p < 0.05$	$p < 0.01$
Skilled subjects	N.S.	$p < 0.05$	N.S.

Differences between skilled and unskilled subjects were non-significant at each range.

(c) Target differences

A mean confidence score for each target was calculated for skilled and unskilled subjects. These values are shown in Table 7.3.8.

TABLE 7.3.8

Mean confidence scores for the seven targets.

	Unskilled subjects		Skilled subjects	
Target	Mean confidence score	Ranking	Mean confidence score	Ranking
14	6.2	1	7.0	1
3	6.0	2	6.5	2
17	5.7	3	5.8	3½
16	5.3	5	5.8	3½
15	4.4	6	4.8	5
13	5.4	4	4.7	6
1	4.0	7	3.5	7

The rankings of the targets, ordered according to mean confidence scores, are also shown in Table 7.3.8. Kendall's tau was evaluated to determine whether there was significant correlation between the rankings for unskilled and skilled subjects, and also to determine whether the rank order of targets based on confidence scores was correlated with rank orders based on detection probabilities and search times. The values of Kendall's tau and their significance are shown in Table 7.3.9. Values significant at the 5% level are underlined.

TABLE 7.3.9

Significance levels of tau values for rank correlations.

	Unskilled subjects		Skilled subjects	
	tau	Significance	tau	Significance
Confidence level/ detection probability	<u>0.68</u>	<u>$p < 0.05$</u>	<u>0.80</u>	<u>$p < 0.05$</u>
Confidence level/ search time	0.62	N.S.	<u>0.68</u>	<u>$p < 0.05$</u>
Confidence levels (unskilled/skilled)		<u>tau = 0.68</u>		<u>$p < 0.05$</u>

It can be seen in Table 7.3.9 that there is a significant correlation between the mean confidence levels assigned to targets by unskilled and skilled subjects. Mean confidence levels are also significantly correlated with detection probabilities and search times, (the one tau value in Table 7.3.9 which does not reach the 5% signifance level is very close to it). These correlations indicate that the performance of unskilled subjects is closely in accordance with that of skilled subjects, as found for other performance measures, and that high confidence levels are associated with high detection probabilities and low search times.

Since target differences were found to have a significant effect on confidence scores for both unskilled and skilled subjects in the analysis of variance (see Tables 7.3.3 and 7.3.4) the significance of differences between the mean confidence scores for targets shown in Table 7.3.8 was determined. Table 7.3.10 shows the difference between mean confidence levels for targets, (unskilled subjects only).

TABLE 7.3.10

Differences between mean confidence levels for targets.

TARGETS	1	15	16	13	17	3	14
1	-	0.39	1.28	1.33	1.67	2.00	2.22
15		-	0.89	0.94	1.28	1.61	1.83
16			-	0.05	0.39	0.72	0.94
13				-	0.34	0.67	0.89
17					-	0.33	0.55
3						-	0.22
14							-

Values singly underlined are significant at 5% level.
Values doubly underlined are significant at 1% level.

This table indicates that two of the targets No. 1 and 15, gave rise to significantly lower confidence scores than the other five targets, and that target 14 was associated with significantly higher confidence scores than all targets except Nos. 17 and 3. Otherwise differences were non-significant. These results are shown graphically in Figure 7.3.1 (c.f Figures 7.1.2 and 7.2.3).

(d) <u>Confidence levels for correct and incorrect decisions</u>

Mean confidence scores associated with correct and incorrect decisions were calculated for both groups of subjects. These values and the number of judgments (N) on which they were based are shown in Table 7.3.11.

<u>TABLE 7.3.11</u>

<u>Mean confidence scores for correct and incorrect decisions.</u>

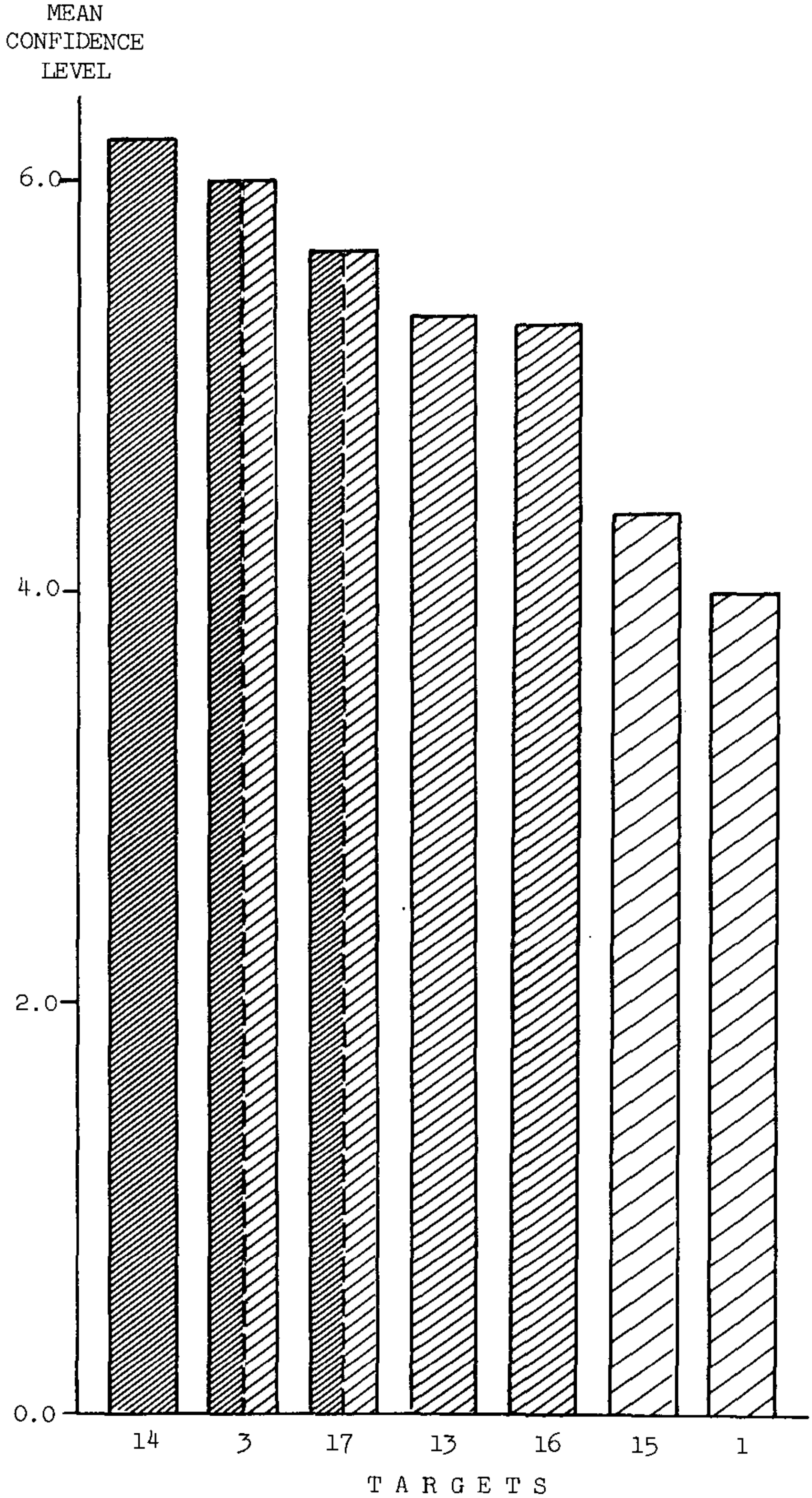
	Unskilled	N	Skilled	N
Correct	5.77	79	5.96	27
Incorrect	4.42	47	4.53	15
Overall	5.25	126	5.45	42

t-tests were carried out to determine whether the mean confidence scores for correct decisions were significantly different from those for incorrect decisions. For both skilled and unskilled subjects it was found that the differences were highly significant, ($p < 0.001$). As can be seen in Table 7.3.11 higher confidence scores are associated with correct decisions.

FIGURE 7.3.1

Mean confidence levels for the seven targets.

(Unskilled subjects)



NOTE The three different types of shading represent statistically significant differences between the confidence scores. The combination of two shadings indicates that the targets (Numbers 3 and 17) are not significantly different from targets shaded with either of the component shadings.

7.4 Map-briefing times

Subjects were allowed as much time as they required to brief themselves on the appropriate area of map around the target. It was emphasised that there was no pressure on them to work quickly during this part of the task. In practice it was found that, for the unskilled subjects, approximately 83% of the map times recorded were between 1 minute and 2 minutes, 8% being less than 1 minute and 9% greater than 2 minutes. The skilled subjects tended to work much more quickly, approximately 69% of the map briefing times being less than 1 minute.

The raw data on the map times is shown in Tables 7.4.1 and 7.4.2 for unskilled and skilled subjects respectively. The analysis of variance carried out on the data in Table 7.4.1 is shown in Table 7.4.3. The two significant factors are targets and groups. The fact that targets are a significant factor here suggests that different types of terrain and different degrees of 'clutter' in the target area influenced the amount of time the subject required to brief himself.

There was no significant effect due to navigational uncertainty although this might have been expected since a larger area of map had to be memorised for the condition of greater navigational uncertainty. Since the subject did not know the range at which the target would be presented no effect of range on briefing time would be expected and none was found. All interactions were non-significant.

Table 7.4.4 shows the corresponding analysis of variance for the skilled subjects. None of the main factors, or the interactions, reach the 5% significance level.

TABLE 7.4.1

Map-briefing times for the three groups of unskilled subjects

	Group A							Group B							Group C						
	Uncertainty 1			Uncertainty 2				Uncertainty 1			Uncertainty 2				Uncertainty 1			Uncertainty 2			
	Range			Range				Range			Range				Range			Range			
TARGETS	1	2	3	1	2	3	4	1	2	3	1	2	3	4	1	2	3	1	2	3	4
3	59.6	64.4	29.8	74.8	68.8	58.2	34.6	94.4	52.8	85.8	48.0	42.4	110.4	80.0	62.4	75.2	78.6	111.4	63.8	51.8	94.4
14	57.2	148.2	94.0	70.2	93.0	105.8	76.8	105.6	91.2	120.2	122.0	98.4	177.4	66.6	81.8	79.8	88.8	62.2	112.0	65.2	96.4
17	124.8	82.6	93.0	57.0	91.8	116.0	115.8	99.2	77.8	132.0	68.2	116.4	80.6	89.8	65.0	93.4	56.0	87.0	64.4	107.8	101.4
16	116.6	89.4	80.2	79.8	80.2	87.6	107.6	111.8	95.6	95.8	116.4	61.4	105.0	78.0	99.4	56.2	93.0	70.8	89.2	76.6	95.2
15	110.4	108.6	86.4	98.0	124.4	67.6	91.8	94.8	81.4	95.2	90.6	169.2	77.8	107.2	102.0	115.4	46.2	126.2	101.4	117.8	65.6
13	65.4	73.6	83.2	95.8	89.8	61.0	103.6	64.4	97.8	73.4	87.6	109.2	99.8	124.4	90.9	75.2	91.4	115.8	63.2	105.0	104.0
1	60.6	91.0	80.2	97.6	85.2	129.4	111.2	113.2	132.8	62.8	108.6	83.6	117.2	100.8	135.6	79.8	79.8	68.2	88.8	90.2	64.8

All times given in seconds.

The range values are given in miles.

TABLE 7.4.2

Map-briefing times for skilled subjects

	Uncertainty 1			Uncertainty 2			
	Range			Range			
	1	2	3	1	2	3	4
3	20.1	33.4	25.6	36.2	39.4	62.2	24.8
14	38.2	34.0	36.8	38.0	28.2	17.6	37.0
17	64.8	39.4	26.8	55.6	64.8	39.6	72.8
16	83.0	53.6	29.4	25.4	55.6	45.0	75.0
15	48.6	82.8	68.6	40.2	27.2	50.2	67.2
13	33.2	66.0	41.4	114.6	66.8	48.4	16.6
1	52.0	27.4	59.6	47.4	43.8	90.6	45.8

All times are given in seconds.

The range values are given in miles.

TABLE 7.4.3

Analysis of variance on map-briefing times for unskilled subjects shown in Table 7.4.1*

Source	D.F.	S.S.	M.S.	V.R.	Significance
Uncertainties (U)	1	449.18	449.18	- (c)	N.S.
Ranges (R)	2	3.79	1.90	- (c)	N.S.
Targets (T)	6	12437.90	2072.98	3.93(c)	$p<0.005$
Groups (G)	2	3388.12	1694.06	3.21(c)	$p<0.05$
U x R	2	1300.97	650.49	1.19(b)	N.S.
U x T	6	1755.91	292.65	- (b)	N.S.
U x G	2	81.65	40.83	- (b)	N.S.
R x T	12	8445.66	703.81	1.29(b)	N.S.
R x G	4	2097.29	524.32	- (b)	N.S.
T x G	12	4776.76	398.06	- (b)	N.S.
U x R x T	12	4279.86	356.65	- (a)	N.S.
R x T x G	24	11194.75	466.45	- (a)	N.S.
T x G x U	12	4941.16	411.76	- (a)	N.S.
G x U x R	4	228.51	57.13	- (a)	N.S.
Residual (a)	24	20962.34	873.43		
Pooled residual (b) (Residual (a) + URT, RTG, TGU, GUR)	76	41606.62	547.46		
Pooled residual (c) (Pooled residual (b) + UR, UT, UG, RT, RG, TG)	114	60064.86	526.88		
TOTAL	125	76343.85			

* Map briefing data relating to Uncertainty 2, Range 4 miles have not been included in the analysis since there are no corresponding values for Uncertainty 1.

TABLE 7.4.4

Analysis of variance on map-briefing times for skilled subjects shown in Table 7.4.2 *

Source	D.F.	S.S.	M.S.	V.R.	Significance
Uncertainties (U)	1	123.77	123.77	- (b)	N.S.
Ranges (R)	2	112.44	56.22	- (b)	N.S.
Targets (T)	6	3809.17	634.86	1.56(b)	N.S.
U x R	2	211.95	105.97	- (a)	N.S.
U x T	6	3726.22	621.04	1.52(a)	N.S.
R x T	12	4167.27	347.27	- (a)	N.S.
Residual (a)	12	4899.49	408.29		
Pooled residual (b) (Residual (a) + UR, UT, RT)	32	13004.92	406.40		
TOTAL	41	17050.31			

* Map briefing data relating to Uncertainty 2, Range 4 miles have not been included in the analysis since there are no corresponding values for Uncertainty 1.

(a) Navigational uncertainty.

Table 7.4.5 shows the mean map-briefing times under each uncertainty condition. The overall means for unskilled and skilled subjects are also shown.

TABLE 7.4.5

Mean map-briefing times for each uncertainty condition

	Uncertainty condition		Overall mean
	$\pm$ 1 mile	$\pm$2 miles	
Unskilled subjects	87.7	91.5	89.6
Skilled subjects	45.9	49.5	47.7

The time values are given in seconds.

Differences between the means for the two navigational uncertainty conditions were shown to be non-significant by t-tests for both skilled and unskilled subjects. This confirmed the results of the analyses of variance. The difference between the overall mean map-briefing times for the skilled and unskilled subjects was highly significant ($t = 11.25$, D.F. = 146, $p < 0.001$), the skilled group requiring on average little over half the time required by the unskilled group.

(b) Target differences

The mean times required for map briefing on each target are shown in Table 7.4.6. The data from range 4 miles are excluded.

TABLE 7.4.6

Mean map-briefing times for the seven targets.

	Unskilled subjects		Skilled subjects	
Target	Map-briefing time (seconds)	Ranking	Map-briefing time (seconds)	Ranking
3	68.5	1	36.2	2
14	98.5	6	32.1	1
17	89.6	4	48.5	3
16	89.2	3	48.7	4
15	100.7	7	52.8	5
13	85.7	2	61.7	7
1	94.7	5	53.5	6

Kendall's rank correlation coefficient, tau, was evaluated for the two sets of rankings shown in Table 7.4.6. Kendall's tau values were also calculated to see if there were any correlations between these rankings and the rankings according to the three other measures of performance, detection probability, search time and confidence level.

Table 7.4.7 shows the values of Kendall's tau. It can be seen that only one of these values is significant at the 5% level or higher. This indicates that in general the mean length of time taken in map-briefing for a particular target is not related to subsequent performance at detecting the target.

TABLE 7.4.7

Significance levels of tau values for rank correlations

	Unskilled subjects		Skilled subjects	
	tau	Significance	tau	Significance
Map-briefing time/ detection probability	0.10	N.S.	0.59	N.S.
Map briefing time/ search time	0.43	N.S.	0.52	N.S.
Map-briefing time/ confidence level	0.24	N.S.	0.88	$p < 0.01$
Map-briefing time (Unskilled/skilled)			tau = 0.05	N.S.

The significance of the correlation between map times and confidence level rankings for skilled subjects suggests that the less time spent on map briefing the greater the confidence in the detection judgment. This apparently anomalous result is not in accordance with the other performance data and could possibly have arisen by chance.

7.5 Relationship between detection performance and measures made in the preliminary tests.

During the preliminary tests numerical values relating to each subject's intelligence and personality were obtained. These scores were analysed to determine whether detection performance, in terms of number of test targets correctly detected and mean search time, was related to intelligence or personality variables, or, in the case of skilled subjects, to experience as measured in flight hours.

Tables 7.5.1 and 7.5.2 show the mean and standard deviation values for the scores obtained on Heim's A. H. 5. test of high-grade intelligence, and on Eysenck's personality inventory, which gives values relating to the subject's extraversion-intraversion (E) and neuroticism (N). For comparison purposes the relevant population norms are also shown. The distributions of these scores are shown in Figure 7.5.1.

TABLE 7.5.1

Unskilled subjects.

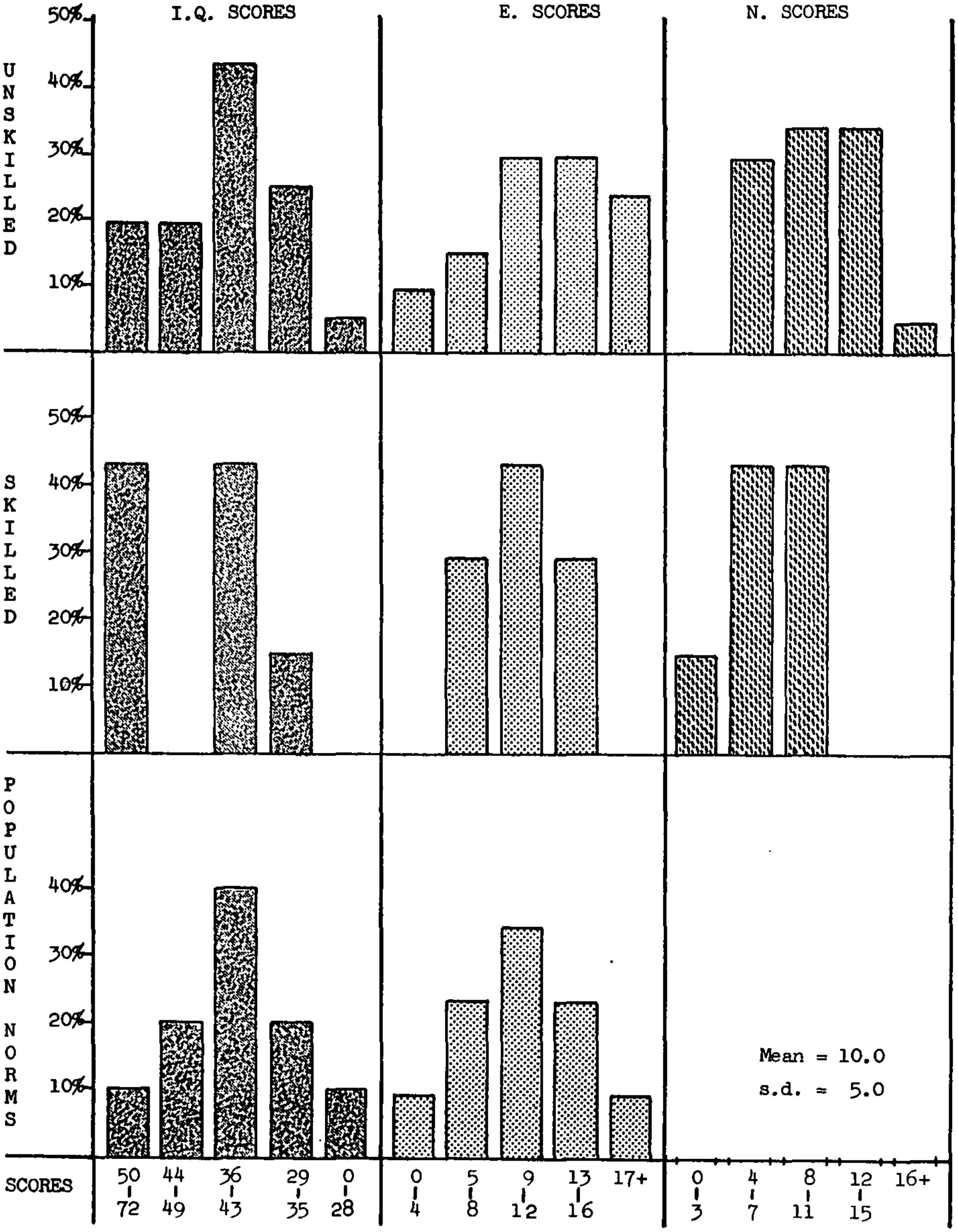
	Subjects tested. (21 students)		Population norms.*	
	Mean	s.d.	Mean	s.d.
A. H. 5. intelligence score	41.7	7.4	39.1	8.3
Eysenck personality inventory.				
E	12.7	4.6	11.1	4.5
N	10.0	3.8	10.0	5.0

* Population norms for the A. H. 5. values and the Eysenck E and N values relate to students.

Average age of the 21 students was 21.3 years.

FIGURE 7.5.1

Distribution of I.Q. scores, E scores and N scores.



NOTE The population distribution of N scores has not been shown as the distribution is asymmetric and cannot be derived from the mean and s.d. values given.

TABLE 7.5.2

Skilled subjects

	Subjects tested. (7 R.A.F. pilots and navigators)		Population norms.	
	Mean	s.d.	Mean	s.d.
A. H. 5 intelligence score	43.7	11.1	39.9	6.7
Eysenck personality inventory.				
E	11.0	2.9	11.1	4.5
N	6.7	3.3	10.0	5.0

* Population norms for the A. H. 5. scores relate to R.A.F. permanent commission candidates and for the Eysenck E and N values to students.

Average age of the 7 aircrew was 33.3 years.

Calculation of the standard error of the sample means for each of the three factors showed that there was no evidence that either the skilled or the unskilled subjects differed significantly from the populations with which they are compared.

Differences between skilled and unskilled subjects were non-significant for I.Q. scores and for E scores, but the skilled group had a significantly lower N score, i.e. they were less neurotic than the unskilled group.

The relatively high value of the standard deviation of the I.Q. scores for skilled subjects reflects the fact that in this respect the skilled subjects were a less homogenous group than the unskilled ones. There appeared to be a considerable difference between the pilots and the navigators who made up the skilled group, exceptionally high scores being recorded for the pilots and relatively low ones for the navigators.

For each subject two measures of detection performance were calculated. These were (a) accuracy, i.e. the number of correct detections out of the seven test targets and (b) mean search time, i.e. the mean of the search times recorded for the seven targets. Correlation tests were carried out to determine whether an individual's detection performance was related to his intelligence or personality. Subjects, unskilled and skilled considered separately, were ranked according to accuracy and these rankings were compared with those relating to the I.Q., E and N scores by means of the Kendall rank correlation coefficient, tau. Similarly, comparisons were made between rankings according to mean search time and the I.Q., E and N rankings. Finally, the rankings for accuracy and search time were compared for each group of subjects.

The values of Kendall's tau and their significance are shown in Table 7.5.3.

TABLE 7.5.3

Correlations between psychometric measures and individual performance

	Unskilled subjects		Skilled subjects	
	Accuracy	Mean time	Accuracy	Mean time
I.Q.	tau = 0.494 z = 3.14 $p < 0.002$	tau = -0.024 z = 0.156 p = 0.87	tau = 0.466 p $\simeq$ 0.34	tau = -0.489 p = 0.18
E	tau = -0.051 z = 0.324 p = 0.75	tau = -0.055 z = 0.346 p = 0.73	tau = 0.356 p $\simeq$ 0.40	tau = 0.056 p = 1.00
N	tau = -0.147 z = 0.933 p = 0.35	tau = -0.501 z = 3.18 $p < 0.002$	tau = 0.593 p $\simeq$ 0.15	tau = -0.731 p = 0.06
Flying experience	-	-	tau = 0.733 $p < 0.06$	tau = 0.429 p = 0.24
	Accuracy/mean time, tau = 0.011 z = 0.070 p = 0.94		Accuracy/mean time, tau = -0.621 p = 0.11	

NOTE A positive correlation in this table indicates that high accuracy and low mean time, i.e. good performance, was associated with high I.Q., low E score, low N score and greater flying experience at the probability levels shown.

The values shown in Table 7.5.3 indicate that for the unskilled subjects high accuracy is very significantly related to high I.Q. score, whereas for skilled subjects there is no significant relationship. This is an interesting result and one that has important implications in the preliminary screening of unskilled subjects for future experiments. Mean search time however is not related to I.Q. for either skilled or unskilled subjects.

Table 7.5.3 also shows that detection performance is apparently not related to an individual's E score, but that for both skilled and unskilled subjects low mean search time is related to a high N score. This suggests that those subjects who were likely to find the situation more stressful, i.e. the more neurotic ones, were the ones who worked more quickly.

One other significant result shown is that a subject's experience, as measured in flight hours, was related to his accuracy; the pilots with greater experience being more accurate. This is a reassuring result in terms of the suitability of the simulated task but one that should be regarded with caution since it does not quite reach the 5% level.

7.6 Summary of results

For convenient reference the main results obtained from this experiment have been summarised in tabular form on the following pages.

TABLE 7.6.1

Summary of results for unskilled subjects

	DETECTION PROBABILITY	SEARCH TIME	CONFIDENCE LEVEL	MAP-BRIEFING TIME
NAVIGATIONAL UNCERTAINTY	No significant effect. Page 56	No significant effect. Page 70	No significant effect. Page 86	No significant effect. Page 97
RANGE	Significant linear relationship between increasing range and decreasing detection probability. Detection probabilities fell from 0.74 at 1 mile to 0.52 at 3 miles. Pages 56 - 60	Significant linear relationship between increasing range and decreasing search time. Mean search times increased from 9.7 secs. at 1 mile to 14.0 secs. at 3 miles. Pages 71 - 73	Significantly higher confidence scores for lower ranges. Page 87	No effect found (None was expected since the subject was not told the range of the target while briefing himself on the map). Page 92
TARGET DIFFERENCES	Detection probabilities varied from 1.00 to 0.28 for the seven targets. Significant differences between easy, average and difficult targets. Pages 60 - 63	Significant differences in mean search times between easiest and most difficult targets. Range: 4.4 - 18.1 secs. Pages 74 - 77	Significant differences between targets. Pages 87 - 90	Significant differences but rankings on map-briefing time not related to rankings on other performance measures. Pages 97 - 99
DIFFERENCES BETWEEN SKILLED AND UNSKILLED SUBJECTS	No significant differences. Overall detection probability was 0.59 for the unskilled and 0.61 for the skilled group. Pages 56 - 57	Skilled group were significantly faster than unskilled group, but target rankings on search time were closely similar for each group. Pages 74, 79-80	No significant differences Pages 86 - 88	Skilled group were significantly faster than unskilled group. Page 97

TABLE 7.6.2

Summary table showing the significance of the correlations between the target rankings on the four performance measures.

	Detection probability	Search time	Confidence level	Map-briefing time
Detection probability	0.95* $p < 0.01$	0.68 $p < 0.05$	0.68 $p < 0.05$	0.10 N.S.
Search time	0.68 $p < 0.05$	0.81* $p < 0.01$	0.62 N.S.	0.43 N.S.
Confidence level	0.75 $p < 0.05$	0.68 $p < 0.05$	0.68* $p < 0.05$	0.88 $p < 0.01$
Map-briefing time	0.59 N.S.	0.52 N.S.	0.24 N.S.	0.05* N.S.

*These values of Kendall's tau relate to the correlation between the target rankings for unskilled and skilled subjects on each of the four performance measures.

Values above and to the right of the diagonal line relate to the correlations between the rankings for unskilled subjects on each pair of measures, and those below and to the left of the diagonal line are the corresponding values for skilled subjects.

This table shows clearly that rankings on map-briefing times are not, with one exception, correlated with any of the other rankings, or between skilled and unskilled subjects. The other correlation values, again with one exception, reach the 5% significance level or better indicating a consistent tendency for greater detection probability to be associated with shorter search times and higher confidence levels. The table also shows that there is a close correspondence between the performance of the skilled and unskilled subjects.

8. DISCUSSION OF EXPERIMENTAL TECHNIQUES

Since this was a preliminary experiment, intended to investigate the general suitability of the experimental method and to establish a baseline of detection performance, on which future work could be based, the results should be considered in relation to these aims. The discussion can therefore be conveniently divided into two parts. In this section the general suitability of the apparatus, experimental material, subjects and analytical techniques used is assessed, and in Section 9 the specific results obtained are considered.

8.1 Display apparatus

The display and recording apparatus designed for this experiment proved satisfactory. The display apparatus provided a simple and flexible method of displaying the maps and photographs as required. Although only the centre portion of the original photograph was displayed in this experiment, in designing the apparatus provision was made for displaying any portion of the original photograph in the centre of the subject's field of view. Illumination and viewing distance could both be varied but in this work they were kept constant at predetermined values. This flexibility was incorporated into the design of the display apparatus so that later experiments could be carried out without modification of the equipment. The timing and recording apparatus was reliable and accurate to 0.2 seconds. Throughout this work both the display and recording equipment functioned satisfactorily with no failures.

8.2 <u>Maps.</u>

In general there are three important factors to be considered in assessing the suitability of various types of maps for aerial navigation tasks. These are:-

(i) amount of detail shown,

(ii) scale, and

(iii) orientation of map in relation to the heading of the aircraft.

The maps used in this experiment were sections cut from a standard Ordnance Survey map, scale 1" = 1 mile. These maps are primarily intended for use on the ground and show much more detail than is visible from an altitude of 2,000 feet. In addition, the inclusion of a large number of place names gives the maps a cluttered appearance. In a dynamic simulation of a typical aircraft navigation task it was found that pilots were able to maintain geographic orientation equally well whether or not the place names of geographic features were included on the map (McGrath, Osterhoff and Borden, 1964).

In fact, Angwin (1957) has recommended that on maps intended for high-speed low-level flight place names should be severely limited in comparison with the profusion customary in general purpose charts. He also suggests that when place names are included for the purpose of communication or flight planning the selection of features to be named should be based on a system which provides a fairly even and well-spaced pattern rather than on population, size or similar criteria.

A number of the subjects who took part in the present experiment commented that they found the maps too detailed and it is possible that the use of simplified maps, showing only those features which could be detected in the photographs, and omitting place names, would improve performance.

The map scale of 1" = 1 mile (1 : 63,360) used in this experiment was greater than that with which the skilled subjects normally worked. McGrath et al (1964) have shown that in a dynamic simulation a change in map scale did not affect orientation performance except when accompanied by a change in information content. He found no differences between performance when a 1 : 1,000,000 map was used and when the map was enlarged to 1 : 500,000. However, differences between two types of maps of different information content were significant in terms of navigation performance.

Work reported by Heap (1965) indicates that T.V. navigation performance at high aircraft speeds is significantly improved by the use of 1 : 250,000 ($^1/4$M) maps instead of 1 : 500,000 (½M). The overall density of useful terrain features, (1.3 per mile), shown in ½M maps is less than half that shown on $^1/4$M maps, (3.0 per mile). For 1" = 1 mile maps this value rises to approximately 3.9 per mile. These values relate to Southern England. However, in high-speed flight the handling problems are considerable when the relatively large scale 1" = 1 mile maps are used. Heap therefore recommends the use of $^1/4$M maps under operational conditions.

No map handling problems were involved in the present static simulation experiment and therefore in this respect there was no drawback to the use of 1" = 1 mile maps.

The problem of map orientation has also been studied by McGrath et al (1964). They outline three possible ways of orientating a map with respect to the viewer in an airborne navigation situation:

(i) The map may be fixed in a 'North-up' position.

(ii) The chart may rotate when the aircraft turns so as to maintain a 'heading-up' position.

(iii) The chart may rotate so as to constantly maintain a 'track-up' position even when the aircraft is travelling crab-wise into cross-winds.

Louks (1949) suggested that the North-up position orientation would be most suitable for navigation displays. In this orientation all figures and place names are upright. A recent experiment (Upton, Willis and Dougherty, 1964) has shown that map orientation had no affect on either accuracy or speed in reading numbers, but that there was a twelve-fold increase in errors, and more than a three-fold increase in response latency, in reading names when the map was inverted as compared with the upright position. In this respect therefore, the 'North-up' map orientation is favoured. However, if place names are of little or no value in carrying out an aerial navigation task, and can be almost completely omitted from air-maps without affecting performance, then there is little need to retain 'North-up' displays, which have serious disadvantages.

McGrath et al (1964) favour a flexible display system in which map orientation is optional, since they consider that none of the three possible systems are alone adequate for all types of navigation problem. This is in agreement with the experimental findings of Payne (1952) and Narva (1958).

In the present work the 'North-up' display system was used and many subjects particularly the skilled air-crew commented that it was difficult to read the map in this orientation especially when the air-craft track was due South.

8.3 Photographic material.

The photographic display material used in this experiment was intended as preliminary material only and no attempt was made to control factors such as target/background contrast, target size, meteorological conditions, masking effects, etc. Thus the results must be interpreted with some caution. Factors over which some degree of control was attempted were; camera field of view and angle of inclination, range at which target was photographed and line of approach to the target.

However, during the course of this experiment it became apparent that some of the target photographs had not been exposed under the specified conditions of range, altitude and camera angle of inclination. Although the errors were in general only slight it could be seen that in some instances the photographs had been taken from positions up to ½ mile away from those specified. Normally these discrepancies, and those which arose from the fact that the points from which the four photographs of each target were taken, were not always co-linear, were allowed for by the $\pm$ 1/4 mile off-track error introduced into the navigational uncertainty parameter. However, in a few cases it appeared that the photographs had been taken from outside the area of navigational uncertainty which was designated according to the grid references given (see Appendix I). Thus the information given to the subject was not always completely accurate. It is unlikely though that the subject's performance was significantly affected by this since it only occurred in a few photographs and the errors were small relative to the overall search area.

A further lack of control over the exposing of the photographs was evident from the wide variation in the position of the horizon which varied in the 8" x 8" photographs from less than 1 inch to

3 inches below the top of the photograph. Although some variation would be expected from different areas of terrain and varying amounts of cloud, the extent of the variation in horizon level and a study of the terrain shown in the foreground suggested that camera angle of inclination was not kept constant for all the photographs.

Since the angle of inclination of the camera affected the extent of the 'dead-space' in front of the aircraft it was of some importance in briefing the subjects that this angle was as specified. However, masking the photographs so that the horizon was always $^1/4$ inch below the top of the portion displayed largely compensated for any variation in camera inclination when the photographs were taken. This portion was calculated to be in the centre, vertically, of the original 50^{o} photograph when the camera inclination was 10^{o}. In cases where the angle of inclination had not been 10^{o} the portion displayed was not central vertically but showed the required portion of the terrain, i.e. the terrain that would have been in the centre of the 50^{o} photograph had the camera inclination been correct. Distortion effects caused by this asymetric masking were negligible.

8.4 Subjects.

The students who acted as unskilled subjects in this experiment were, on average, more than 10 years younger than the skilled aircrew but comparable in intelligence and personality.

Motivation, although it could not be quantitatively assessed, was an important factor in this experiment, particularly among the unskilled subjects who were required to learn a new task. All the students who took part were volunteers and, on the whole, they showed a high degree of interest in the experiment. Motivation appeared to be further increased by the payment they received for participating. In general it seemed that students were a very suitable group to act as unskilled subjects in this experiment since their intelligence and personality characteristics corresponded closely with those of the skilled aircrew, and there was no shortage of volunteers.

8.5 Analytical techniques.

Most of the statistical methods used in analysing the results of this experiment were simple and conventional techniques. As indicated in Section 6, Experimental results, the only serious difficulty was the analysis of the quantal data relating to detection probabilities. The conventional techniques applied were not well suited to this type of data. However, the general trends revealed by these conventional methods were closely in accordance with those found from the Logit analysis, a sophisticated technique applicable to quantal data.

Another difficulty in analysis arose from the imbalance between the two conditions of navigational uncertainty. This necessitated the exclusion of data relating to the 'Range 4 miles' condition from many analyses, particularly the analyses of variance, thus inevitably some information on the effect of the 4 miles range on detection performance was lost.

However in general the statistical methods used revealed consistent and meaningful results, broadly in accordance with expectation. This confirmed the validity of the initial assumptions made in the statistical design of the experiment, (see Section 3, Experimental Design).

9. DISCUSSION OF EXPERIMENTAL RESULTS.

In this section the results of this experiment are discussed in terms of the specific aims of the investigation, i.e. to determine the effect of navigational uncertainty, range and target difficulty on detection performance; to investigate performance differences between skilled and unskilled subjects; and to assess the extent to which performance differences between individuals were associated with differences in intelligence and personality.

9.1 Navigational uncertainty.

Navigational uncertainty was not observed to have a significant effect on any of the performance measures made in this experiment. In fact, in most cases the results obtained for the two uncertainty conditions were very similar. Three possible explanations of this result can be suggested:

(i) The levels of navigational uncertainty chosen, $\pm$ 1 mile and $\pm$ 2 miles, were possibly not sufficiently high to demonstrate any effect. The corresponding areas of map with which the subject had to familiarise himself did not differ greatly although under the $\pm$ 1 mile condition the maximum range was 3 miles and under the $\pm$ 2 mile condition the maximum range was 4 miles. It is possible that had a higher level of uncertainty, e.g. $\pm$ 5 miles, been investigated some effect would have been apparent but this would have involved a much more extensive experiment in terms of both experimental material and number of subjects required.

(ii) A second possible explanation is that the effect of navigational uncertainty cannot be demonstrated under static conditions, since in the airborne situation positional uncertainty is related to aircraft speed. Dynamic simulation methods could be used to investigate this possibility.

(iii) Finally, there is the possibility that navigational uncertainty at the levels tested has in fact no effect on target detection performance in the operational situation. This could be true under some conditions but many other factors, e.g. aircraft speed, altitude, visibility etc. are involved and the lack of control inherent in flight trials make investigation difficult.

Without further experimentation it is impossible to say whether any of these possibilities, or a combination of them, is the explanation of the negative results obtained in this experiment. However, the very fact that such a consistent negative result was obtained is in itself of interest.

9.2 Ranges.

A significant deterioration in detection performance with increasing range was observed. The two basic performance measures, detection probability and search time were found to be linearly related to range for unskilled subjects. In general, differences observed between the measures for the 1 mile and 3 mile ranges were significant but the single mile differences, i.e. those between 1 mile and 2 miles, and between 2 miles and 3 miles, gave rise to differences in the performance measures which were non-significant although consistent with the general trends. With a larger number of subjects it is likely that these differences would have reached significance.

The linear regression of detection probability on range can be regarded as predictive of performance only between the limits of 1 and 4 miles tested. To extrapolate the regression line to, say, 6 miles would give an unrealistic estimate of detection probability at that range. The value predicted is approximately 0.2 whereas in fact none of the targets could be detected at that range. Mean confidence levels decreased significantly with increasing range, as would be expected, but the relationship was not a linear one.

9.3 Target differences.

The results of the analyses of variance carried out on the data obtained in this experiment indicated that target differences were the largest source of variation for each of the performance measures. The magnitude of this variation tended to dwarf that due to other factors. Target differences were also the most difficult factor to control since they depended on so many interacting factors, e.g. size and shape of target, contrast between target and background, masking by other features, nature of terrain and meteorological conditions. Furthermore, the relative importance of these factors can vary with range although no significant ranges x targets interaction was observed in this experiment. Thus it was impossible to quantitatively control target differences in the same way as the other two main factors, navigational uncertainty and range.

Target differences therefore could only be analysed on the basis of an ordinal or ranking scale. It can be seen from the rank correlation coefficients that the rankings of the targets according to detection probability, search time and confidence level were closely related and also that there was very good agreement in these rankings for skilled and unskilled subjects. Thus, although target differences could not be objectively predetermined according to contrast, size, etc., the results showed a high degree of consistency. In addition, significant differences were found in the performance measures between those targets which were 'easy', i.e. had a high detection probability and low search time, and those which were 'difficult', i.e. had a low detection probability and high search time. To investigate target differences more exactly a much larger number of targets would be required, together with a greater degree of control over the exposing and processing of the photographs.

9.4 Differences between skilled and unskilled subjects.

One of the most important results observed in this experiment was the close similarity between the performance of skilled and unskilled subjects. The only significant differences found were that the skilled group took less time in searching for the target and less time in map-briefing. This result has significant implications for future experiments since large numbers of subjects may be required and aircrew experienced in high-speed, low-level flight may not be available. Detection probability, the basic performance measure in this experiment, was almost equal for the skilled and unskilled subjects, whereas it might have been expected that the skilled group would have shown a higher overall detection probability. However the static nature of the simulation made the experimental task unrealistic in terms of the operational experience of the skilled subjects, and possibly dynamic simulation techniques would reveal differences between the skilled and unskilled subjects.

9.5 Relationship between detection performance and measures made in the preliminary tests.

The measures made in the preliminary tests, i.e. the assessment of intelligence and personality scores for each subject, were intended to determine whether performance was related to these factors. The results showed that for the unskilled subjects detection performance was positively and significantly related to intelligence. This was reasonable in view of the fact that these subjects were being asked to learn a new and unfamiliar task and the more intelligent subjects could be expected to learn more effectively in the time available. This result has important implications for future work since it suggests that an intelligence test could be used to screen potential subjects and eliminate those who would be less likely to be successful at the experimental task. For the skilled subjects intelligence test score was not significantly related to detection performance, possibly because, since the task was not entirely unfamiliar to them, less learning was involved.

Of the two personality variables measured, extraversion-introversion and neuroticism, only the latter was found to relate significantly to detection performance. Subjects with a high N score were found to work more quickly, i.e. they had shorter mean search times, than those with lower N scores. For the skilled subjects mean search times were also related to N scores although at a lower significance level. In addition, for these subjects there was a positive relationship between experience, as measured in flying hours, and accuracy. However, since there were only seven subjects in the group and the relationship was only of borderline significance, ($p < 0.06$), this result must be regarded with caution, although it is reassuring in terms of the suitability of the experimental task.

10. FURTHER WORK.

This experiment was intended to establish a base-line of performance under favourable viewing conditions, i.e. good illumination, relatively short viewing distance, no degradation of the photographic material and unlimited viewing time. In experiments at present being carried out the effect on detection performance of longer viewing distances, display degradation and limited viewing time is being investigated, and will shortly be reported.

Throughout this experiment it was clear that the subject's main difficulties arose from inability to transform the plan information obtained from the map into the perspective view of the terrain as seen from the air. This suggested that one method of improving performance would be to provide the subject with a perspective drawing of the target area derived from the map, as additional briefing material, i.e. to transform the map information into a perspective view for the subject instead of expecting him to carry out this transformation mentally. The degree of complexity of the drawing, i.e. whether an artist's view, or simply a diagrammatic representation is more effective would be an important aspect of this study. At present this work is only at an early stage but suitable briefing material is being developed.

The question of map orientation and information content is also relevant to this programme. An experiment to investigate the effect of map orientation in this static detection task is shortly to be carried out and further work on map information content is being considered.

Finally, it is hoped that a comparison of performance under conditions of static and dynamic simulation will be attempted since this is obviously of fundamental performance in assessing the results obtained from static simulation experiments in terms of operational requirements.

APPENDICES

APPENDIX I

Targets and Photographic Points

All points are on Sheet 169 of the 1 inch OS map

Target	1 mile point	2 miles point	4 miles point
1. Aldershot Garrison Church SU854510	Fleet Road, Near Rushmoor Arena SU852524	Iveley Gate SU852546	Edge of wood, Fox Lane area SU850575
2. Aldershot Gas Holders SU882501	Railway junction SU883519	North Camp Station SU886537	The Green, at Frimley Green SU888567
3. Fleet Station SU816552	Bramshot SU830555	Railway, near Southwood camp SU846557	Rail over rail crossing at Farnborough Street SU878562
4.* Wokingham Church SU805680	Road/rail crossing SU792700	Winnersh Station SU781708	Earley Station SU753719
5. Wellington Monument SU717616	Road fork SU732608	Road/river crossing SU749600	Road fork on A30 SU781583
6. Road/river bridge E. of Shinfield SU743678	Wood adjacent to river SU734660	Swallowfield Church SU732648	Wellington Monument SU717616
7. Rail/road bridge SU651545	Minor road SU663542	Minor road junction SU681541	Cross-roads (A30) SU713534
8. Level crossing Bramley Station SU655594	Road junction, Bramley Green SU664589	Road fork, Sherfield-on-Loddon SU680580	Rotherwich Church SU712562
9. Buildings, Odiham Airfield SU737496	Minor road junction SU719492	Upton Grey Church SU697485	Winslade Church 5¼ miles from target SU654481
10. Rail/road bridge W. of Chawton SU703373	Wood SU720370	Cross-roads SU734366	Road junction SU770360
11. Roundabout S.W. of Farnham SU829459	River close to road SU815451	Bull Inn(on N. side of dual carriageway) SU803444	Start of dual carriageway, W. of Bentley SU771434

APPENDIX I cont'd

Target	1 mile point	2 miles point	4 miles point
12. Lasham Aerodrome SU675435	Middle of wood SU686426	Minor road junction S. of Shalden SU699416	Alton Station SU723397
13. Cross roads, Bordon Camp SU799366	Station and rail fork SU789361	Road junction SU770360	Road junction SU739349
14. Frensham Great Pond SU845403	Road fork SU833390	Minor road SU821382	Bordon Camp SU795365
15. Cross Roads at Hindhead SU887356	Grayshott Church SU872354	Waggoners Wells SU861343	Road fork SU828333
16. Chiddingfold Village SU962355	Cross-roads SU971342	Bend in road SU985331	Plastow Church TQ005310
17. Charterhouse School SU964451	Road junction in Godalming SU973439	Minor cross-roads SU982426	Minor road junction SU999398
18. Rail/road bridge S. of Liphook SU838302	S. edge of Forest Mere SU819298	Bend in railway entering a cutting SU802291	Liss Station SU886277
19* Bracknell Station and road/rail bridge SU869689	Road junction SU882690	Cross-roads SU900689	Road junction SU933687
20. Major road-over-road crossing SU966486	Railway entering cutting SU968502	Road junction SU970519	Road triangle SU964548

* Target photographs not provided.

APPENDIX II

Preliminary assessments of target detection difficulty by two experienced navigators

TARGET NUMBER AND NAME	RANGE 1 mile A	B	2 miles A	B	3 miles A	B	4 miles A	B	OVERALL A	B	FINAL RANKING
1. Aldershot Garrison Church	7	6	7	7	7	7	7	7	7	7	7
2. Aldershot Gas Holders	1	2	2	3	6	5	7	7	3	4	4
3. Fleet Station	1	1	1	1	3	2	5	3	1	1	1
5. Wellington Monument	1	2	3	3	7	5	7	6	3	4	3
6. Road/river bridge, East of Shinfield	3	4	4	6	6	7	7	7	4	6	4
7. Rail/road bridge	2	3	5	3	7	5	7	7	4	5	4
8. Level crossing at Bramley Station	1	1	2	3	3	4	5	6	2	3	3
9. Buildings at Odiham Airfield	1	1	1	2	3	3	7	6	2	2	2
10. Rail/road bridge, West of Chawton	2	3	4	5	7	7	7	7	5	5	5
11. Roundabout, South West of Farnham	1	1	1	2	3	4	5	5	1	2	1
12. Lasham Aerodrome	1	1	1	1	1	1	1	1	1	1	1
13. Cross-roads at Bordon Camp	1	2	6	4	6	6	7	7	6	4	6
14. Frensham Great Pond	1	1	1	1	3	2	3	4	1	2	2
15. Cross-roads at Hindhead	2	3	5	5	7	7	7	7	4	5	5
16. Chiddingfold Village	2	3	4	4	6	6	6	7	4	4	4
17. Charterhouse School	1	1	4	3	5	5	6	7	2	4	3
18. Rail/road bridge, South of Liphook	3	2	4	4	4	5	4	6	3	4	3
20. Major road-over-road crossing	2	2	3	3	4	5	5	6	2	4	3

In this table the two navigators are designated A and B. Target detection difficulty was assessed on a seven-point scale, 1 representing very easy and 7 representing very difficult.

APPENDIX II (Cont'd)

Overall difficulty rating	Target numbers
1	3, 11, 12
2	9, 14
3	5, 8, 17, 18, 20
4	2, 6, 7, 16
5	10, 15
6	13
7	1

One target from each category was chosen for the test matrix. Targets chosen were numbers 3, 14, 17, 16, 15, 13 and 1.

APPENDIX III

This matrix shows the 7 targets and 7 conditions tested. Subjects (numbered 1 - 7) are arranged within this matrix in a Latin square arrangement. The presentations of particular target and condition combinations to any one subject were randomly ordered and the resultant experimental schedule is shown on the next page.

	Uncertainty →	Uncertainty 1			Uncertainty 2			
	Range →	1	2	3	1	2	3	4
TARGETS	1	7	2	5	4	3	1	6
	3	2	5	4	3	1	6	7
	13	5	4	3	1	6	7	2
	14	4	3	1	6	7	2	5
	15	3	1	6	7	2	5	4
	16	1	6	7	2	5	4	3
	17	6	7	2	5	4	3	1

APPENDIX III (cont'd)

Experimental schedule of targets and conditions for each of the seven subjects in a matrix.

Subjects

1			2			3			4			5			6			7		
T	R	C	T	R	C	T	R	C	T	R	C	T	R	C	T	R	C	T	R	C
13	1	2	16	1	2	3	1	2	3	3	1	3	2	1	16	2	1	1	1	1
3	2	2	17	3	1	16	4	2	16	3	2	16	2	2	1	4	2	16	3	1
15	2	1	1	2	1	14	2	1	15	4	2	1	3	1	13	2	2	3	4	2
17	4	2	15	2	2	1	2	2	13	2	1	15	3	2	17	1	1	14	2	2
1	3	2	13	4	2	15	1	1	14	1	1	14	4	2	3	3	2	13	3	2
14	3	1	14	3	2	13	3	1	1	1	2	17	1	2	14	1	2	15	1	2
16	1	1	3	1	1	17	3	2	17	2	2	13	1	1	15	3	1	17	2	1

T = Target R = Range C = Uncertainty condition

APPENDIX IV

A sample result sheet from this experiment is shown on the following page.

Preliminary studies

Name

Age 20

Occupation Prodⁿ Eng. I

Flying experience, if any. ~ 3 Hrs.

Visual acuity: Snellen D=9 Landolt C's 6/12 Jaeger Test Type N.5

Eysenck questionnaire:

N = 5 E = 12 L = 0

Intelligence test AH5/[illegible]

Part I 18 C Part II 24 B Overall. 42 C

Pre-test

Target	Range	Condition	Map time	Phototime	Confidence	Result
10	2	1	91.6	11.2	5	✓
6	4	2	71.6	18.4	4	x
5	3	1	60.0	32.6	3	✓
9	1	2	97.2	5.8	6	✓

Test: schedule number I 4 (N.)

Target	Range	Condition	Map time	Phototime	Confidence	Result
3	3	1	29.8	7.2	6	x
16	3	2	87.6	20.0	4	✓
15	4	2	91.8	7.8	5	✓
13	2	1	73.6	14.0	5	✓
14	1	1	57.2	2.6	7	✓
1	1	2	97.6	29.2	6	✓
17	2	2	91.8	23.8	7	x

Comments: Map not always orientated in direction of aircraft track - made task more difficult.

Some map features e.g. woodland area did not always correspond exactly to that seen in the photo.

APPENDIX V

This appendix shows the detailed results of the Logit analysis of the detection probability data carried by Professor P. Armitage of the Department of Medical Statistics and Epidemiology, London School of Hygiene and Tropical Medicine, who wrote the following report.

Logit analysis of detection probability data

We ignored differences between subjects in the same group here, since these had been deliberately made rather small. We therefore investigated differences between targets, groups, uncertainty conditions and range.

The model is that the probability, P, of a correct identification is related to the factors by the following multiple regression equation:

$$Y = \text{logit } P = \tfrac{1}{2} \ln \frac{P}{1-P} = \sum b_i \, x_i$$

where

$x_1 = 1$	for all observations		
$x_2 = 1$	for target 3,	otherwise	0
$x_3 = 1$	" " 14,	"	0
$x_4 = 1$	" " 17,	"	0
$x_5 = 1$	" " 16,	"	0
$x_6 = 1$	" " 15,	"	0
$x_7 = 1$	" " 13,	"	0
$x_8 = 1$	for Group A,	"	0
$x_9 = 1$	" " B,	"	0

$x_{10} = 0$ for Uncertainty 1, 1 for Uncertainty 2

$x_{11} =$	-1	for U_1, range 1	
	0	" " " 2,	0 for U_2
	1	" " " 3	
$x_{12} =$	1	for U_1, range 1	
	-2	" " " 2,	0 for U_2
	1	" " " 3	
$x_{13} =$	-3	for U_2, range 1	
	-1	" " " 2,	0 for U_1
	1	" " " 3	
	3	" " " 4	
$x_{14} =$	1	for U_2, range 1	
	-1	" " " 2,	0 for U_1
	-1	" " " 3	
	1	" " " 4	
$x_{15} =$	-1	for U_2, range 1	
	3	" " " 2,	0 for U_1
	-3	" " " 3	
	1	" " " 4	

Note: Most people define logit P as $\ln \frac{P}{1-P}$ The program we use inserts the factor $\tfrac{1}{2}$.

Thus, x_1 represents a general level for target 1, U_1 and Group C; x_2 to x_7 represent differences between targets 3, 14, 17, 16, 15 and 13 as compared with target 1; x_8 and x_9 represent effects of Groups A and B, versus Group C; x_{10} represents an effect of U_2 versus U_1; x_{11} and x_{12} represent a trend and curvature effect moving from range 1 to 3 in U_1; x_{13} to x_{15} represent a trend, curvature and cubic effects from range 1 to 4 in U_2.

First we fit the multiple regression with constants x_1 to x_7 (this is a maximum likelihood solution which involves successive approximation). i.e. we allow only for targets. The regression coefficients are

		Target	Total successes out of 21
b_1	-0.46 ± 0.24		
b_2	0.80 ± 0.33*	3	14
b_3	1.58 ± 0.44*	14	19
b_4	0.60 ± 0.33	17	12
b_5	1.58 ± 0.44*	16	19
b_6	0.22 ± 0.33	15	8
b_7	0.31 ± 0.33	13	9
		1	6

Note that the rank order of the b_i (i = 2, ... 7) is the same as that of the successes out of 21 for the corresponding targets, as would be expected. There are fairly clear differences between targets (asterisks show values > twice their SE). In comparing different b's care must be taken because b_2 to b_7 are positively correlated with each other. The differences are therefore <u>more</u> significant than if they were independent. The standard errors of the differences are in fact about the same as those of the individual b's i.e. about 0.3 to 0.4.

We now fit the regression with all 15 constants, i.e. allowing for targets, groups, uncertainty and range. The regression coefficients are

1	b_1	-0.98 ± 0.35	Uncert.	b_{10}	-0.24 ± 0.22
3	b_2	1.04 ± 0.39*	U_1R	b_{11}	-0.31 ± 0.20
14	b_3	1.98 ± 0.51*	U_1R	b_{12}	-0.05 ± 0.12
17	b_4	0.77 ± 0.38*			
16	b_5	1.98 ± 0.51*	U_2R	b_{13}	-0.20 ± 0.07*
15	b_6	0.26 ± 0.38	U_2R	b_{14}	0.04 ± 0.14
13	b_7	0.40 ± 0.38	U_2R	b_{15}	-0.04 ± 0.06
A	b_8	1.13 ± 0.29*			
B	b_9	0.46 ± 0.26			

The value of b_1 necessarily changes with the introduction of the new variables, and need not concern us. The values of b_2 to b_7 are somewhat changed, but not greatly so. The values b_8 and b_9 differ somewhat, b_8 is significantly different from zero and b_9 is nearly so. This merely reflects the known differences between groups. b_{10}, b_{11} and b_{12} are not significant. There is thus no suggestion of differences between uncertainties or between ranges for uncertainty 1. b_{13} is highly significant; that is, there is evidence of a gradual trend in success rate from range 1 to range 4 under uncertainty 2. The relevant totals of successes are

	U_1			U_2			
Range	1	2	3	1	2	3	4
Successes out of 21	15	14	11	16	12	11	8

Note that the trend with range under U_1, although not significant, is in the same direction as that under U_2.

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PART II

VISUAL AND TELEVISUAL DETECTION STUDIES

Mintech contract PD/170/04/AT

PART II

THE EFFECT OF VIEWING DISTANCE ON TARGET DETECTION PERFORMANCE

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SUMMARY

This report describes the second of a series of experiments intended to investigate performance at a statically simulated target detection task. The main aim was to determine whether detection performance was affected by a reduction in apparent display size, i.e. by a decrease in the angular subtense of the display at the observer's eye. This was brought about by keeping the actual display size constant (4.8" x 3.6") and increasing the viewing distance from 13" to 21" and to 30", giving corresponding angular subtense values of $21^{\circ} \times 15\frac{3}{4}^{\circ}$, $13^{\circ} \times 9\frac{3}{4}^{\circ}$ and $9^{\circ} \times 7^{\circ}$.

Data relating to the 13" viewing distance were taken from Experiment 1, the first experiment in this series. Data for the 21" and 30" viewing distances were obtained in the present experiment from two groups of 9 unskilled subjects who underwent preliminary training and practice. At each viewing distance the experimental design was based on a Latin square of targets and range conditions.

The results showed that the effect of viewing distance on the three main performance measures i.e. detection probability, search time and confidence level was statistically non-significant. However, there was a tendency for performance to deteriorate as viewing distance increased, particularly at the 30" distance. The main results of this experiment are detailed in tabular form on the following page.

The general trends found in the present experiment e.g. effect of range on performance, relative difficulty of targets, correlations between high detection probability, low search time and high confidence level, etc. were in close agreement with those found in Experiment 1.

The implications of the results and their relevance to the operational situation are considered in the discussion.

Summary of results

	DETECTION PROBABILITY	SEARCH TIME	CONFIDENCE LEVEL
VIEWING DISTANCE	No significant effect but shorter viewing distances tended to be more favourable. Overall mean detection probability = 0.56 (23-25)	No significant effect but shortest viewing distance appeared to be most favourable. (39)	No significant effect but there was a tendency for mean confidence level to decrease with increase in viewing distance. (49)
RANGE	Significant decrease in detection probability at 3 mile range. Values ranged from 0.69(1 mile) to 0.37 (3 miles). (26-28)	Mean search times for range 1 mile were significantly shorter than those for 2 miles and 3 miles. (39-41)	Significant differences between mean confidence levels for each range. Values decreased linearly with increasing range. (49-51)
TARGET DIFFERENCES	Significant differences between easy (14), intermediate (13,3,17) and difficult (15,1) targets. Mean detection probabilities ranged from 0.93 to 0.19. (29-30)	Significant differences in search time between easy targets (14 and 3) and difficult targets (17,15 and 1). Mean times ranged from 6.8 secs. to 18.6 secs. (41-45)	Significance differences in mean confidence levels for different targets. Targets 1 and 15 were associated with significantly lower confidence levels than all other targets. (52-54)
FURTHER POINTS	Results of logit analysis of detection probability data agreed well with analysis of variance. (34) Significant R x D x T interaction found in analysis of variance. (30-34)	Mean search times for incorrect detections were much longer (18.2 secs) than those for correct detections (10.0 secs.) (45)	Mean confidence levels for targets corrected detected were significantly higher than those for targets incorrectly detected. (54)

NOTE The numbers at the bottom left corner of each block relate to the relevant pages of the report.

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INDEX

ILLUSTRATIONS

1. INTRODUCTION

If navigation or missile guidance is carried out by means of a television viewing system, parameters such as viewing distance, display size and the orientation of the display relative to the observer may affect the efficiency with which the task can be carried out. This investigation is concerned with the effect of viewing distance on performance at a simulated airborne target detection task. Display size and viewing distance are normally selected on a basis of engineering considerations and little work has been carried out on the optimum size and distance of a television display for target recognition. However, even if optimum values were known, it might not always be possible to accommodate them in the limited space available in an aircraft cockpit and it is therefore important to determine whether performance is significantly affected by these display parameters.

Since the detection task requires close attention to detail, sometimes for prolonged periods, it is possible to specify a minimum viewing distance below which accommodation and convergence strain would be likely to cause excessive fatigue. Morgan et al (1963) recommends, for this reason, that no display should be located less than 13" from the observer. However, in an aircraft cockpit it is more likely that difficulty will arise from a viewing distance that is too great in relation to the display size. If it is necessary for the operator to be able to reach the display to make control adjustments then the maximum distance at which it may be situated must be related to arm length. A maximum value of 29½" is recommended, this being the 5th percentile value for arm reach based on American data, (Morgan et al, 1963). This is particularly important in an aircraft where the use of safety harnesses may prevent the observer from leaning forward to view the display more closely, or to adjust control knobs situated in the plane of the display and around its periphery. Another consideration which may affect the layout of the cockpit is, if ejection seats are installed, that nothing must obstruct the space above the seat, and thus displays and equipment may have to be placed at a greater distance than would otherwise be desirable.

Because of the severe constraints imposed on display size by the limited amount of space available, it is not always possible to compensate for a long viewing distance by using a large display. Further complications arise when the orientation of the display relative to the observer is considered. The optimum viewing angle in which to locate a display is within 15° of the normal line of sight, taken as being 15° below horizontal for a seated observer, falling on the mid-sagittal plane. Within this solid angle any point can be fixated with speed and accuracy by eye rotation alone, (Sanders, 1963). Changes in the point of fixation requiring a greater angular shift tend to involve both head and eye rotation. If both types of rotation are used, points within a much wider area can be fixated. A maximum lateral angle of 95° on either side, and a vertical angle of 75° above and 85° below horizontal, can be obtained, (Morgan et al, 1963).

However, fixations involving head movement as well as eye movement cannot be made as accurately or rapidly as those involving eye movements alone. Thus no display should subtend an angle greater than 30° at the observer's eye if rapid and accurate scanning is necessary, as in the task under consideration. Furthermore, although a relatively wide area is available for positioning displays if head movements as well as eye movements are used to fixate them, the central position, i.e. the area towards which the eyes are directed when at rest, is most suitable for the positioning of important displays. However, in sophisticated modern aircraft much information vital for safe operation needs to be displayed and the exact position and size of the television display may depend on its relative frequency of use and the other instruments in conjunction with it.

It is therefore important to consider how performance is likely to be affected by the use of a small display and/or a relatively long viewing distance. The combined effect of these two factors is represented by the visual angle subtended by the display at the observer's eye. Reducing display size and/or increasing viewing distance results in a decrease in this visual angle. The effect of this increase on detection performance depends on a number of factors including the size and type of target and the type of background. If the visual angle subtended by the display is decreased the number of fixations required to completely search the display is also decreased. However, the target area/search area ratio remains unaltered and, provided it is such that an efficient search can be performed rapidly, decreasing the overall visual angle subtended by the display may favour performance.

A more important factor is the absolute size of the target as it appears on the screen. Work carried out by Steedman and Baker (1960) shows that search time and errors in detecting a reference form against a complex background remained approximately constant until the angle subtended by the target at the eye fell below 12' of arc. They concluded that for reasonably accurate target identification the angular subtense of the target should be at least 12'. However, this value relates to the detection of targets against a complex but unstructured background whereas the present work is concerned with the detection of targets against a background structured by the presence of geographical features which can be related to a map.

Thus it is possible for a static target, e.g. a bridge whose position is indicated on a map, to be accurately located on the screen by the presence of large, conspicuous geographic features nearby, even if the target itself is masked by other features or its angular subtense is below threshold. For this reason, provided that the 'lead-in' features remain well above recognition threshold, increase in viewing distance may not adversely affect detection performance, which depends largely on correct geographic orientation.

However, a different situation is presented by small targets, e.g. army vehicles, whose position is variable and cannot always be accurately located on a map. The detection of such targets cannot therefore be facilitated by nearby conspicuous features and thus the task becomes one of identifying a small target against a complex background which may contain many confusing forms. In such cases the angular subtense of the target at the observer's eye is likely to be a critical factor in determining whether it is detected. For this type of task the 12' of arc threshold suggested, which is equivalent to a linear size of 0.045" at a 13" viewing distance, is likely to be over-optimistic particularly if detection is to be followed by recognition and identification. The degree of contrast between target and background must also be considered.

If both viewing distance and display size are fixed by engineering considerations the only way in which the angular subtense of the target can be increased is by increasing the magnification, i.e. narrowing the camera field of view so that the target occupies a larger proportion of the display. The greater the magnification the greater is the probability of detecting and recognising a given target, providing that it is in the field of view. However, this magnification is only achieved at the expense of reducing the extent of the terrain shown in the display. The result of this is to make geographic orientation more difficult since there will be fewer conspicuous features, and thus the overall probability of detection is likely to be decreased. Rusis and Snyder (1965) found in a study of the effect of television camera field of view that as the field was decreased, probability of correct detection fell but mean recognition range for correct recognitions increased. Theoretically one way of overcoming the difficulty caused by these opposing requirements would be to specify an optimum field of view for correct geographic orientation and a minimum size for the angular subtense of the target. It would then be possible to specify a suitable display size/viewing distance combination to achieve this target size. However, in practice, if small targets were involved, a relatively large display size would be required and, even if it could be accommodated in the cockpit, further complications would be involved in searching such a large display area.

Another possible solution is the use of a variable focal length lens which allows a wide field of view for orientation purposes, and high magnification for actual target identification. This is a feasible and, in many respects, advantageous system but it may involve additional complexity and cost and a loss of resolution. In practice a compromise solution is normally adopted, necessitating the use of a lens which tends to give a less than optimum field of view for orientation purposes and/or a lower than optimum magnification for small target recognition.

Thus the effect of viewing distance and display size on detection performance is likely to interact with target size, target type and background type and camera field of view. For the detection of small targets the resolution of the system is also an important factor but this discussion assumes that the system which is interposed between the terrain being viewed and the observer has a resolution inherently compatible with the detection task requirements.

These interactions complicate the interpretation of laboratory studies of viewing distance effects in relation to airborne target acquisition tasks. A number of studies have been carried out on the optimum viewing distance for P.P.I. radar displays. Bartlett and Williams (1947) reported that target detection at 6" was superior to that at 24" where target location was known, but Craik and Macpherson (1945) found 18" to be optimum distance for a 9" oscilloscope when target location was not known. Wright et al (1965) used a $9\frac{1}{4}$" display at distances of 6", 12" and 18" and the subjects searched either the whole of the display; or one quadrant; or a circle, diameter 11/16". They found that the greater the search area the worse the performance and the greater the viewing distance the worse the performance. The viewing distance effect was quite small but as search area increased the optimum viewing distance increased. These detection tasks, however, all involved target detection against an unstructured background. A more relevant study (Crawley, Silverthorn and Snailum, 1966) involved the tele-cine projection of airborne film material at two different screen sizes, 7" x 5" and 5" x 4". The viewing distance was 29". No significant differences in detection performance were found but a trend towards worse performance with the smaller screen was noted.

The present investigation was intended to determine whether decreasing the visual angle subtended by the display at the observer's eye by means of an increase in viewing distance affected performance at a statically simulated air-to-ground target acquisition task. Previous work had provided detailed performance data on the detection of a series of ground targets, e.g. bridges, stations, etc. at a viewing distance of 13". In this investigation the viewing distance was increased to 21" and to 30", while the display size (4.8" x 3.6") was kept constant.

It should be noted that the original intention of this experiment had been to investigate the effect of display size on detection performance, at constant viewing distance. However, this direct study of display size would have involved reprinting the photographic material which would have given rise to a possible additional source of variation due to photographic processing. It was therefore decided that in this experiment reduction in apparent display size, i.e. in the angular subtense of the display at the observer's eye, would be obtained by keeping display size constant and increasing viewing distance. Longer viewing distances were chosen so that the visual angles subtended were equivalent to those of smaller displays viewed at 13", as shown in Table 1.0.1.

TABLE 1.0.1

Effect of viewing distance on angular display size

Viewing distance	Angular subtense of display at eye	Equivalent display size*
13"	$21^{\circ} \times 15\frac{3}{4}^{\circ}$	4.8" x 3.6" (actual value)
21"	$13^{\circ} \times 9\frac{3}{4}^{\circ}$	3.0" x 2.2"
30"	$9^{\circ} \times 7^{\circ}$	2.1" x 1.6"

* i.e. Display size which would give rise to angular subtense shown when viewed from 13"

In this report the results are described in terms of the actual viewing distance studied but they can also be interpreted as applying, at least to a close approximation, to the smaller display sizes, shown in Table 1.0.1, viewed from 13".

Throughout the experiment altitude (2000 ft.) and camera field of view ($30 \times 22\frac{1}{2}^{\circ}$) were kept constant.

2. PURPOSE OF EXPERIMENT

The main aim of this experiment was to determine whether detection performance was affected by reducing the apparent display size, i.e. by decreasing the visual angle subtended by the display at the observer's eye. This was brought about by increasing the viewing distance from 13", used in Experiment 1, to a maximum of 30". This reduced the apparent area of the display to less than one quarter of its previous value. An intermediate viewing distance value of 21" was also tested.

This experiment was also intended to confirm the general trends e.g. relative difficulty of targets, relationship between detection performance and intelligence, and correlations between detection probabilities, search times and confidence scores, found previously.

Although it had been shown in Experiment 1 that the performance of unskilled subjects was similar, in terms of detection probability, to that of skilled subjects it would nevertheless have been preferable to use skilled subjects in the present experiment. However, none were available and, accordingly, unskilled subjects of comparable age and intelligence were used.

3. EXPERIMENTAL DESIGN

The main aim of this experiment was to compare detection performance at the 13" viewing distance previously investigated with that at two greater distances, 21" and 30". The experimental design was intended to achieve this without repetition of the 13" data. This necessitated certain restrictions on the design chosen, viz.:

(i) Since the subjects tested in Experiment 1 had been exposed to a single viewing distance (13") only, two separate groups of subjects should be used to test the 21" and 30" viewing distances.

(ii) Subjects should undergo the same training and pre-test programme as previously used and should be exposed to the same number of test targets.

(iii) The experimental design should have a similar structure to that used previously, which required 21 subjects and 7 targets to test 2 conditions of navigational uncertainty and 4 range conditions, i.e. it should be based on a Latin square arrangement of subjects within a targets x conditions matrix.

The simplest way of meeting these conditions would have been to replicate the experimental programme previously carried out at a viewing distance of 13" at each of the longer viewing distances using two groups of 21 subjects each. However, this was thought to be uneconomical in terms of the total number of subjects, and hence the time, required. It was therefore decided to reduce the number of experimental conditions, and thus the number of subjects, by reducing the navigational uncertainty factor to a single level ($\pm$ 1 mile) instead of the two previously tested, ($\pm$ 1 mile and $\pm$ 2 miles). It had been found that detection performance was not significantly affected by this factor. This left three range conditions associated with the nominal range to target of 2 miles and the ±1mile navigational uncertainty (these being actual ranges of 1, 2 and 3 miles) instead of the previous total of seven conditions.

In addition, six of the seven targets used in Experiment 1 were chosen for the present study. As three ranges were to be investigated the use of six test targets allowed a balanced experimental design to be devised. Although seven test targets had been used previously it was not thought that this discrepancy would seriously affect the results.

Thus, under the two principal experimental conditions of 21" and 30" viewing distances, there was a 6 x 3 matrix of targets and range conditions. Subjects were assigned to a matrix with the following conditions:

(a) Each subject must see each target once and once only.

(b) Each subject must see each range condition twice and twice only.

Thus, for one viewing distance 3 subjects were required to fill the matrix. This was replicated 3 times. Therefore 9 subjects were tested for each viewing distance condition, making a total of 18 in all. To minimise order and learning effects the order of presentation of target and range combinations to each subject was randomised, as shown in Appendix II.

For direct comparisons to be made between the data obtained in this experiment and that relating to the 13" viewing distance it was necessary to extract the relevant data (i.e. that relating to the ± 1 mile uncertainty condition) from Experiment 1. This data, which had been obtained during the investigation of two navigational uncertainty conditions, ($\pm$ 1 mile and $\pm$ 2 miles), related to 21 subjects. In the present experiment the data used for comparison purposes included 3 readings from twelve of these subjects and 2 readings from the remaining nine subjects. (This discrepancy was due to the omission of target Number 16 in the present experiment). Thus the complete set of data consisted of either 6, 3 or 2 readings from each subject. However, since each subject was exposed to almost the same number of test targets altogether (i.e. 6 or 7), it was not thought that this would seriously affect the validity of the results. Since performance had been found to correlate with intelligence the mean of the I.Q. scores in the three groups of subjects assigned to the three viewing distance conditions was kept approximately constant.

Thus, this experiment enabled a comparison to be made between performance at the three viewing distances on the basis of 54 readings at each distance. Since the experimental material and technique remained the same as before it was possible to investigate further the trends in detection performance found in Experiment 1.

4. DISPLAY AND RECORDING EQUIPMENT

The display and recording equipment used in this experiment was the same as that described in detail in Experiment 1. It consisted of a simple display box for the map and an adjustable viewing system for displaying the photographs. In the present experiment the viewing distance was increased to 21" by extending the viewing tunnel as shown in Figure 4.0.1, and to 30" by adding an extra section as shown in Figure 4.0.2. The photographs were mounted by means of magnetic strip on the back of a metal mask so that only the required portion was displayed to the subject when the mask was slid into the back of the viewing system. A general view of the experimental area is shown in Figure 4.0.3 and a subject seated at the display in Figure 4.0.4.

The timing and recording equipment consisted of a Decatron timer linked to a print-out by means of which the time the subject spent studying the map, the time he spent searching for the target and the confidence level of his judgment on a 1 - 7 scale, could be recorded automatically. Thus, the experimenter had only to record whether or not the target was correctly identified when the subject pointed it out.

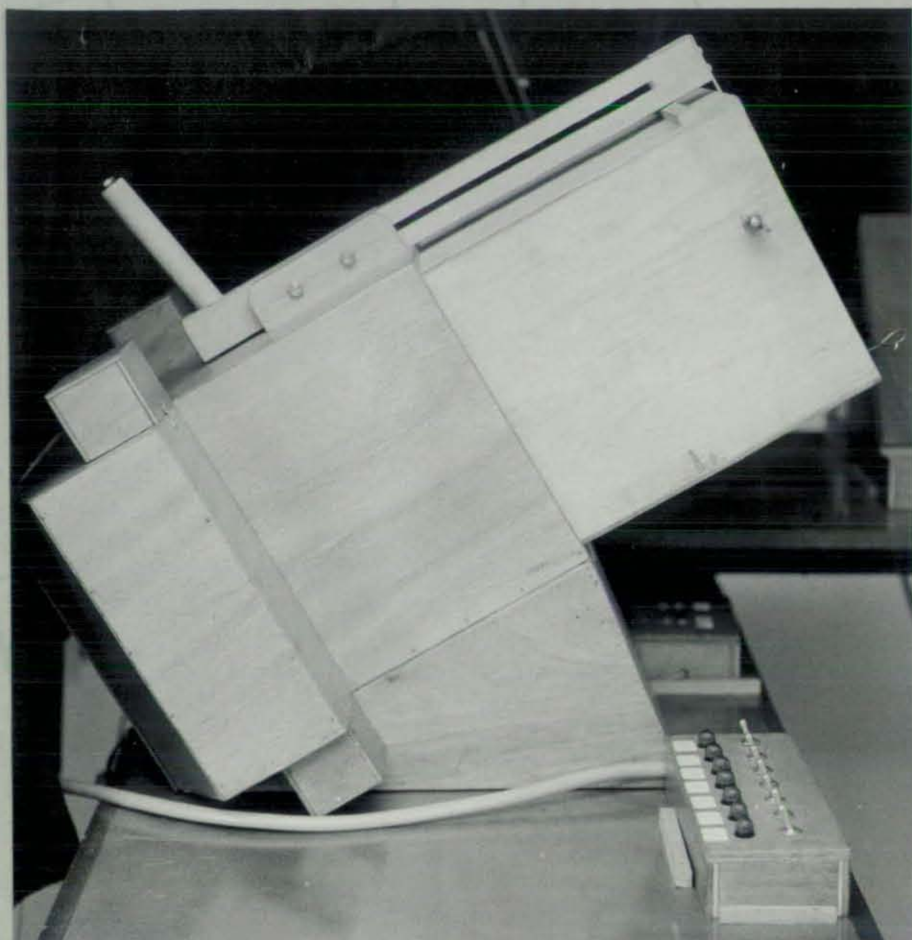


FIGURE 4.0.1
Display box adjusted for
the 21" viewing distance.

FIGURE 4.0.2
Display box adjusted for
the 30" viewing distance.

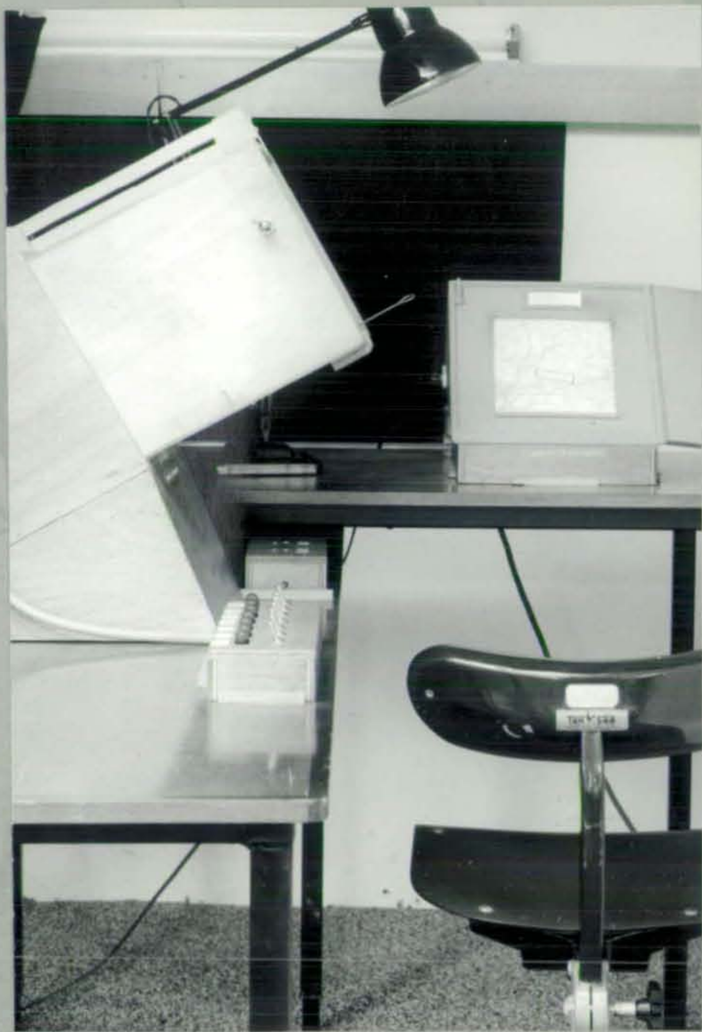


FIGURE 4.0.3
Experimental area

FIGURE 4.0.4
Subject seated at display box

5. EXPERIMENTAL MATERIALS

The maps and photographs used for training and test purposes were the ones used for the $\pm$ 1 mile condition of navigational uncertainty in Experiment 1, with the exception of those relating to target Number 16, Chiddingfold Village, which were not required in the present experiment.

The maps were $6\frac{1}{4}$" x $6\frac{1}{4}$" sections, one for each target, of the 1" = 1 mile Ordnance Survey map, Sheet 169. Each map showed the target position and surrounding terrain. In addition, a rectangle (2" x $\frac{1}{2}$") representing the limit of the uncertainty in the aircraft position under the $\pm$ 1 mile condition of navigational error was marked.

The photographic material consisted of a series of 8" x 8" aerial photographs taken from an altitude of 2,000 ft. at ranges of 1, 2 and 3 miles from each of 18 ground targets. For display purposes these photographs were masked so that only a central portion 4.8" x 3.6" was shown, representing a 30° x $22\frac{1}{2}^{\circ}$ camera field of view. In each case the horizon appeared $\frac{1}{4}$" below the top of the displayed portion.

6. EXPERIMENTAL PROCEDURE

The training and test procedures adopted were in all respects similar to those described in detail in Experiment 1. For convenience a brief description is given below.

Each subject was tested individually and the session lasted approximately 3 hours. Preliminary tests of intelligence (Heim's A.H.5 test), personality (Eysenck personality inventory) and memory (digit-span test) were carried out. This took approximately $1\frac{1}{4}$ hours. Training in map reading, explanation of the photographic and navigational parameters involved, and practice with sample maps and photographs took a further $\frac{3}{4}$ hour. The subject was then shown how to operate the display and recording apparatus, and a series of four targets was presented for further practice. After each presentation the subject was told whether or not he had located the target correctly and, if not, was given a further opportunity to do so.

Finally, a series of eleven targets was presented during which the subject received no knowledge of results. The last seven of these constituted the test run. In each case the subject was required to study the map section on which the target and the limits of the aircraft's possible position were marked and turn to the photographic display and locate the target as rapidly as possible. He then indicated his confidence in the accuracy of his judgment on a seven point scale and pointed out the target position to the experimenter who recorded it as correct or incorrect. Thus, for each presentation four measures of the subject's performance were obtained, (a) whether or not the target was correctly detected, (b) search time, (c) confidence level, and (d) map time.

7. EXPERIMENTAL RESULTS

In the statistical analysis of the results obtained in this experiment each of the main factors tested, i.e. viewing distances, ranges and targets is considered in relation to the four basic performance measures recorded, i.e. detection probability, search time, confidence level and map time. A separate section is given to each of these performance measures and in each case the raw data and the analyses relating to it are shown. The main emphasis is on the effect of viewing distance, but analyses have also been carried out to determine the extent to which the results parallel those found in Experiment 1. For convenience a cross-referenced summary table is given in the final section.

In the statistical treatment of the results the raw data were treated as if each value in a 6 x 3, targets x conditions, matrix were independent. This assumption, which was also made in Experiment 1, was thought to be reasonable although each subject contributed six readings to a matrix.

All tests of statistical significance shown in the following sections are two-tail tests unless otherwise stated.

7.1 Detection probability

The raw data on detection probabilities at each of the three viewing distances are shown in Table 7.1.1. The overall probability of detection is 0.56. The analysis of variance carried out on this probability data is shown in Table 7.1.2. This shows that the overall effect of viewing distance is non-significant but that the effects of ranges and targets are both significant at the 0.1% level. The overall significance of the ranges and targets effects is in accordance with the results previously obtained in Experiment 1. In addition the viewing distance x range x target interaction is significant. This represents the variation between individual cells of the results matrix shown in Table 7.1.1 and indicates that different targets are differently affected by the range and viewing distance conditions tested.

In carrying out this analysis of variance it was assumed that the analysis of variance model could be applied to quantal data, as in Experiment 1. The results of the Logit analysis, which is more appropriate to this type of data, are considered in a later section. The effects of viewing distances, ranges and targets on detection probability are considered separately in the following sections.

TABLE 7.1.1

Correct and incorrect target identifications at each of the three viewing distances

Overall probability of detection = 0.56

Viewing Distance	13"			21"			30"		
Range / Targets	1	2	3	1	2	3	1	2	3
3	1 1 0	1 1 1	0 0 0	1 1 1	1 1 1	1 1 0	0 1 1	0 1 1	1 0 0
14	1 1 1	1 1 1	1 1 1	1 1 1	1 1 0	1 0 1	1 1 1	1 1 1	1 1 1
17	1 1 1	1 1 0	1 1 1	1 1 1	1 0 0	0 1 0	1 0 1	1 1 1	0 0 0
15	1 1 0	1 0 0	0 0 0	0 1 0	0 1 1	0 0 1	0 0 1	1 1 0	0 0 0
13	1 1 0	1 0 0	1 0 1	1 1 1	1 1 1	0 0 0	1 0 1	1 1 0	0 0 0
1	0 0 0	1 0 0	0 0 0	1 0 0	0 0 0	0 0 1	0 0 1	0 0 0	0 0 1

1 = correct identification

0 = incorrect identification

TABLE 7.1.2

Analysis of variance on detection probability data shown in Table 7.1.1

Source	D.F.	S.S.	M.S.	V.R.	Significance
Viewing Distance (D)	2	0.16	0.08	-	N.S.
Ranges (R)	2	3.05	1.52	11.46	$p < 0.001$
Targets (T)	5	8.99	1.80	13.52	$p < 0.001$
R x D	4	0.40	0.10	-	N.S.
D x T	10	1.84	0.18	1.38	N.S.
T x R	10	2.06	0.21	1.55	N.S.
R x D x T	20	9.01	0.45	3.39	$p < 0.01$
Residual	108	14.37	0.13		
TOTAL	161	39.88			

(a) Viewing distance

Table 7.1.3 shows the mean detection probability at each viewing distance. The data are shown graphically in Figure 7.1.1.

TABLE 7.1.3

The effect of viewing distance on detection probability

Viewing Distance	13"	21"	30"
Detection Probability	0.57	0.59	0.52

Although there appears to be some fall-off in performance at 30", the longest viewing distance, t-tests show that the differences between this value and the values for the two shorter viewing distances are non-significant.

Since a longer viewing distance might be expected to have a greater effect on targets which occupied only a small proportion of the total display, i.e. targets at long ranges, the performance data has been broken down to show the detection probability for each range at each viewing distance. Table 7.1.4 shows these values.

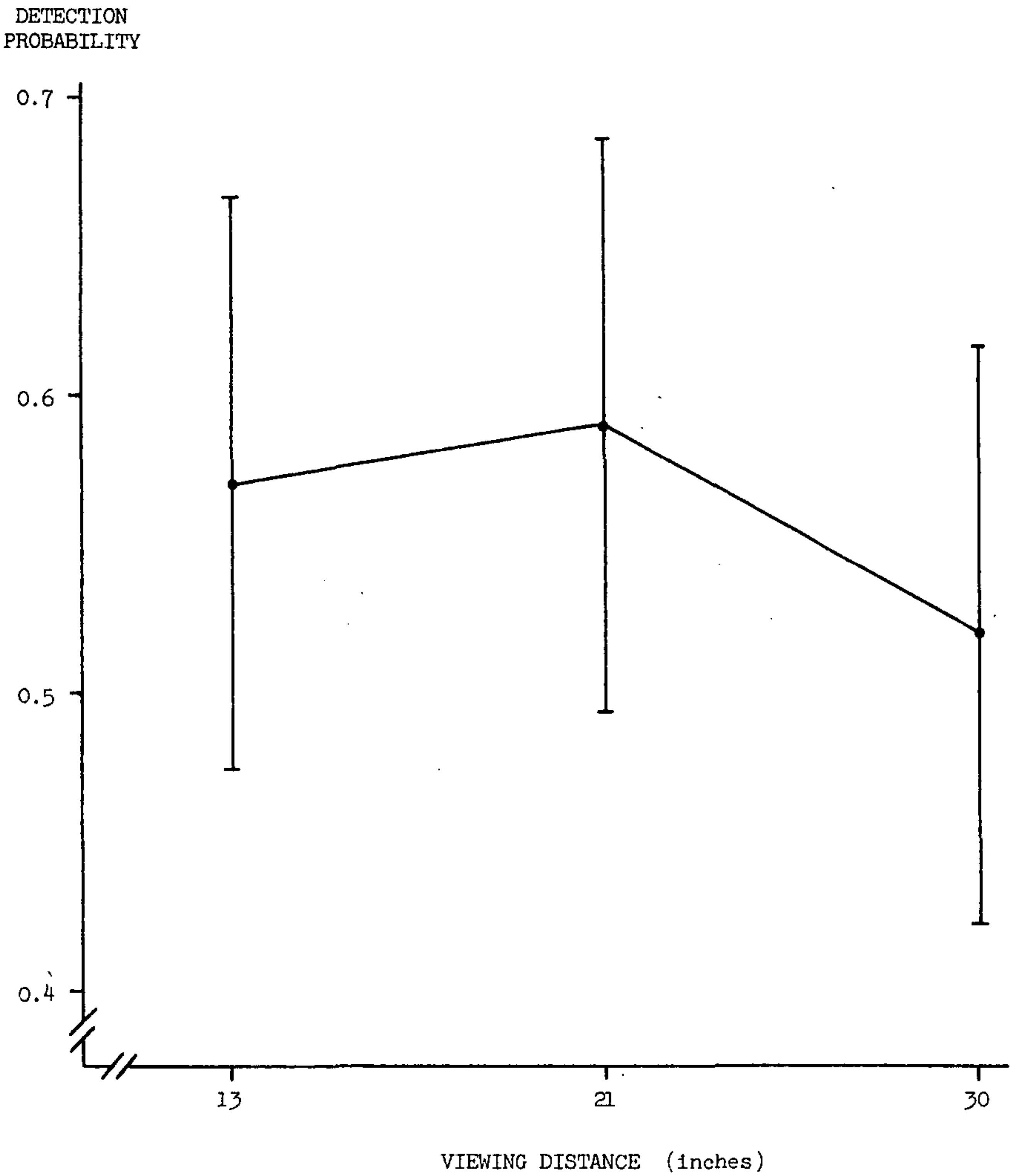
TABLE 7.1.4

The effect of viewing distance on detection probability at each range

Range (miles)	Viewing distance		
	13"	21"	30"
1	0.67	0.78	0.61
2	0.61	0.61	0.67
3	0.45	0.39	0.28

FIGURE 7.1.1

The effect of viewing distance on detection probability



NOTE The vertical lines represent the 95% confidence limits of the means. Differences between the means were not significant.

Differences within this table must reach ± 0.24 to be significant at the 5% level. It can be seen that, at each range, viewing distance has no significant effect at the 5% level but the difference in detection probability at range 3 miles between viewing distances 13" and 30" is very close to the 10% significance level. As would be expected the shortest viewing distance is most favourable for targets at 3 miles range, which occupy a relatively small proportion of the display.

Since the targets used varied both in size and in the predominant features of the surrounding terrain it might have been expected that different targets would be differently affected by a change in viewing distance. However, the targets x viewing distance interaction was not found to be significant in the analysis of variance. This absence of interaction was confirmed by calculating the coefficient of concordance, W, for the rankings of the targets based on detection probability at each viewing distance. Table 7.1.5 shows the detection probability values and corresponding rankings.

TABLE 7.1.5

Target rankings according to detection probability at each viewing distance

Target	Viewing Distance					
	13"		21"		30"	
	Probability	Ranking	Probability	Ranking	Probability	Ranking
3	0.56	$3\frac{1}{2}$	0.89	1	0.56	$2\frac{1}{2}$
14	1.00	1	0.78	2	1.00	1
17	0.89	2	0.56	4	0.56	$2\frac{1}{2}$
15	0.33	5	0.44	5	0.33	5
13	0.56	$3\frac{1}{2}$	0.67	3	0.44	4
1	0.11	6	0.22	6	0.22	6

The value of W determined from these rankings was 0.85 which was significant at the 1% level. Thus the rank order of target difficulty is apparently not affected by increase in viewing distance.

(b) Ranges

The mean detection probability at each range is given in Table 7.1.6., and shown graphically in Figure 7.1.2.

TABLE 7.1.6

The effect of range on detection probability

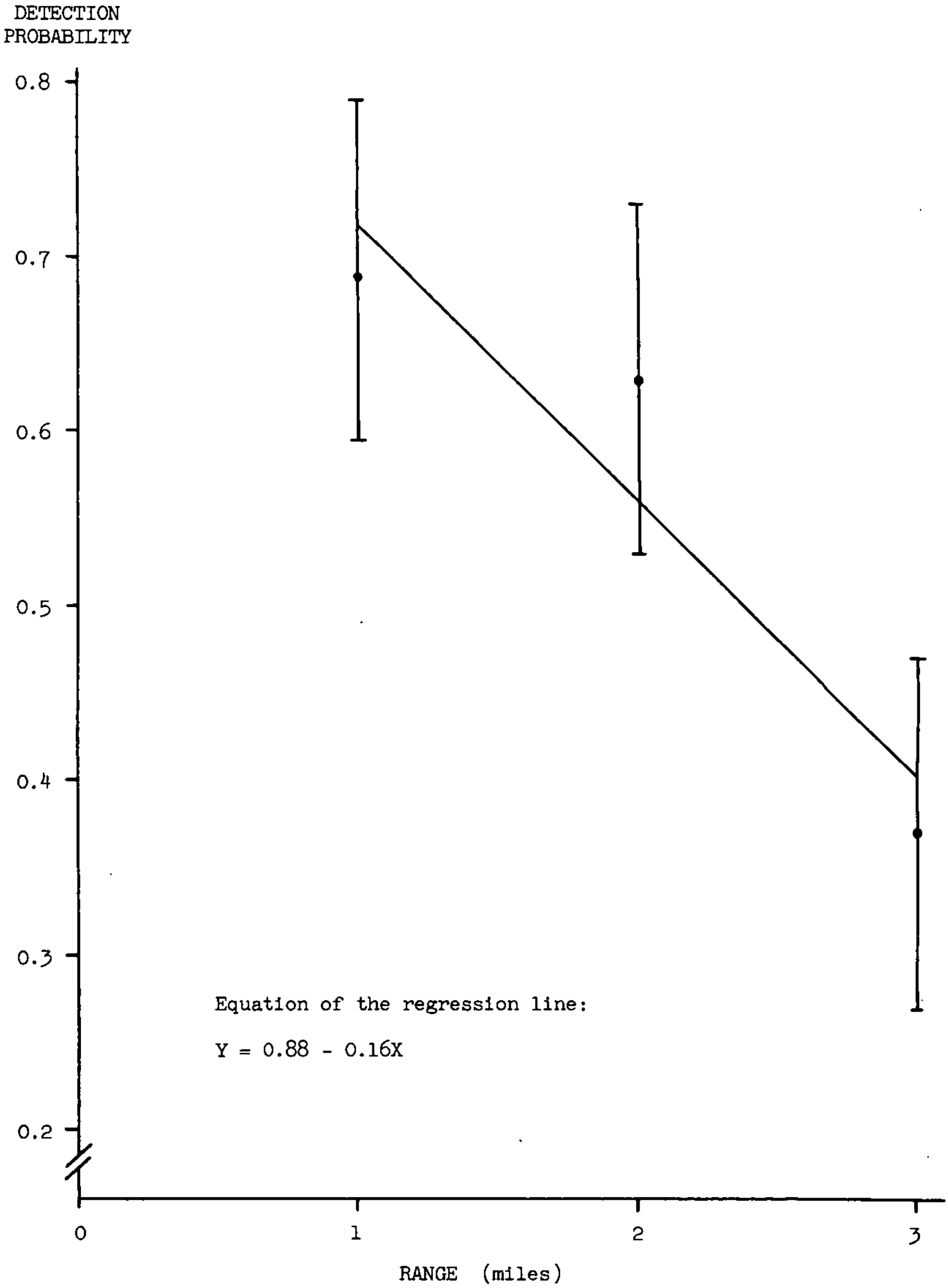
Range (miles)	1	2	3
Detection probability	0.69	0.63	0.37

T-tests showed that the differences in detection probability between the 3 mile range and the 1 mile range, and the 3 mile and the 2 mile range, were significant at the 5% level but the difference between the 1 mile and 2 mile values was not significant. These overall trends are in accordance with those found in Experiment 1.

The total variance due to range, as shown in Table 7.1.2., was further analysed into linear and deviation components. This analysis is shown in Table 7.1.7.

FIGURE 7.1.2

The effect of range on detection probability



NOTE The vertical lines represent the 95% confidence limits of the means.

TABLE 7.1.7

Analysis of range variance

Source	D.F.	S.S.	M.S.	V.R.	Significance
Ranges	2	3.05	1.52		
Linear regression	1	2.68	2.68	20.61	$p < 0.001$
Deviation	1	0.37	0.37	2.84	$(p < 0.10)$
Residual	108	14.37	0.13		

This table indicates that the linear regression of detection probability on range is significant. There seems to be a slight suggestion, however, that the relation between detection probability and range is curvilinear as the deviation component is significant at the 10% level. The mean detection probability values for each range together with the associated 95% confidence limits of the means are shown in Figure 7.1.2.

(c) Targets

The mean detection probabilities for each of the six targets are shown in Table 7.1.8.

TABLE 7.1.8

Mean detection probabilities for each target

Target	Detection probability
3	0.67
14	0.93
17	0.67
15	0.37
13	0.56
1	0.19

The difference between each pair of values was calculated and its significance determined. The results are shown in Table 7.1.9 in which 5% significance is indicated by underlining and 1% by double underlining.

TABLE 7.1.9

Differences in mean detection probabilities for targets

Targets	1	15	13	3	17	14
1	-	0.18	$\underline{\underline{0.37}}$	$\underline{\underline{0.48}}$	$\underline{\underline{0.48}}$	$\underline{\underline{0.74}}$
15		-	$\underline{0.19}$	$\underline{\underline{0.30}}$	$\underline{\underline{0.30}}$	$\underline{\underline{0.56}}$
13			-	0.11	0.11	$\underline{\underline{0.37}}$
3				-	0.00	$\underline{\underline{0.26}}$
17					-	$\underline{\underline{0.26}}$
14						-

It can be seen from this table that the targets can be divided into three groups, such that differences in detection probability within a group are not statistically significant but differences between groups are significant at the 1% or 5% level. The two most difficult targets, i.e. those with the lowest probability of detection, are Numbers 1 and 15 which form the first group. The second group consists of targets Number 13, 3 and 17, and the third of a single target, Number 14. These results, which are shown graphically in Figure 7.1.3, agree very closely with those found in Experiment 1.

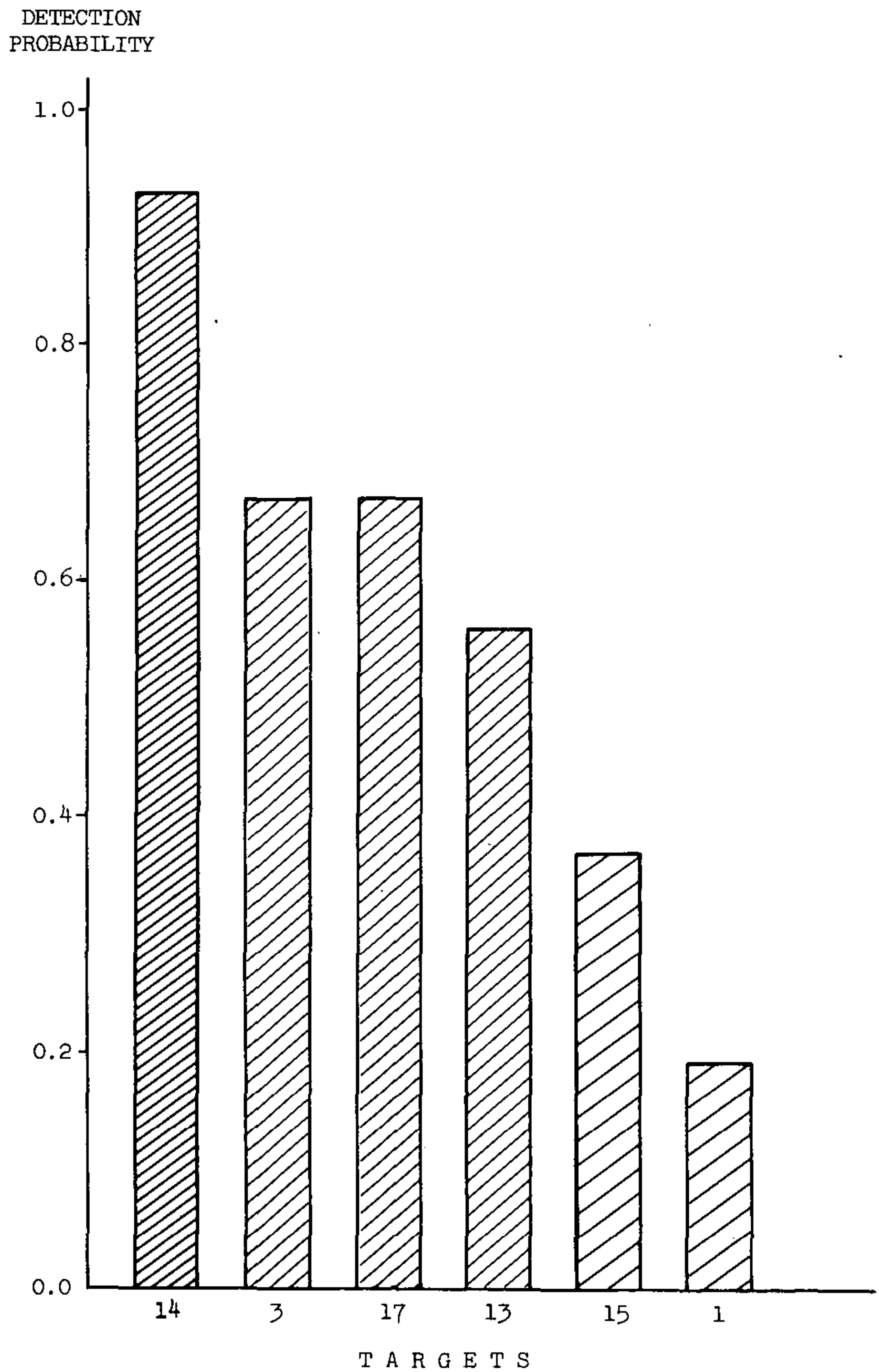
(d) Viewing distance x targets x ranges interaction

In the analysis of variance of the detection probability data shown in Table 7.1.2 the viewing distance x targets x ranges interaction is highly significant. This interaction, which indicates that target and range conditions are differently affected by the different viewing distances, is represented graphically in Figure 7.1.4. It can be seen in this figure that for any given target the lines relating detection probability to viewing distance are not parallel to the x - axis, indicating that viewing distance affects detection probability. However, in addition, the lines for each of three ranges for any given target are not parallel to each other, indicating that viewing distance interacts with range. Furthermore, the combinations of lines are not similar for each target, indicating that target differences are also involved in this interaction, as shown by the analysis of variance.

This somewhat confused picture possibly results from the wide variation between different targets and between the same target at different ranges combined with the relatively small number of subjects

FIGURE 7.1.3

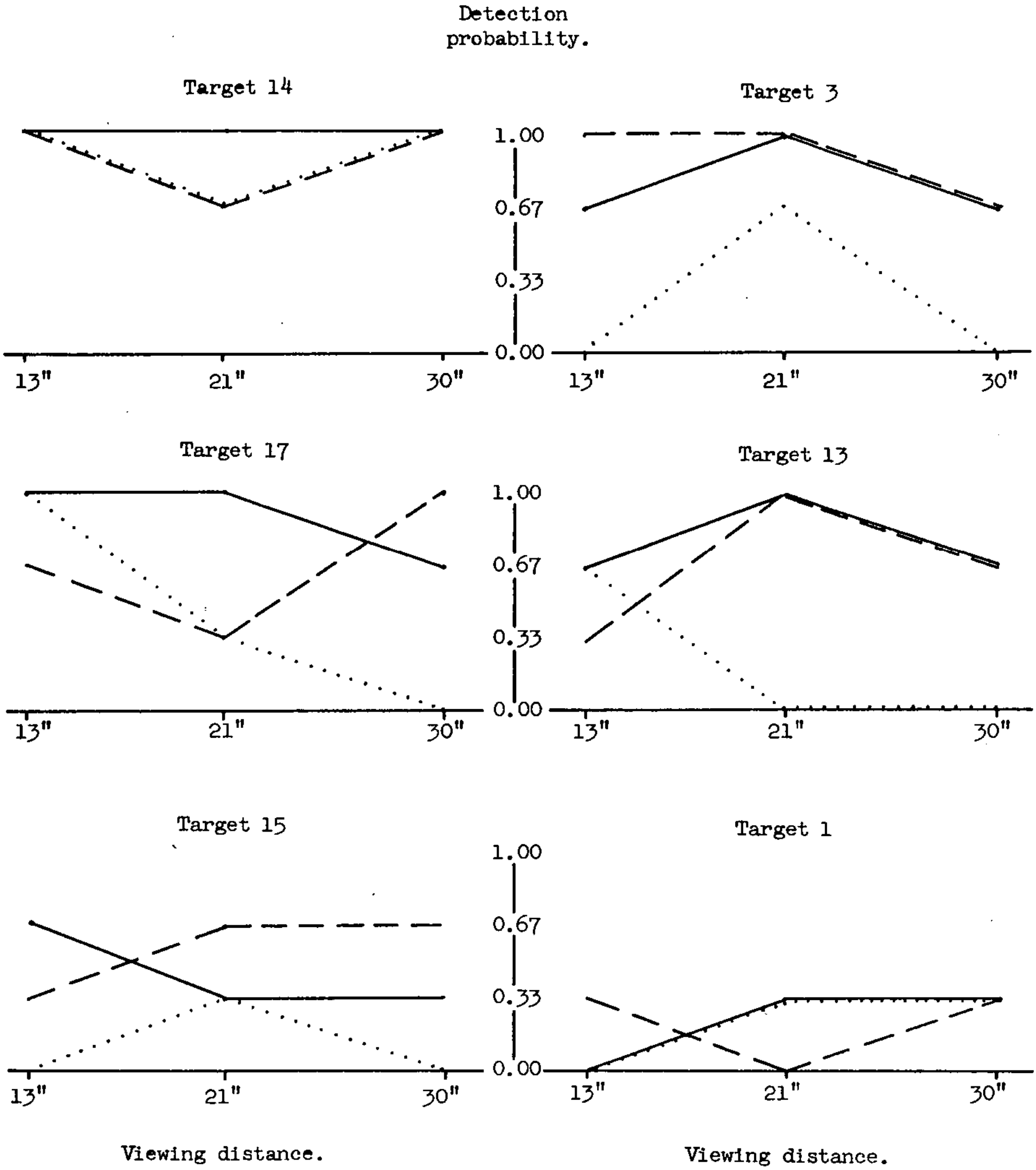
Mean detection probabilities for the six targets.



NOTE The different types of shading represent statistically significant differences in the mean detection probabilities for the targets.

FIGURE 7.1.4

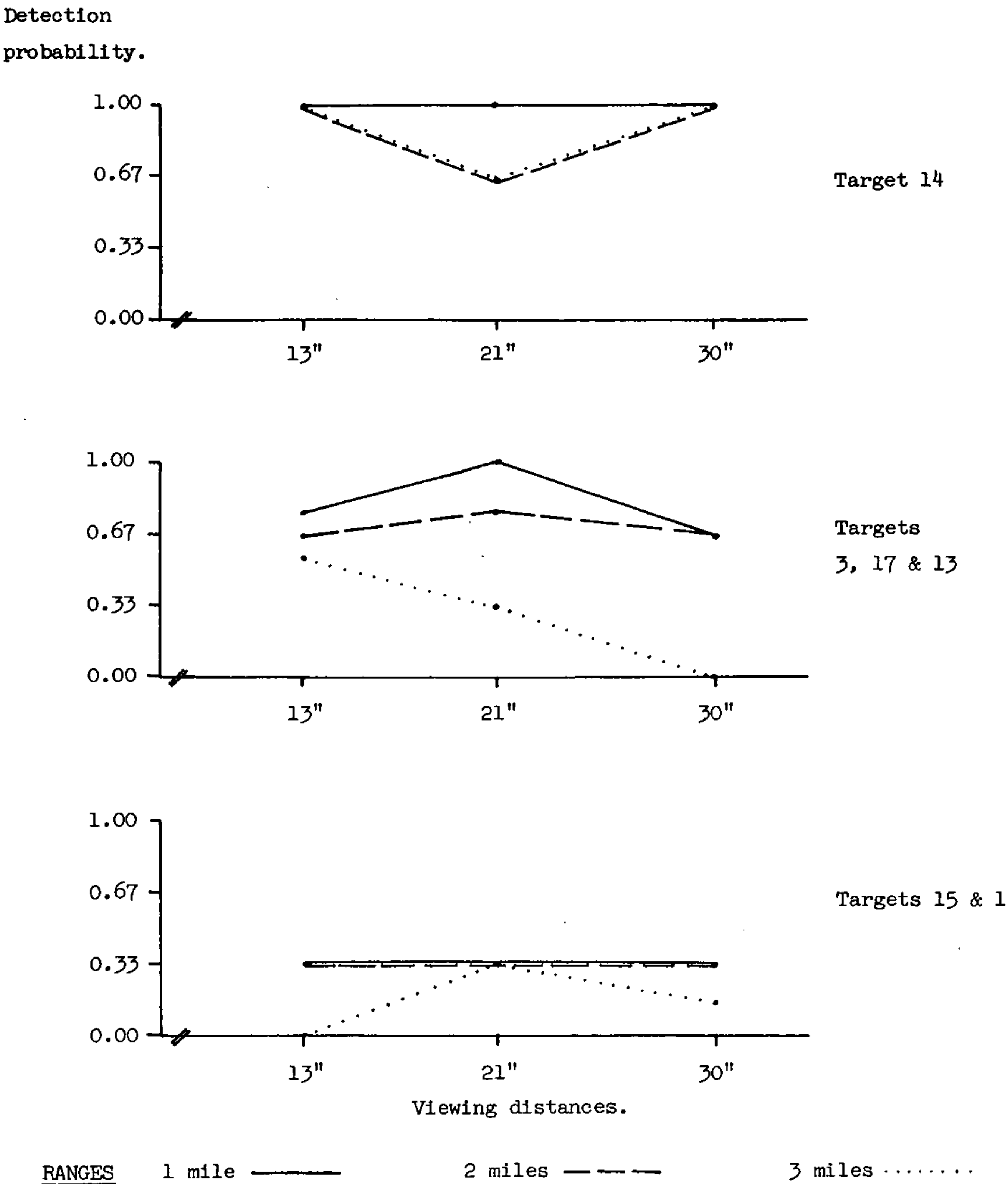
Graphical representation of viewing distances x targets x ranges interaction.



RANGES 1 mile ———— 2 miles — — — — 3 miles ....

FIGURE 7.1.5

Graphical representation of viewing distances x ranges interaction for groups of targets.



tested in each group. This resulted in each point in Figure 7.1.4 being based on only 3 readings. It can be clarified slightly by averaging the probability values for each of the three significantly different groups of targets discussed in the previous section. These mean values are shown in Figure 7.1.5. It can be seen in this figure that mean detection probability is consistently low (0.33 or less) for the most difficult targets (Numbers 1 and 15) at each viewing distance and range, and is consistently high (0.67 or better) for the easiest target, (Number 14) at each viewing distance and range. The adverse effect on detection probability of longer viewing distances and longer ranges is however, shown by the mean detection probabilities for the intermediate group of targets (Numbers 13, 3 and 17).

(e) Logit analysis

The raw data on detection probabilities shown in Table 7.1.1 were not altogether suited to the conventional analysis of variance techniques used since there were only three responses in each cell and each response could only take the values of 0 or 1. The results obtained from the conventional analysis were therefore compared with those found by a more sophisticated technique, Logit analysis.

The model used in this method was that the probability, P, of a correct detection is related to the factors tested by the following multiple regression equation:

$$Y = \text{Logit } P = \tfrac{1}{2} \ln. \frac{P}{1 - P} = \sum b_i x_i$$

In this equation the x values are constants relating to the experimental conditions and the b values are the corresponding regression coefficients, derived by successive approximations. The analysis, which was carried out by Professor P.Armitage of the London

School of Hygiene and Tropical Medicine, is shown in full in Appendix III.

The results obtained from this analysis indicate that the effect of viewing distance is non-significant but that there is a trend effect for range with some suggestion of curvature. This agrees closely with the results found from the analysis of variance. In addition, the Logit analysis showed significant differences between targets which again agreed well with those determined by conventional methods.

Thus, in the present experiment, as in Experiment 1, the results obtained from Logit analyses appear to be closely similar to those obtained from conventional statistical techniques.

7.2 Search time

In this experiment, as in Experiment I, the search time was taken to be the time, in seconds, required by a subject to view the display before making a response indicating that he was ready to designate the target position.

Since these search times relate to a static simulation they are not of direct relevance to the airborne situation. However, the analyses described in the following sections were carried out to determine which conditions resulted in longer search times and, in particular, to discover whether search times were affected by viewing distance.

Table 7.2.1 shows the raw data on search times and Table 7.2.2 shows the analysis of variance carried out on these data. It can be seen that the effect of viewing distance is not significant at the 5% level but that both targets and ranges are significant, at the 2.5% level and the 5% level respectively. As with the detection probability analysis shown in Table 7.1.2 the targets effect accounts for the largest proportion of the total variance. All interactions are non-significant. These results are in accordance with those obtained in Experiment I.

TABLE 7.2.1

Search times for target identification by unskilled subjects at three different viewing distances.

Viewing distances	13"			21"			30"		
Ranges (miles) / Targets	1	2	3	1	2	3	1	2	3
3	4.2 4.0 $\underline{9.2}$	7.4 2.0 4.2	$\underline{12.0}$ $\underline{11.6}$ $\underline{7.2}$	5.4 3.2 7.0	73.8 16.8 9.4	9.8 8.2 $\underline{5.4}$	$\underline{11.2}$ 5.7 8.6	$\underline{11.2}$ 8.2 6.6	3.4 $\underline{8.4}$ $\underline{8.8}$
14	2.6 2.0 2.2	8.8 1.2 4.0	11.8 1.2 4.8	2.0 0.8 1.0	$\underline{32.8}$ 4.0 0.8	29.4 $\underline{10.4}$ 6.0	3.2 5.4 9.0	2.4 5.0 16.0	2.4 3.6 12.0
17	2.0 6.0 21.4	4.4 23.2 $\underline{17.6}$	4.4 12.2 18.8	2.4 2.4 12.8	$\underline{31.4}$ $\underline{25.2}$ 21.0	$\underline{5.2}$ 10.0 $\underline{6.4}$	7.6 $\underline{13.2}$ 2.6	20.2 8.4 3.0	$\underline{8.8}$ $\underline{99.2}$ $\underline{12.4}$
15	$\underline{4.4}$ 13.0 15.4	20.6 $\underline{12.6}$ $\underline{34.4}$	$\underline{13.2}$ $\underline{42.2}$ $\underline{6.8}$	$\underline{36.2}$ 11.4 $\underline{4.6}$	17.6 31.0 $\underline{13.4}$	16.8 $\underline{6.4}$ $\underline{38.0}$	$\underline{9.2}$ $\underline{4.2}$ 6.8	15.0 11.2 $\underline{6.2}$	$\underline{35.8}$ $\underline{20.8}$ $\underline{11.4}$
13	4.4 13.2 $\underline{55.6}$	14.0 $\underline{10.0}$ $\underline{16.0}$	11.0 26.0 $\underline{9.0}$	17.2 6.2 14.8	5.4 4.2 6.2	$\underline{5.6}$ $\underline{32.6}$ $\underline{13.6}$	31.8 $\underline{13.6}$ 4.8	20.6 5.2 $\underline{8.4}$	$\underline{12.0}$ $\underline{5.8}$ $\underline{16.8}$
1	$\underline{12.2}$ $\underline{16.0}$ $\underline{4.0}$	7.8 $\underline{13.0}$ $\underline{28.2}$	$\underline{14.0}$ $\underline{7.8}$ $\underline{27.8}$	12.8 $\underline{5.4}$ $\underline{6.4}$	$\underline{33.8}$ $\underline{44.6}$ $\underline{16.2}$	19.8 $\underline{25.8}$ $\underline{16.8}$	$\underline{11.0}$ $\underline{33.2}$ 8.4	$\underline{47.4}$ $\underline{7.0}$ $\underline{26.0}$	$\underline{13.4}$ $\underline{36.8}$ 7.8

Values underlined relate to incorrect identifications.
All the search times are given in seconds.

TABLE 7.2.2

Analysis of variance on the search time data shown in Table 7.2.1

Source	D.F.	S.S.	M.S.	V.R.	Significance
Viewing distances (D)	2	189.89	94.45	-	N.S. (c)
Ranges (R)	2	1135.54	547.92	3.37	$p<0.05$ (c)
Targets (T)	5	2613.12	522.62	3.21	$p<0.01$ (c)
R x D	4	978.31	244.58	1.50	N.S. (b)
D x T	10	1209.52	120.95	-	N.S. (b)
T x R	10	1611.39	161.14	-	N.S. (b)
R x D x T	20	3043.08	152.15	-	N.S. (a)
Residual	108	17867.67	165.44(a)		
Pooled residual (Residual + R x D x T)	128	20910.75	163.41(b)		
Pooled residual (Residual + R x D x T + D x T + T x R + R x D	152	24709.97	162.57(c)		
TOTAL	161	28,647.82			

(a) Viewing distance

The mean search times for the three viewing distances are shown in Table 7.2.3.

TABLE 7.2.3

Mean search times for each viewing distance

Viewing distance	Mean search time (seconds)
13"	12.3
21"	15.0
30"	13.7
Overall mean	13.6

Differences within this table were found to be non-significant by t tests, which confirmed the results of the analysis of variance shown in Table 7.2.2. The data are shown graphically in Figure 7.2.1., together with the confidence limits of the means.

(b) Ranges

The mean search times for the three ranges are given in Table 7.2.4.

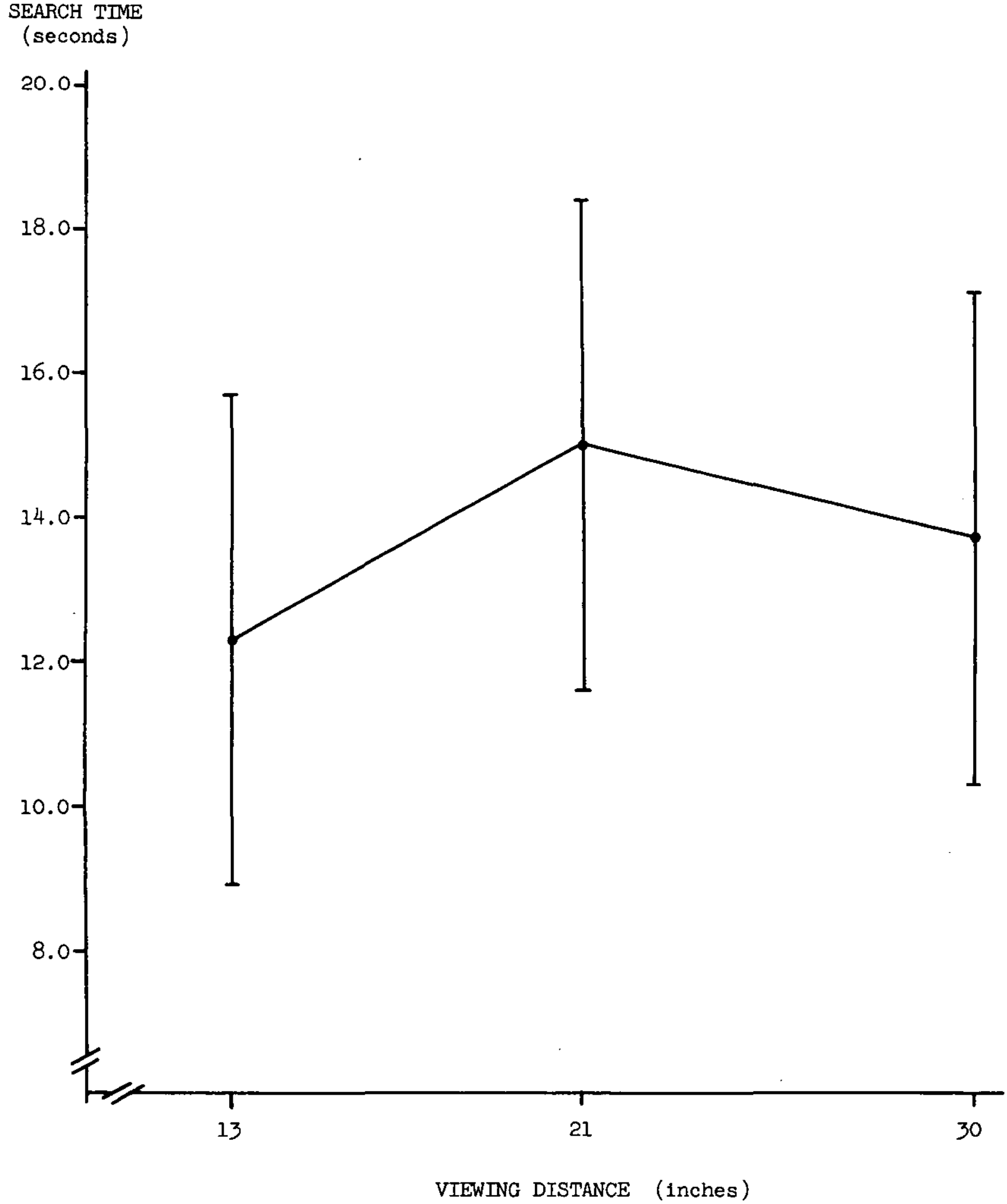
TABLE 7.2.4

Mean search times for each range

Range (miles)	Mean search time (seconds)
1	9.9
2	15.6
3	15.3
Overall mean	13.6

FIGURE 7.2.1

The effect of viewing distance on search time.



NOTE The vertical lines represent the 95% confidence limits of the means. Differences between the means were not significant.

For significance at the 5% level differences between these values must be equal to or greater than 4.9. It can be seen that the mean search time for the 1 mile range is significantly different from and less than those for the 2 mile and 3 mile ranges but that there is no significant difference between the 2 mile and the 3 mile values. In Experiment 1 a significant difference was only found between the mean search times for ranges 1 and 3 miles. The data is shown graphically in Figure 7.2.2, together with the confidence limits of the mean values.

(c) Target differences

The overall mean search times for each target are shown in Table 7.2.5 together with the rank order of the targets according to these search times and also according to detection probability.

TABLE 7.2.5

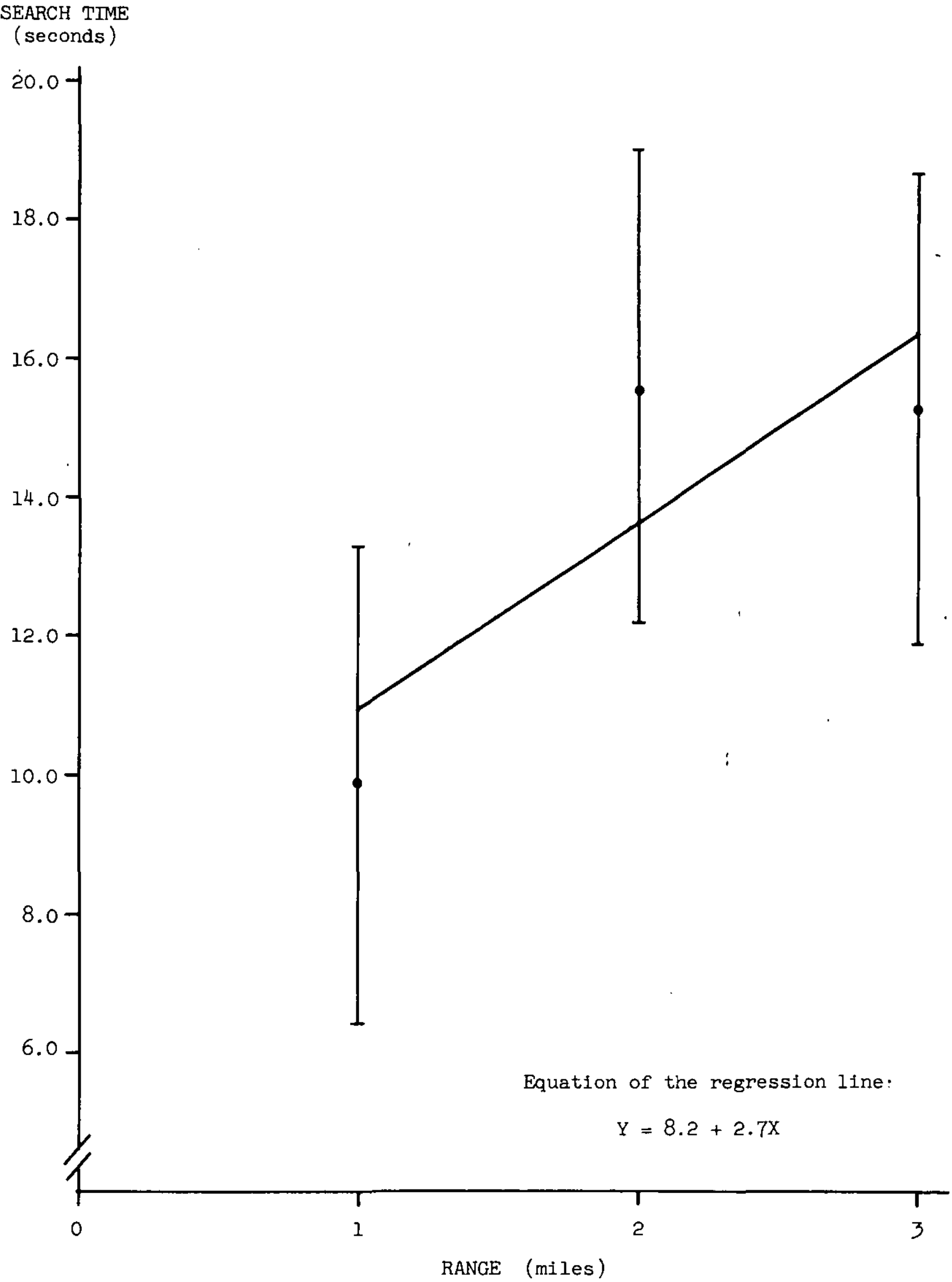
Mean search times for targets

Target	Mean search time	Ranking (search times)	Ranking (Detection probability)
14	6.8	1	1
3	10.1	2	$2\frac{1}{2}$
13	14.2	3	4
17	14.9	4	$2\frac{1}{2}$
15	17.0	5	5
1	18.6	6	6

It can be seen that there is a wide variation in mean search time ranging from 6.8 secs. for Target 14 to 18.6 secs. for Target 1. However, there is a very close correspondence between the rankings

FIGURE 7.2.2

The effect of range on search time



NOTE The vertical lines represent the 95% confidence limits of the means.

of the targets according to detection probability and according to search time. The significance of this correspondence was evaluated by means of Kendall's tau. The value of tau was 0.83 which is significant at the 3% level. This indicates that targets having a high detection probability tend to have short search times and vice versa. This result was also found in Experiment 1.

The significance of the differences between search times shown in Table 7.2.5 was calculated for each pair of targets. The results are shown in Table 7.2.6 in which 5% significance is indicated by single underlining and 1% significance by double underlining.

TABLE 7.2.6

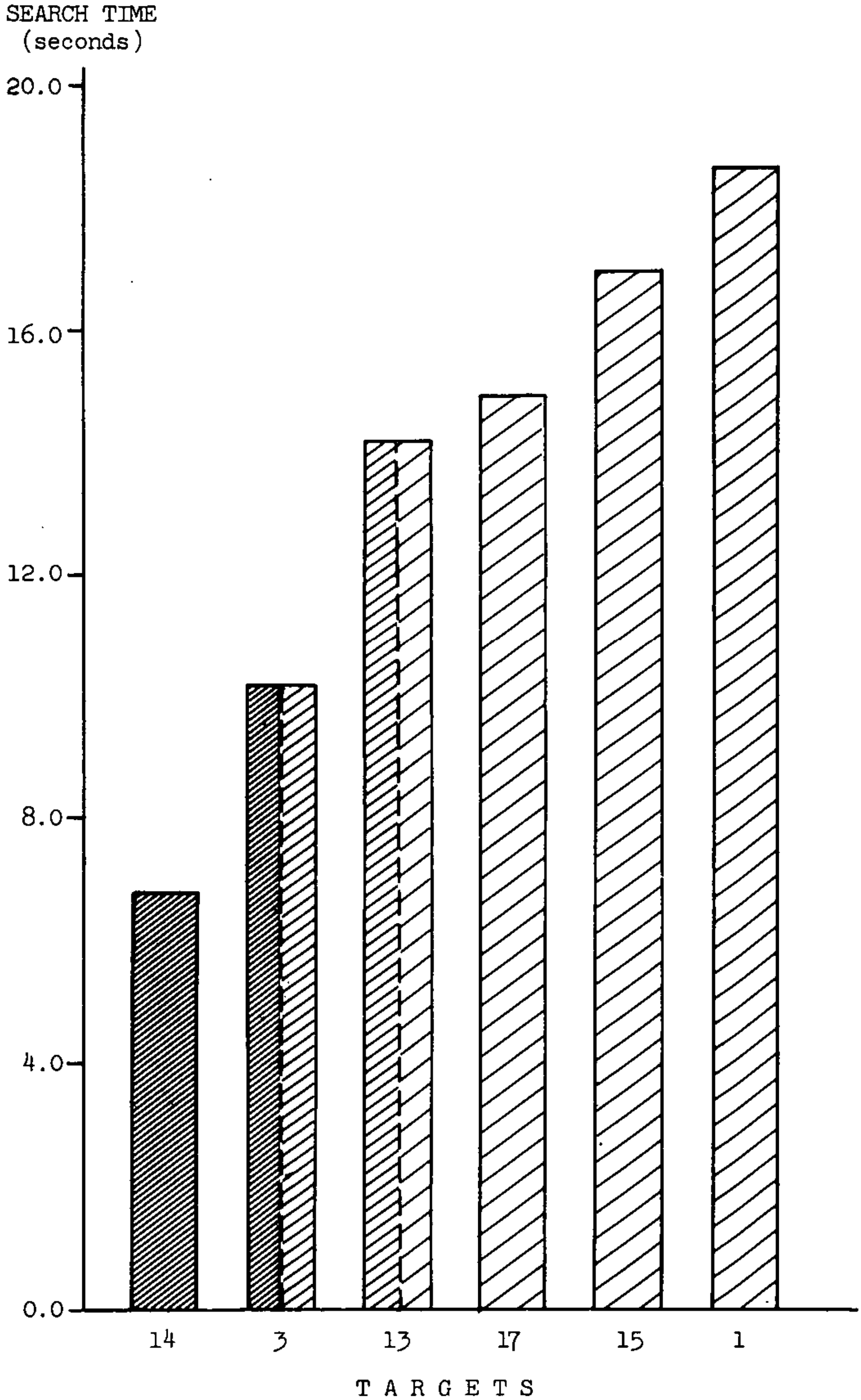
Differences between pairs of target mean search times

Targets	14	3	13	17	15	1
14	-	3.3	$\underline{\underline{7.4}}$	$\underline{\underline{8.1}}$	$\underline{\underline{10.2}}$	$\underline{\underline{11.8}}$
3		-	4.1	$\underline{4.8}$	$\underline{\underline{6.9}}$	$\underline{\underline{8.5}}$
13			-	0.7	2.8	4.4
17				-	2.1	3.7
15					-	1.6
1						-

It can be seen from this table that targets Number 14 and 3 are significantly different from Targets Number 17, 15 and 1. The remaining target Number 13 is intermediate between the two groups and is significantly different only from Target 14. These results, which are closely similar to those found in Experiment 1, are shown graphically in Figure 7.2.3. If this figure is compared

FIGURE 7.2.3

Mean search times for the six targets



NOTE The different types of shading indicate significant differences between the mean search times for the targets. Combinations of shadings (Targets 3 and 13) indicate that the targets are not significantly different from those shaded with either of the single shadings.

with Figure 7.1.3 the inverse relationship between detection probability and search time is clearly shown.

(d) Search times for correct and incorrect decisions

In carrying out the analysis of variance on the search time data no distinction was made between search times resulting in correct detections and those which resulted in incorrect detections. To analyse the search times related to correct and incorrect detections separately would have involved analysing an incomplete matrix. However, in Experiment 1 it had been found in general, that incorrect detections were associated with longer search times than correct detections. It can be seen from Table 7.2.7, which shows the overall mean search times for correct and incorrect decisions, that this is also the case in the present experiment.

TABLE 7.2.7

Mean search times for correct and incorrect detections

	Mean search time	N*
Correct detections	10.0	91
Incorrect detections	18.2	71
Overall mean	13.6	162

* N = Number of detections each value is based on.

The difference between the mean values for correct and incorrect detections was found by means of t-tests to be significant at the 0.1% level. These results are in agreement with the significance of the correlation between high detection probability and low search time shown in the previous section.

7.3 Confidence level

After each target identification a confidence level score was recorded. This was a subjective measure on a seven-point scale of the degree to which the subject was confident of his judgment. Complete certainty was indicated by 6, lesser degrees of confidence ranged from 5 to 1 and in a few cases where the subject was unable to make a judgment this was indicated by 0. These 0 - 6 values appeared on the print-out as 1 - 7, i.e. each value was recorded as 1 greater than the number shown on the subject's control box. This difference did not affect the analysis which has been carried out on the 1 - 7 data.

The raw data on the confidence scores are shown in Table 7.3.1 and the analysis of variance on this data in Table 7.3.2. It can be seen that viewing distance is non-significant but that targets and ranges both reach the 0.1% level of significance. As in Tables 7.1.2 and 7.2.2 target differences account for by far the largest proportion of the total variance. All interactions are non-significant. These results are in close agreement with those found in Experiment 1.

TABLE 7.3.1

Confidence levels associated with target identifications at each of the three viewing distances

Viewing Distance	13"			21"			30"		
Range / Targets	1	2	3	1	2	3	1	2	3
3	7 7 $\underline{7}$	7 5 7	$\underline{6}$ $\underline{4}$ $\underline{6}$	7 7 7	6 2 4	$\underline{6}$ 7 5	$\underline{7}$ 7 5	$\underline{7}$ 7 7	7 $\underline{4}$ $\underline{4}$
14	7 7 6	7 7 7	6 5 7	6 7 7	7 7 $\underline{7}$	6 $\underline{2}$ 6	7 7 3	5 7 5	5 6 7
17	7 4 5	7 6 $\underline{6}$	7 7 4	5 7 7	4 $\underline{6}$ $\underline{6}$	$\underline{4}$ 6 $\underline{4}$	5 $\underline{2}$ 6	7 4 6	$\underline{6}$ $\underline{2}$ $\underline{4}$
15	4 6 $\underline{6}$	4 $\underline{1}$ $\underline{2}$	$\underline{3}$ $\underline{3}$ $\underline{3}$	$\underline{5}$ $\underline{7}$ $\underline{5}$	$\underline{4}$ 3 2	$\underline{3}$ $\underline{3}$ 4	$\underline{5}$ $\underline{5}$ 6	4 4 $\underline{5}$	$\underline{2}$ $\underline{2}$ $\underline{5}$
13	7 7 $\underline{4}$	5 $\underline{7}$ $\underline{6}$	3 $\underline{6}$ 5	5 6 6	6 6 5	$\underline{5}$ $\underline{4}$ $\underline{6}$	7 $\underline{4}$ 6	5 7 $\underline{5}$	$\underline{3}$ $\underline{6}$ $\underline{4}$
1	$\underline{5}$ $\underline{4}$ $\underline{3}$	6 $\underline{1}$ $\underline{3}$	$\underline{6}$ $\underline{6}$ $\underline{1}$	$\underline{4}$ $\underline{7}$ 3	$\underline{6}$ $\underline{4}$ $\underline{2}$	$\underline{4}$ $\underline{3}$ 5	$\underline{5}$ $\underline{5}$ 5	$\underline{2}$ $\underline{3}$ $\underline{3}$	$\underline{4}$ $\underline{2}$ 4

Confidence level values range from 1 to 7, high values being associated with high confidence.

Values relating to incorrect decisions are underlined.

TABLE 7.3.2

Analysis of variance on confidence levels data shown in Table 7.3.1

Source	DF	S.S.	M.S.	V.R.	Significance
Viewing distances (D)	2	3.05	1.53	-	N.S.
Ranges (R)	2	33.53	16.77	9.27(c)	$p < 0.001$
Targets (T)	5	129.90	25.98	14.36(c)	$p < 0.001$
D x T	10	12.14	1.21	-	N.S.
T x R	10	28.99	2.90	1.50(b)	N.S.
R x D	4	5.28	1.32	-	N.S.
R x D x T	20	46.64	2.33	1.38(a)	N.S.
Residual	108	182.00	1.69(a)		
Pooled residual (Residual + R x D x T)	128	228.64	1.94(b)		
Pooled residual (Residual + R x D x T + D x T + T x R + R x D)	152	275.05	1.81(c)		
TOTAL	161	441.53			

(a) Viewing distance

Table 7.3.3. shows the mean confidence level scores for each of the three viewing distances, together with the overall mean.

TABLE 7.3.3

Mean confidence levels for viewing distances

Viewing distance	13"	21"	30"
Mean confidence scores	5.3	5.1	4.9
Overall mean		5.1	

It can be seen that although there is no significant difference between these values there is a tendency for mean confidence levels to decrease with increasing viewing distance, as shown in Figure 7.3.1.

(b) Ranges

Mean confidence scores decreased approximately linearly with increasing range as shown in Table 7.3.4. The data is displayed graphically in Figure 7.3.2 in which the 95% confidence limits of the means are also shown.

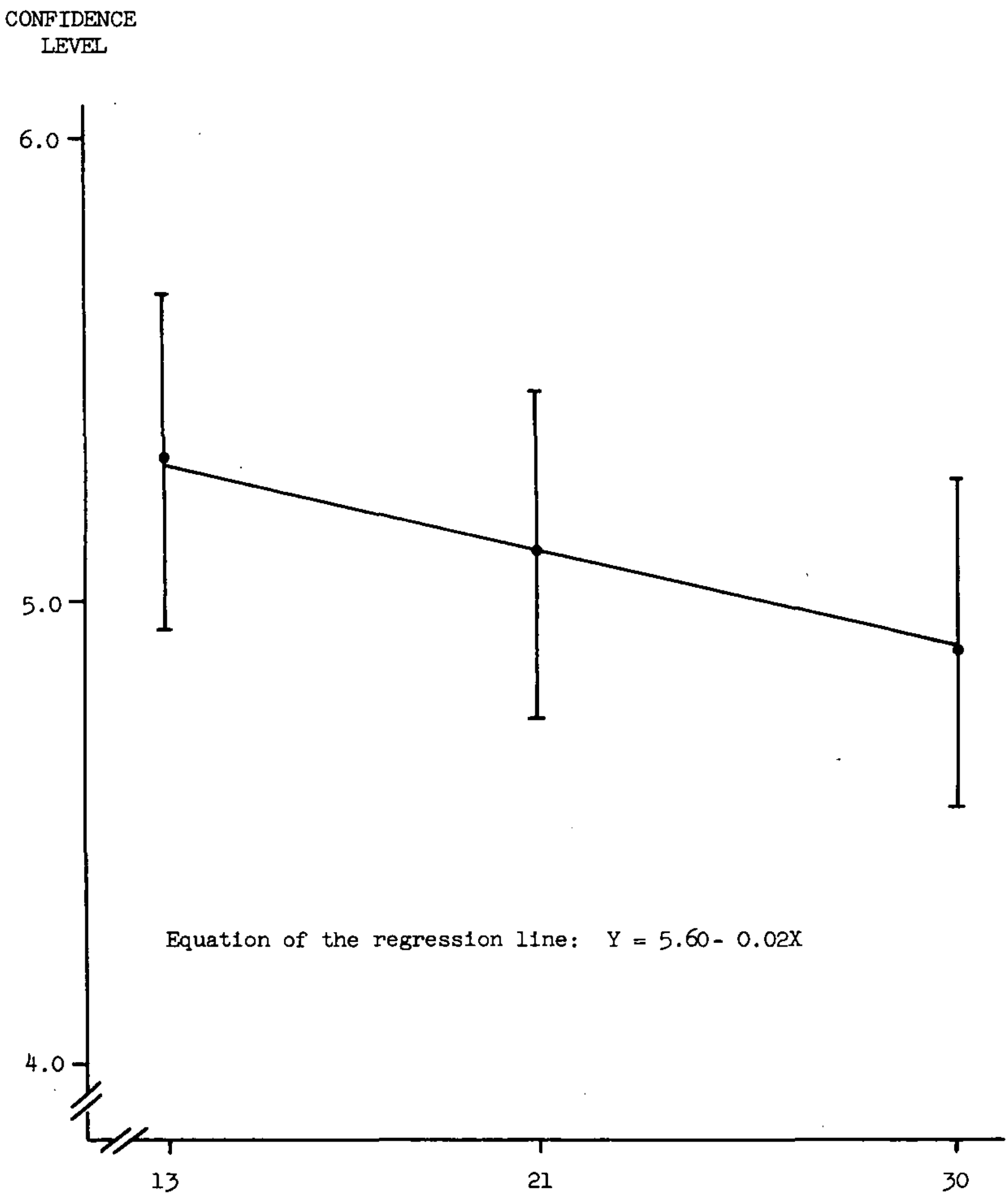
TABLE 7.3.4

Mean confidence scores for ranges

Range (miles)	1	2	3
Mean confidence score	5.7	5.1	4.6

FIGURE 7.3.1

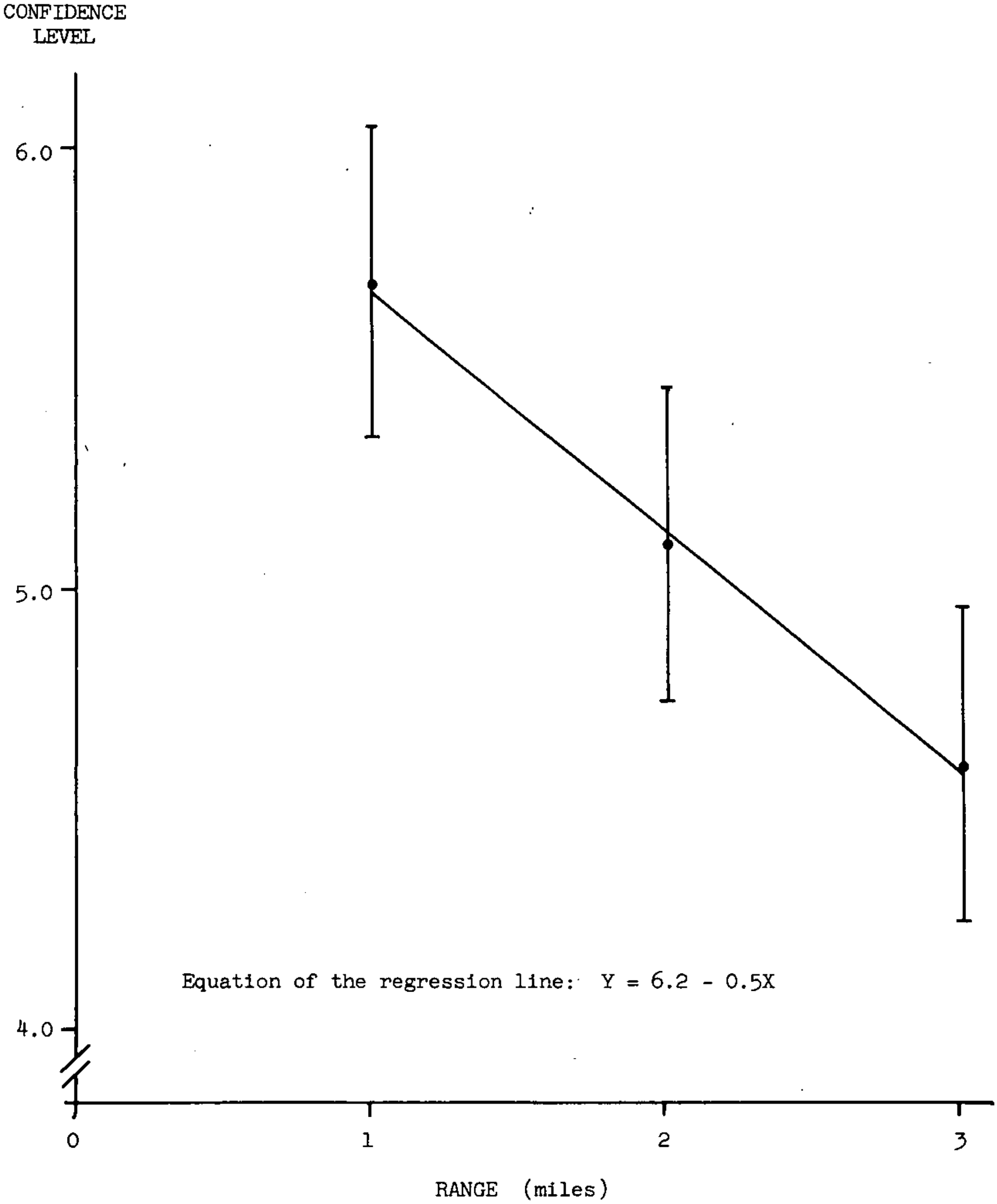
The effect of viewing distance on confidence level



NOTE The vertical lines represent the 95% confidence limits of the means.

FIGURE 7.3.2

The effect of range on confidence level



NOTE The vertical lines represent the 95% confidence limits of the means.

Differences in these mean values were significant at the 5% level for the single mile differences (i.e. between 1 and 2 miles, and between 2 and 3 miles) and at the 0.1% level for the difference between the 1 and 3 miles values.

(c) Targets.

Mean confidence scores were calculated for each target. These values are shown in Table 7.3.5 together with the rankings of the targets according to the mean confidence scores.

TABLE 7.3.5

Mean confidence scores for targets

Target	Mean confidence score	Ranking
14	6.2	1
3	6.0	2
13	5.4	3
17	5.3	4
15	3.9	$5\frac{1}{2}$
1	3.9	$5\frac{1}{2}$

Kendall's tau was evaluated to determine whether there was a correlation between these rankings and the rankings shown in Table 7.2.5 which relate to detection probability and search time. The values of tau and their significance are shown in Table 7.3.6.

TABLE 7.3.6

Values of Kendall's tau for confidence level correlations

	tau	Significance
Confidence level/ search time	0.97	$p < 0.01$
Confidence level/ detection probability	0.82	$p < 0.05$

It can be seen that there is significant correlation between confidence level and detection probability and between confidence level and search time, indicating that high confidence is associated with high detection probability and low search time. This result was also found in Experiment 1.

Since target differences were found to have a significant effect on confidence scores the significance of the differences between mean confidence scores was determined. In Table 7.3.7 which shows the difference between each pair of values 5% significance is indicated by single underlining and 1% significance by double underlining.

TABLE 7.3.7

Differences between mean confidence scores

Targets	14	3	13	17	15	1
14	-	0.2	0.7	0.9	2.3	2.3
3		-	0.6	0.7	2.1	2.1
13			-	0.1	1.5	1.5
17				-	1.4	1.4
15					-	0.0
1						-

This table shows that there were significant differences in mean confidence scores between targets. Numbers 1 and 15 gave rise to significantly lower confidence scores than the other targets and Number 14 was associated with a significantly higher confidence score than all targets except Number 3. There was also a significant difference between the mean confidence scores for targets 17 and 3. These results, which are similar to those obtained in Experiment I, are shown graphically in Figure 7.3.3 (c.f. Figures 7.1.3 and 7.2.3).

(d) Confidence levels for correct and and incorrect detections

The level of confidence a subject assigned to his response was a measure of how certain he was that he had correctly located the target. If, therefore, he was able to assess his own performance it would be expected that correct detections would, on average, be associated with higher confidence levels than incorrect detections. Table 7.3.8 shows the mean and deviation values for the confidence levels associated with correct and incorrect detections.

TABLE 7.3.8

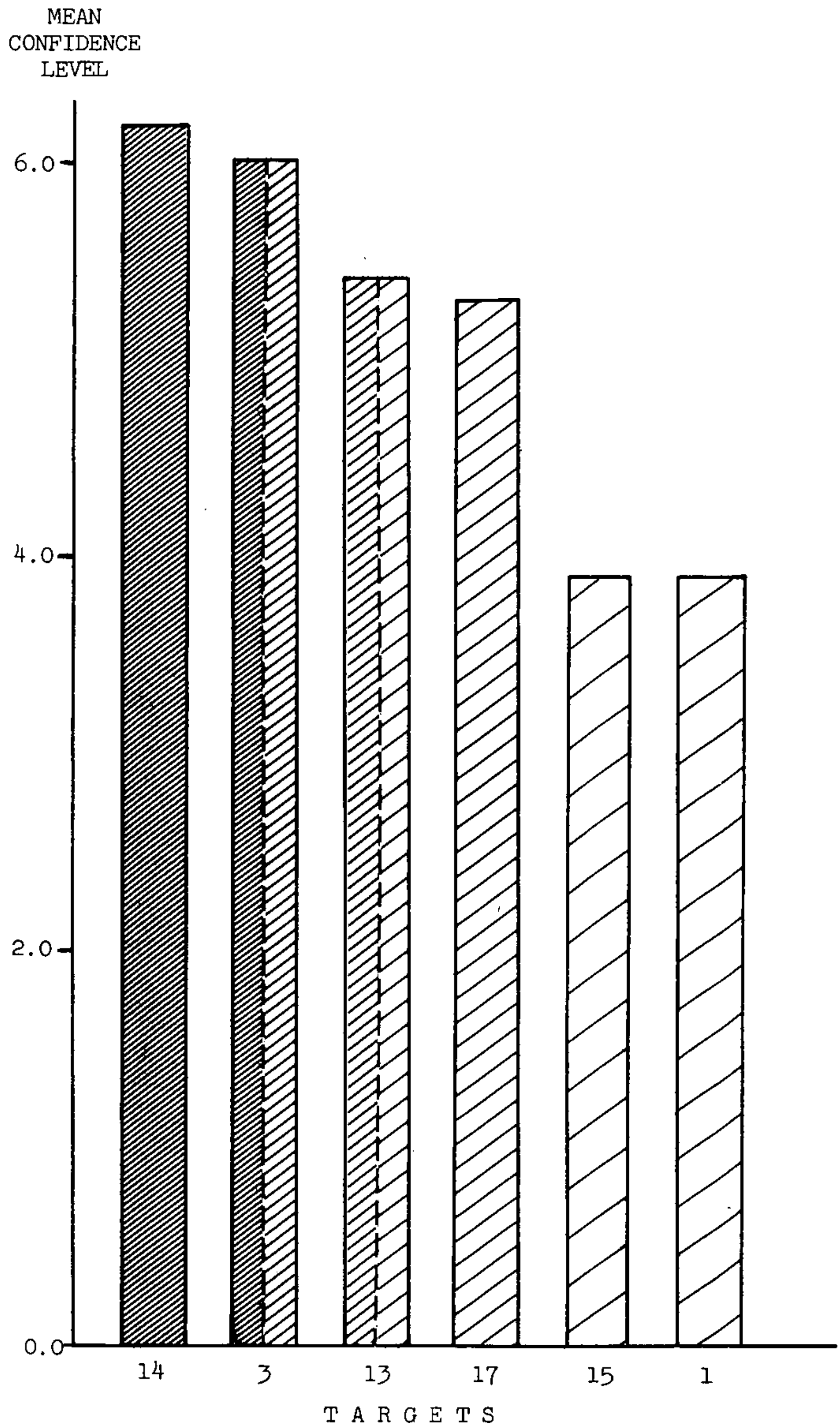
Mean confidence levels for correct and incorrect detections

	Mean	s.d.
Correct detections	5.8	1.4
Incorrect detections	4.3	1.6

The difference between the two means was found to be highly significant. ($t = 6.06$, $p < 0.001$). This indicates that, in general, subjects assigned higher confidence scores to the detections which had in fact been made correctly.

FIGURE 7.3.3

Mean confidence levels for the six targets.



NOTE The different types of shading indicate significant differences between the mean confidence levels for the targets. Combinations of shading (Targets 3 and 13) indicate that the targets are not significantly different from those shaded with either of the single shadings.

7.4 Map-briefing time

Subjects were allowed as much time as they wanted to study the map before the target photograph was displayed. The time taken for map briefing was recorded, in seconds, on the print-out. In the analysis of the data from Experiment 1 it was found that the map times were not related to any of the other performance measures and, with the exception of marked target differences, showed no significant factors. In the present experiment therefore only an outline analysis of the map times data has been carried out, to confirm that this data is not related to other performance measures.

The raw data is shown in Table 7.4.1 and the analysis of variance on this data in Table 7.4.2. It can be seen that the only significant factor in the analysis of variance is viewing distance. Although this factor reaches a high level of significance it seems possible that this could be a chance effect particularly in view of the random nature of the map times found in the analysis of Experiment 1.

TABLE 7.4.1

Map-briefing times for the three viewing distances

Viewing Distances	13"			21"			30"		
Targets \ Ranges	1	2	3	1	2	3	1	2	3
3	59.6 94.4 62.4	64.4 52.8 75.2	29.8 85.8 78.6	125.8 321.0 152.6	73.0 35.8 74.0	47.4 98.8 70.0	45.8 59.4 31.0	114.8 66.4 42.0	43.6 49.0 90.8
14	57.2 105.6 81.8	148.2 91.2 79.8	94.0 120.2 88.8	58.8 113.8 151.6	52.6 344.2 136.4	164.6 72.0 94.0	138.6 84.2 125.2	66.0 85.2 31.6	50.0 96.4 47.0
17	124.8 99.2 65.0	82.6 77.8 93.4	93.0 132.0 56.0	166.0 60.4 129.6	95.0 145.6 56.4	62.2 412.0 145.4	70.4 69.2 42.2	60.0 81.8 116.0	163.2 89.6 52.8
15	110.4 94.8 102.0	108.6 81.4 115.4	86.4 95.2 46.2	63.4 113.6 78.6	175.4 272.8 148.4	99.4 55.8 164.2	64.6 142.6 34.8	112.6 85.2 117.2	47.2 60.6 33.0
13	65.4 64.4 90.8	73.6 97.8 75.2	83.2 73.4 91.4	85.6 228.0 74.4	46.0 71.0 134.4	229.8 127.0 175.8	50.4 77.6 87.2	69.6 87.4 55.8	201.0 63.2 50.6
1	60.6 113.2 135.6	91.0 132.8 79.8	80.2 62.8 79.8	52.8 74.8 193.4	234.4 109.2 132.4	82.8 335.6 43.2	180.0 82.6 54.0	48.6 111.6 46.6	65.4 90.6 99.6

All times given in seconds.

TABLE 7.4.2

Analysis of variance on map briefing times shown in Table 7.4.1

Source	DF	S.S.	M.S.	V.R.	Significance
Viewing distances (D)	2	85,536.03	42.768.02	13.91	$p < 0.005$ (c)
Ranges (R)	2	83.54	41.77	-	N.S. (c)
Targets (T)	5	13,409.19	2,681.84	-	N.S. (c)
D x T	10	1,573.67	157.37	-	N.S. (b)
T x R	10	4,333.02	433.30	-	N.S. (b)
R x D	4	2,171.19	542.80	-	N.S. (b)
R x D x T	20	99,813.14	4,990.65	1.49	N.S. (a)
Residual	108	359,579.40	3,329.44(a)		
Pooled residual (Residual + R x D x T)	128	459,392.54	3,589.00(b)		
Pooled residual (Residual + R x D x T + D x T + T x R + R x D)	152	467,470.42	3,075.46(c)		
TOTAL	161	566,499.18			

(a) Viewing distance

Analysis of the viewing distance data indicates that mean map times are highest for the 21" viewing distance as shown in Table 7.4.3.

TABLE 7.4.3

Mean map times for each viewing distance

Viewing distance	Mean map time (seconds)
13"	86.8
21"	130.7
30"	78.4

The fact that no explicable or consistent trend is shown by these means suggests that their significance is due to a chance effect which could have arisen from the use of different groups of subjects for each viewing distance. It is of interest to note that mean search time is also a maximum for the 21" viewing distance group. Although in this case the differences were non-significant these results do suggest that in general the 21" group may have been slightly slower and more cautious than the other two groups. However, the personality variables assessed, i.e. neuroticism and intraversion-extraversion, do not show any evidence to support this view.

(b) Ranges

Since subjects did not know at which range they would see a given target no range effect would be expected in the map time data and none was found.

(c) Target differences

Target differences were found to be non-significant in the analysis of variance. When the targets were ranked according to mean map time it was found that there was no correlation between these rankings and those according to detection probability, search time or confidence level. This lack of correlation of map times with any other performance measure was also found in Experiment 1. In general, therefore, it appears that map times bear little relation to subsequent performance and, since the subject is not under any pressure to map-read quickly, these times may well be influenced by extraneous distractions.

7.5 Relationship between detection performance and measures made in preliminary tests.

During the preliminary tests numerical values relating to each subject's intelligence and personality were obtained. The mean and standard deviation values of the intelligence and introversion - extraversion (E) and neuroticism (N) scores for each group of subjects are shown in Table 7.5.1. For comparison purposes the population norms are also shown.

TABLE 7.5.1

Mean and standard deviation values of IQ, E and N scores

		13" group	21" group	30" group	Population norms
I.Q.	Mean	41.7	42.3	40.0	39.1
	s.d.	7.4	7.4	2.2**	8.3
E	Mean	12.7	13.9	17.1**	11.1
	s.d.	4.6	2.9	1.8*	4.5
N	Mean	10.0	9.0	7.8	10.0
	s.d.	3.8	3.9	4.3	5.0

Asterisks indicate values significantly different from the corresponding population norms. ** 0.1% level, * 5% level.

In this table only three of the values shown are significantly different from the corresponding population norms. The low value of the standard deviation of the I.Q. scores for the group exposed to the 30" viewing distance indicates that the I.Q. scores of this group were much more closely bunched around the mean than would have been expected, both in comparison with the population standard deviation and in comparison with the values found for the other two groups. Since students were tested at random there is no obvious explanation of this but as the mean I.Q. values in each group were approximately equal it is unlikely that the low deviation value would bias the experimental results.

The other two significantly different values are the mean and standard deviation of the extraversion scores for the 30" group. The mean is significantly higher than and the deviation significantly lower than the population values although they are not significantly different from the mean and deviation values for the other two groups. Again, there is no obvious explanation of these anomalous values but since performance was not found to correlate with E score they appear to be of little importance.

It had been found in Experiment 1 that when the subjects were ranked according to (a) mean accuracy and (b) mean search time the rankings according to accuracy were correlated with those according to I.Q. and the rankings according to mean search time were negatively correlated with those according to N score, i.e. subjects of high intelligence tended to make more correct detections and more neurotic subjects tended to work more quickly. In the present experiment the correlation coefficients were again evaluated to determine whether the same result was obtained for the two additional groups of nine subjects. An accuracy score (i.e. percentage of correct detections made) and a mean search time was calculated for each subject. The rankings of these performance scores were compared with those of the I.Q., E and N scores by means of Kendall's tau. For the 21" group no significant correlations were found. The only significant tan value ($p < 0.025$) found for the 30" group was that for the correlation between mean search time and N score, i.e. subjects who were less neurotic tended to work more quickly. This result is the opposite of that found previously and it is not possible at present to determine whether one or both of these contradictory results arose by chance. As shown in Table 7.5.1 the distribution of I.Q. and E scores in the 30" group is relatively small and therefore it is less likely that significant correlations between individual performance measures and corresponding I.Q. and E scores would be found. However, the distribution of I.Q., E and N scores of the 9 subjects in the 21" group was representative of the populations compared. Thus, the absence in the present experiment of correlation between I.Q. and accuracy and between N score and speed,which were highly significant in Experiment I,cannot readily be explained. It is hoped that the results of later experiments will clarify this situation.

7.6 Summary of results

A cross-referenced summary table of the main results of this experiment is shown on the following page.

TABLE 7.6.1

Summary of results

	DETECTION PROBABILITY	SEARCH TIME	CONFIDENCE LEVEL
VIEWING DISTANCE	No significant effect but shorter viewing distances tended to be more favourable. Overall mean detection probability = 0.56 (23-25)	No significant effect but shortest viewing distance appeared to be most favourable. (39)	No significant effect but there was a tendency for mean confidence level to decrease with increase in viewing distance. (49)
RANGE	Significant decrease in detection probability at 3 mile range. Values ranged from 0.69(1 mile) to 0.37 (3 miles). (26-28)	Mean search times for range 1 mile were significantly shorter than those for 2 miles and 3 miles. (39-41)	Significant differences between mean confidence levels for each range. Values decreased linearly with increasing range. (49-51)
TARGET DIFFERENCES	Significant differences between easy (14), intermediate (13,3,17) and difficult (15,1) targets. Mean detection probabilities ranged from 0.93 to 0.19. (29-30)	Significant differences in search time between easy targets (14 and 3) and difficult targets (17,15 and 1). Mean times ranged from 6.8 secs. to 18.6 secs. (41-45)	Significance differences in mean confidence levels for different targets. Targets 1 and 15 were associated with significantly lower confidence levels than all other targets. (52-54)
FURTHER POINTS	Results of logit analysis of detection probability data agreed well with analysis of variance. (34) Significant R x D x T interaction found in analysis of variance. (30-34)	Mean search times for incorrect detections were much longer (18.2 secs) than those for correct detections (10.0 secs.) (45)	Mean confidence levels for targets corrected detected were significantly higher than those for targets incorrectly detected. (54)

NOTE The numbers at the bottom left corner of each block relate to the relevant pages of the report.

8. DISCUSSION

Two clear results emerge from the detailed analyses shown in the previous section. Firstly, the effect of viewing distance on the three main measures of detection performance recorded is statistically non-significant. Secondly, the general trends shown by the data in the present experiment are in close agreement with those found previously. Both these results are important but it is necessary to consider their implications in relation to the nature of the experiment from which they were obtained.

Detailed analyses of three performance measures indicated that an increase in viewing distance, which results in a decrease in the angular subtense of the display at the observer's eyes, gave rise to no significant changes in detection performance, i.e. none of the results were significant at the 5% level or better. However, there does appear to be a deterioration in detection probability, search time and confidence level at the longest viewing distance, 30", and in search time and confidence level only, also at the 21" viewing distance. Since this was a limited experiment, in terms of numbers of subjects and targets tested, no definite conclusions can be drawn from these trends. However, had a more extensive experiment been carried out, it is possible that a statistically significant result would have been obtained. In the absence of such an experiment the trends found in the present work should not be ignored, particularly as the experimental conditions, e.g. absence of vibration, low noise level, good illumination and picture quality, and relatively little external distraction, were considerably more favourable than would be encountered under operational conditions.

It is possible that an adverse environment would accentuate the effect of viewing distance on performance.

Furthermore, it must be emphasised that the results obtained apply directly only to the specific experimental conditions tested. In relating them to the more generalised requirements of airborne target detection various qualifications should be mentioned. Firstly, the results apply only within the range of viewing distances investigated, and extrapolation in either direction could prove extremely misleading. This is particularly important in the case of longer viewing distances since further decreases in the angular subtense of the display could result in critical geographic features, in addition to the target itself, being reduced below the threshold level for recognition. This would seriously jeopardise both overall geographic orientation and specific target detection tasks.

Secondly, although in terms of size a wide variety of targets, ranging from churches to airfields was investigated, they were all situated in the same terrain, i.e. Southern England, and all could be exactly located on a map. One cannot necessarily predict from the results obtained the effect of viewing distance on target detection performance over more monotonous types of terrain, e.g. deserts. Moreover, the task of detecting small mobile targets which cannot be exactly located on a map is, as indicated in the Introduction, a more difficult task than the detection of static natural or cultural features. The effect of viewing distance on the detection of these mobile targets is likely to be more serious since it depends on the direct recognition of the target itself rather than nearby 'lead-in' features.

Analysis of the search time data obtained in this experiment indicated that longer viewing distances tended to result in longer search times. Although this experiment used a static simulation technique and thus did not represent the complex dynamic aspects of the environment of a high speed aircraft, this result is important if the implication that the task of geographic orientation and target detection is more difficult at longer viewing distances is valid. However, it is possible that a dynamic display, in which important 'lead-in' features become more conspicuous as the aircraft approaches the target area, would in this respect partially or totally compensate for the adverse effect on static search times found for longer viewing distances.

Thus, in some ways, it appears that the results of this experiment may underestimate the operational effect of increasing viewing distance. However, it should be noted that the experiment was carried out with unskilled subjects rather than the skilled air-crew who would be responsible for navigation and missile guidance in the airborne situation. In Experiment 1 it was shown that, although in terms of detection probability and confidence level the performance of skilled and unskilled subjects was very similar, the mean search times for skilled subjects were considerably less than those for the unskilled group. There was also some evidence to suggest that the skilled subjects were less affected by adverse conditions e.g. longer ranges. It is possible therefore that the results obtained from unskilled subjects overestimate the effect of viewing distance on the performance of skilled aircrew.

In view of the reservations with which the results of this experiment must be considered it is of interest to note that a dynamic target detection experiment reported by Crawley, Silverthorn and Snailum, (1966) yielded very similar results. The aim of their experiment was to investigate detection performance using two different display sizes 7" x 5" and 5" x 4" at a constant viewing distance of 29". The angles subtended at the observer's eyes were thus $14^\circ \times 10^\circ$ and $10^\circ \times 8^\circ$ respectively, as compared with values of $21^\circ \times 15\frac{3}{4}^\circ$, $13^\circ \times 9\frac{3}{4}^\circ$ and $9^\circ \times 7^\circ$ used in the present experiment. The mode of display was a 625 line T.V. monitor and the displayed material consisted of 16 air-to-ground films. Targets were ground features similar to those studied in the present experiment and mean recognition range, about 2 miles, was also comparable. The general conclusion that Crawley et al found from their experiment, which used 8 unskilled subjects, was that target recognition performance was not significantly affected by the display sizes studied but that there was a possible trend towards reduced performance for reduced display size. This result is in agreement with that obtained in the present experiment but no more detailed comparisons can be made since the present experiment used a different series of targets and a static simulation technique. In both cases, as indeed with all work of this type, the importance of comparing data from laboratory simulation studies with flight trial data should be stressed.

Detailed comparison of the results of this experiment with the results of Experiment 1 is complicated by the overlap of some of the data, (i.e. 54 out of 126 readings made in Experiment 1 were included in the total of 162 readings analysed in the present experiment). However, when comparisons of target difficulty and range effects were made between the set of readings taken from Experiment 1 and the two sets of readings obtained in this experiment no significant differences were found. It was therefore possible to compare the overall trends found in the complete set of data for the present experiment with those found previously. As indicated in the Results section there is very close agreement between the general trends found in the two experiments. In particular, the overall detection probabilities for each of the targets remain closely similar in the two experiments, and the correlations between high detection probability, low search time and high confidence level apparent in Experiment 1 were again found in the present experiment. The implications of the general trends are discussed in the report on Experiment 1 (Parkes, 1967) and need not be further considered here. However, the similarity of the results for the two experiments is of considerable importance in that it indicates that the main effects are consistent and can be reproduced with different groups of subjects. It appears therefore that the experimental technique is a suitable one for investigating statically some of the parameters involved in visual navigation tasks.

The main discrepancy between the results of this experiment and those of Experiment 1 lies in the relationship between personality variables and individual performance. The correlations found in Experiment 1 between high intelligence and high detection probability and between high neuroticism scores and low search times are entirely absent from the data obtained in this experiment. This is disappointing in view of the high levels of significance previously found for these correlations but further work should determine whether there is a genuine relationship or whether it was simply an apparent one arising by chance. If the relationship between intelligence and detection probability is valid, it could be used to screen out potentially unsuitable subjects. It is therefore important that the validity of this correlation should be further investigated.

In general, although only tentative conclusions can be drawn as to the effect of viewing distance on detection performance, the results of this experiment are encouraging in terms of the suitability of the experimental technique for further experiments of this type.

9. REFERENCES

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APPENDICES

APPENDIX I

Since this report contains many references to the first experiment carried out in this series, the summary and a table of the main results found in Experiment 1 are shown on the following pages for convenient reference.

EXPERIMENT 1

SUMMARY

A static simulation technique was used in this target detection experiment to investigate the effect of navigational uncertainty, range to target and target difficulty on four measures of performance. These were detection probability, search time, confidence level of decision and map-briefing time. The experiment was based on a 7 x 7 (targets x conditions) Latin Square design. Seven skilled pilots and navigators, and 21 students of comparable ability, as assessed by intelligence and personality tests, acted as subjects.

The results showed that none of the performance measures considered were affected by navigational uncertainty. For unskilled subjects detection probability and search time were significantly related to range. The relation was linear. As range increased from one to four miles detection probability decreased and search time increased. There were significant differences between the targets for each measure of performance. When the targets were ranked according to each of these measures significant associations were found between the rankings. Targets which had high detection probabilities tended to have short search times and high confidence levels associated with them. The converse was also true.

The performance of skilled subjects was very similar to that of the unskilled subjects, but the former took significantly less time in map-briefing and in searching for the targets.

In the discussion sections the general suitability of the experimental technique is assessed and the results considered in relation to further work at present being carried out.

EXPERIMENT 1

TABLE OF MAIN RESULTS FOR UNSKILLED SUBJECTS

	DETECTION PROBABILITY	SEARCH TIME	CONFIDENCE LEVEL	MAP-BRIEFING TIME
NAVIGATIONAL UNCERTAINTY	No significant effect.	No significant effect.	No significant effect.	No significant effect.
RANGE	Significant linear relationship between increasing range and decreasing detection probability. Detection probabilities fell from 0.74 at 1 mile to 0.52 at 3 miles.	Significant linear relationship between increasing range and decreasing search time. Mean search times increased from 9.7 secs. at 1 mile to 14.0 secs. at 3 miles.	Significantly higher confidence scores for lower ranges.	No effect found (None was expected since the subject was not told the range of the target while briefing himself on the map).
TARGET DIFFERENCES	Detection probabilities varied from 1.00 to 0.28 for the seven targets. Significant differences between easy, average and difficult targets.	Significant differences in mean search times between easiest and most difficult targets. Range: 4.4 - 18.1 secs.	Significant differences between targets.	Significant differences but rankings on map-briefing time not related to rankings on other performance measures.
DIFFERENCES BETWEEN SKILLED AND UNSKILLED SUBJECTS	No significant differences. Overall detection probability was 0.59 for the unskilled and 0.61 for the skilled group.	Skilled group were significantly faster than unskilled group, but target rankings on search time were closely similar for each group.	No significant differences.	Skilled group were significantly faster than unskilled group.

APPENDIX II

This appendix shows the schedule of targets and conditions used in Experiment 1, from which the relevant data were extracted for comparison purposes in the present experiment. The detailed schedules used at the 21" and 30" viewing distances are also given. In each case target and condition combinations were presented to subjects in the random orders shown.

APPENDIX II

EXPERIMENT I

Experimental schedule of targets and conditions for each of the seven subjects in a matrix

Subject number	1			2			3			4			5			6			7		
	T	R	C	T	R	C	T	R	C	T	R	C	T	R	C	T	R	C	T	R	C
	13	1	2	16	1	2	3	1	2	3	3	1	3	2	1	16	2	1	1	1	1
	3	2	2	17	3	1	16	4	2	16	3	2	16	2	2	1	4	2	16	3	1
	15	2	1	1	2	1	14	2	1	15	4	2	1	3	1	13	2	2	3	4	2
	17	4	2	15	2	2	1	2	2	13	2	1	15	3	2	17	1	1	14	2	2
	1	3	2	13	4	2	15	1	1	14	1	1	14	4	2	3	3	2	13	3	2
	14	3	1	14	3	2	13	3	1	1	1	2	17	1	2	14	1	2	15	1	2
	16	1	1	3	1	1	17	3	2	17	2	2	13	1	1	15	3	1	17	2	1

T = Target R = Range C = Uncertainty condition

In Experiment 1, this matrix was repeated three times, using a total of 21 subjects. The performance data associated with the target and range combinations underlined (i.e. those relating to Uncertainty 1 and omitting target No. 16) were extracted for inclusion in Experiment 2.

APPENDIX II (cont'd)

Experimental schedule of targets and ranges for each of the nine subjects in the 21" viewing distance group

Subject number	1		2		3		4		5		6		7		8		9	
	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R
	14	3	15	3	15	1	15	3	3	1	3	3	17	1	13	2	3	2
	3	1	17	2	17	3	1	1	17	3	14	1	14	2	17	3	14	3
	17	1	13	1	1	1	14	3	14	2	1	2	3	1	3	3	1	3
	15	2	3	2	3	3	13	2	1	3	17	2	15	3	15	2	17	2
	1	2	1	3	14	2	17	1	13	1	15	1	1	2	14	1	13	1
	13	3	14	1	13	2	3	2	15	2	13	3	13	3	1	1	15	1

T = Target R = Range

APPENDIX II (cont'd)

Experimental schedule of targets and ranges for each group of the nine subjects in the 30" viewing distance group

Subject number	1		2		3		4		5		6		7		8		9	
	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R
	15	2	17	2	3	3	15	1	14	2	1	3	13	3	15	1	1	3
	1	1	3	1	1	3	3	1	15	2	13	2	3	1	14	3	17	2
	17	3	14	3	15	1	13	3	17	3	17	1	1	2	1	1	3	3
	14	1	13	1	14	2	1	2	13	1	15	3	17	1	17	3	14	1
	3	2	15	3	13	2	14	3	3	3	14	1	15	3	13	2	15	2
	13	3	1	2	17	1	17	2	1	1	3	2	14	2	3	2	13	1

T = Target R = Range

APPENDIX III

This appendix shows the detailed results of the Logit analysis of the detection probability data carried out by Professor P.Armitage of the Department of Medical Statistics and Epidemiology, London School of Hygiene and Tropical Medicine.

Logit analysis of detection probability data

The model is that the probability, P, of correct identification is related to the factors tested by the following multiple regression equation:

$$Y \;=\; \text{Logit } P \;=\; \tfrac{1}{2}\ \ln.\ \frac{P}{1-P} \;=\; \sum b_i\, x_i$$

We have ignored subjects within viewing distances. The independent variables were

x_1 = 1 for all observations

x_2 to x_6 representing the presence of targets 3, 14, 17, 15, 13 respectively

x_7 representing trend with viewing distance

x_8 " curvature " " "

x_9 " trend " range

x_{10} " curvature " "

First we fit x_1 to x_6, i.e. we allow only for targets. The regression coefficients are:

		Target	Successes out of 27
b_1	-0.74 ± 0.25		
b_2	1.09 ± 0.32*	3	18
b_3	2.00 ± 0.44*	14	25
b_4	1.09 ± 0.32*	17	18
b_5	0.48 ± 0.32	15	10
b_6	0.85 ± 0.31*	13	15
		1	5

Again, there are obviously significant differences between targets, and the ranking seems to agree well with that found in Experiment 1.

In the next analysis we fit x_1 to x_{10}. The coefficients are

b_1	-0.83 ± 0.26
b_2	1.22 ± 0.34*
b_3	2.24 ± 0.47*
b_4	1.22 ± 0.34*
b_5	0.52 ± 0.33
b_6	0.95 ± 0.33*
b_7	-0.08 ± 0.12
b_8	-0.046 ± 0.068
b_9	-0.44 ± 0.12*
b_{10}	-0.093 ± 0.068

The conclusions about targets are the same as before. The effect of viewing distance is quite non-significant. There is, however, a trend effect with range, and the curvature is somewhat suggestive. The appropriate totals of successes, out of 54, are as follows:

Viewing distance	Success	Range	Success
13	31	1	37
21	32	2	34
30	28	3	20
	91		91

PART III

VISUAL AND TELEVISUAL DETECTION STUDIES

Mintech contract PD/170/04/AT

PART III

A LIMITED EXPERIMENT ON THE EFFECT OF SIMULATED AZIMUTH ERROR ON TARGET DETECTION PERFORMANCE

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OCTOBER 1967

SUMMARY

This report describes the third experiment in a series intended to investigate performance at a statically simulated target detection task. The aim of the experiment was to study the effect of azimuth error on three measures of performance, detection probability, search time and confidence level.

The experimental design, which was severely limited by the nature and quantity of photographic display material available, was based on a 4 x 4 (targets x conditions) Latin Square. Two of the four conditions of simulated azimuth error were -7° and $+7^{\circ}$ (i.e. simulated headings of 7° to the right and the left of the target respectively). These were balanced by two replications of the condition of 0° azimuth error (i.e. heading directly at the target). The four targets used to test these conditions were presented at a simulated range of two miles.

Analysis of the results of this experiment failed to demonstrate any significant effect of azimuth error on the performance measures recorded. Target differences were significant for each performance measure and these differences were in close agreement with those found in previous experiments.

Possible reasons for these disappointing results, which do not correspond with those found in flight trials and dynamic simulations of off-track errors, are considered in the discussion.

ACKNOWLEDGEMENTS

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The author would also like to acknowledge the valuable assistance given by Mr. J. Rennocks who carried out much of the experimental work and assisted with the preparation of this report.

Finally, the author must thank the students who took part in these experiments. She is extremely grateful to all of them.

INDEX

1. INTRODUCTION

The difficulty of an air-to-ground target acquisition task, whether carried out by direct view or via a television viewing system depends partly on the degree of search involved, i.e. on the size of the target relative to the total area in which the target may be situated. The uncertainty in the position of the aircraft due to possible errors in range and/or azimuth determines the area of terrain which must be considered when searching for a target. In high-speed, low-level flight the time available for acquiring the target, i.e. the interval between the time the target first becomes detectable and the time it disappears from the field of view, is extremely limited and thus the extent of the search area is liable to be of considerable importance. The two previous experiments in this series of static simulations both involved search in the forward direction due to range uncertainty but only slight random errors in the lateral position of the target in the display. In the present experiment an attempt was made to study lateral uncertainty by the same static technique.

Reported work on the effect of target off-set on air-to-ground detection performance is concerned mainly with flight trials or dynamic simulation techniques rather than with static simulation methods. These dynamic studies indicate that off-track errors do lead to a significant deterioration in detection performance. For instance, Heap (1965) describes a series of flight trials carried out using a wide field of view on a closed-circuit television system. The limits of the possible uncertainty across track ($\pm$ 1 n.m.) were known to the observer but not the starting point along the track (1 to 6 miles from the target). It was found that serious degradations in detection probability were observed with increasing off-track error. Overall detection probability fell from 90% for zero off-track error to approximately half that value for 3000 ft. off-track error and continued to fall as the error increased to 5000 ft. Detection range did not vary significantly with off-set track error but nevertheless varied from run to run for a given off-set.

A more extensive experiment reported by Wyman, Rawlings and Sturm (1965) studied the effects of altitude, lateral target off-set, background type and target type on acquisition performance under simulated low altitude, high speed conditions. Terrain simulation was carried out by means of a large deck on which could be arranged four different types of background and twenty targets. A motion picture camera was mounted above the deck and travelled along its length at different heights either down the centre or along off-set paths. By this means films in which altitude, background, target type and off-set, accurately controlled according to a pre-determined schedule, could be obtained. Levels of off-set studied were 500, 1500 and 2500 ft. Simulated aircraft speed was Mach 0.9.

The major findings of this study relating to target off-set were:

(a) Increased lateral off-set resulted in significantly fewer target acquisitions.

(b) Errors of commission and errors of omission increased with increasing off-set.

(c) Search ratio, an index of search performance, increased significantly with increasing off-set. This indicated that the greater the off-set the longer it takes to detect a target after it has become detectable.

Other results obtained in this experiment were significant altitude, target and background effects and many significant interactions. In view of the significant results obtained in these and other dynamic experiments it was of interest to determine whether these effects could also be demonstrated by static methods.

The static simulation technique described in detail in Part I of this series of reports (Parkes, 1967) involved the use of aerial photographs taken obliquely from an altitude of 2000 ft. This method was used to investigate some of the parameters, including range uncertainty and target difficulty, which affect performance at an airborne target detection task carried out by means of a television viewing system. The aim of the present experiment was to simulate lateral off-set errors of known magnitude and compare detection performance for targets displayed under these error conditions with performance for the same targets displayed centrally, i.e. under non-error conditions. However, before any specific method of simulation could be decided on, it was necessary to consider in further detail exactly what type of navigational uncertainty was to be simulated and how this could best be done.

In this series of experiments the viewing system simulated is one in which the television camera, mounted in a fixed position in the nose of the aircraft or missile, views directly forward along the main axis, but downwards at a 10° angle of inclination. Thus, if the vehicle is exactly on track towards a particular target, then this target will appear in the lateral centre of the television display, irrespective of range. Such a situation is shown diagrammatically in Figure 1.0.1 (a).

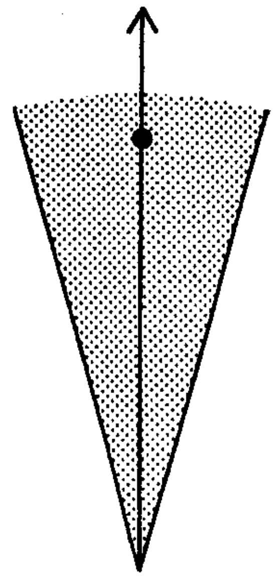
However, it may be that the target, although in the field of view of the television camera, is displaced from the lateral centre of the display. This could occur if the aircraft or missile were travelling on an incorrect track running parallel to the correct one. This type of off-set error, which was studied in both the flight trials and the dynamic simulation experiments mentioned previously, is shown diagrammatically in Figure 1.0.1 (b).

The original intention of the present experiment was to study this type of off-set error, i.e. parallel off-track error. However, it became clear that the available experimental material was not suitable for this kind of experiment. It consisted of a series of four aerial photographs for each of 18 targets taken at ranges of 1, 2, 3 and 4 miles, using a camera field of view of $50^{\circ} \times 50^{\circ}$. In previous experiments these photographs had been masked to display only a central portion representing a camera field of view of $30^{\circ} \times 22\frac{1}{2}^{\circ}$. Using this material it was not possible to simulate accurately an off-track error since, as can be seen in Figure 1.0.1, not only does the target occupy a different position in the camera field of view under off-track conditions, but since the camera axis is displaced sideways, the terrain in the foreground of the display is also different. This could not be simulated satisfactorily using the available material. The only method by which off-track errors could have been simulated would have been to obtain at least two new series of photographs taken from appropriate ranges along parallel tracks off-set to either side of the original one. This was not feasible in terms of the cost and time involved in obtaining these extra photographs, in addition to the difficulties of accurately positioning the aircraft and camera for the appropriate shots. The idea of simulating any type of off-track error had therefore to be ruled out. This eliminated the possibility of simulating the situation shown in Figure 1.0.1 (b) or any situation in which off-track error was combined with error in azimuth.

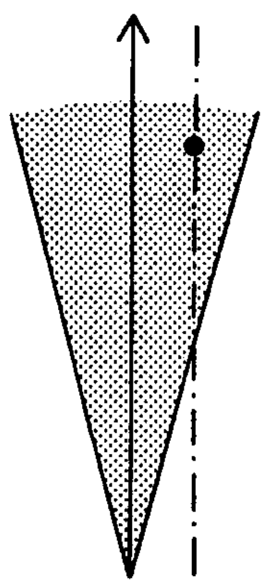
It was clear that the photographic material available was only suitable for simulating a situation in which the target off-set was due to angular displacement of the axis of the television

FIGURE 1.0.1

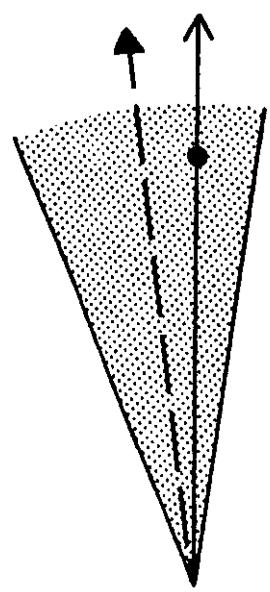
Diagrammatic representation of possible navigational situations.



(a) Track and azimuth correct.



(b) Azimuth correct but actual track displaced parallel to correct track (shown by broken line).



(b) Actual track correct but the true heading (shown by the broken line) is angularly displaced from the track.

NOTE In each diagram the shaded area shows the foreground of the T.V. field of view, the large dot represents the target and the solid arrowed line shows the actual track of the aircraft or missile.

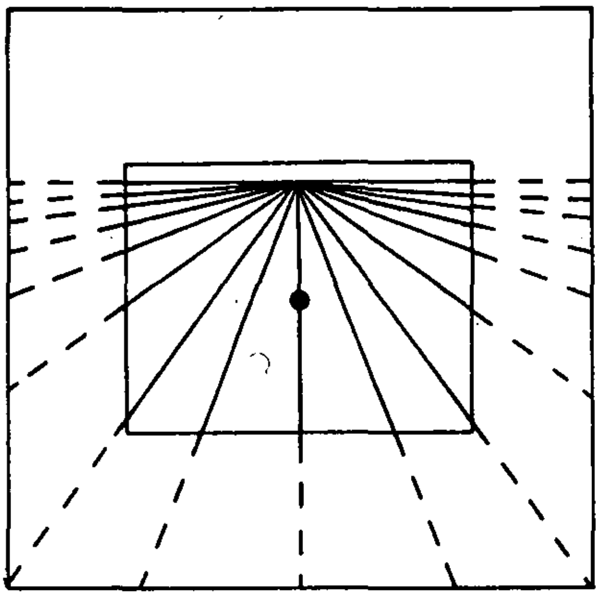
camera, relative to the actual track of the aircraft or missile to the target. This situation is represented diagrammatically in Figure 1.0.1 (c). In this case the target is not in the lateral centre of the field of view, but the off-set is due to angular rather than parallel displacement of the track.

This situation of apparent azimuth error, could be realistically simulated without any new photographic material. The target photographs were masked so that the 4.8" x 3.6" displayed portion was off-set sideways from the centre of the 8" x 8" photograph. Thus a close approximation to the situation shown in Figure 1.0.1 (c) could be simulated. The target position and the area and orientation of the surrounding terrain were correct but a slight distortion of the true perspective had to be accepted. This distortion, which was hardly noticeable, was caused by the asymmetric masking of the photograph as shown in Figure 1.0.2.

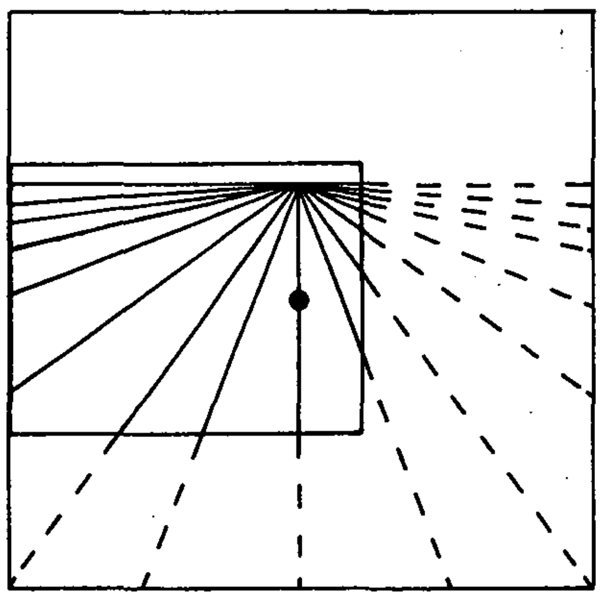
The maximum amount by which the target position could be displaced was 1.2". For the 2 mile range photographs this displacement was equivalent to a simulated azimuth error of 7° to either side of the correct track. Throughout this report the -7° error condition refers to the situation in which the target appears displaced to the right in the display, i.e. the true heading was 7° to the left of the track to the target. Conversely, the $+7^{\circ}$ error condition refers to the situation in which the true heading is 7° to the right of the actual track. The condition of zero error, in which the target appeared laterally central in the camera field of view, simulated the situation in which the heading of the aircraft or missile coincided exactly with its actual track.

FIGURE 1.0.2

Changes in apparent perspective caused by off-setting displayed portion of photograph.



(a) Central portion displayed - perspective correct.



(b) Off-set portion displayed - perspective distorted.

The main advantage of this method of simulation was that it could be carried out simply and rapidly using the same materials and apparatus as in previous experiments. The main disadvantages were that the maximum degree of target off-set that could be introduced was relatively small and only a very limited experiment could be attempted. However, in spite of these restrictions, it was of interest to determine whether this static simulation technique could be used to study the effect on detection performance of lateral uncertainty in the target position.

2. PURPOSE OF THE EXPERIMENT

The aim of this experiment was to study the effect of simulated azimuth error on target detection performance. It was recognised that only a limited amount of experimental material was available and that it was not altogether suited to this type of experiment. However, it was hoped that the experiment would at least determine whether it was feasible to study azimuth errors by the static simulation technique developed during previous experiments.

3. EXPERIMENTAL DESIGN

The statistical design of this experiment was severely limited by the small number of target photographs available for test purposes. In carrying out the experiment it was necessary for control purposes to present conditions of correct azimuth as frequently as those of incorrect azimuth. It was also necessary to balance the presentations of positive and negative azimuth errors i.e. simulated conditions of heading to the right or to the left of the target. Thus there were effectively four error conditions to be considered, two replicated conditions of zero error, i.e. correct azimuth, and two balancing conditions of positive and negative error.

In previous experiments four actual range - to - target conditions were studied. To combine these with the four conditions of azimuth error would have resulted in a total of 16 experimental conditions. However, the maximum number of test targets available for experimental purposes was seven and only some of these were suitable for simulating azimuth error. The remaining targets were slightly off-centre in the original 8" x 8" photographs, and it was therefore not possible to present them off-set to the required extent in the opposite direction without the displayed portion running over the edge of the photograph. Only photographs in which the target appeared very close to the lateral centre of the 8" x 8" photograph were suitable for this experiment.

It was therefore necessary to reduce the experimental conditions to a number compatible with the amount of suitable photographic material available. This had to be done by reducing the range condition to one level. The 2 miles range was chosen. This was the nominal value used in previous experiments, which had involved range uncertainty but no azimuth error. Mean detection probability in these experiments was approximately 60% at range 2 miles. At this range four of the original test targets were suitable for displaying under off-set conditions. The maximum possible azimuth error that could be simulated at this range was 7° on either side of the correct heading and this value was used.

The experiment, like the previous ones was based on a Latin Square design. The matrix of four targets and four conditions of azimuth error, two of which were zero, was filled with four subjects in such a way that each subject saw each target and each error condition once and once only. The order of presentation of the sequence of targets and conditions presented to each subject was randomised. The matrix was replicated three times using twelve subjects in all. The detailed experimental schedules are shown in Appendix II.

4. DISPLAY AND RECORDING APPARATUS

The display and recording apparatus used in this experiment was exactly as described for Experiment I. The viewing distance was 13" and display size 4.8" (horizontal) x 3.6" (vertical). The portion of the 8" x 8" photograph displayed could be varied by adjusting the position of the photograph which was held on the back of the mask by a magnetic mounting device. The performance measures automatically recorded were search time, confidence level and map-briefing time. In addition the experimenter recorded whether or not the target had been correctly detected.

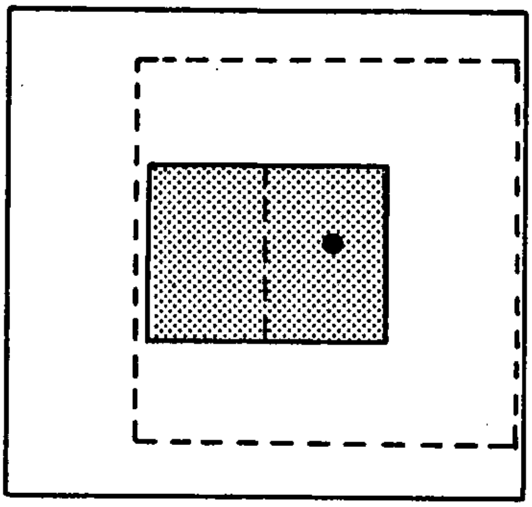
5. EXPERIMENTAL MATERIALS

The display materials used in this experiment were the appropriate maps and photographs selected from those used in Experiment I. The photographs used for both training and test purposes were only those taken from a range of 2 miles from the target. Only four test targets were used, these being Numbers 3, 14, 15 and 13, out of the seven used previously.

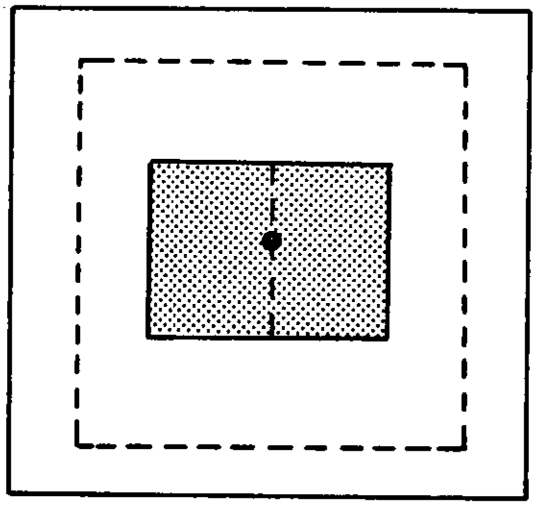
To simulate the conditions of azimuth error the 4.8" x 3.6" portion of the 8" x 8" photograph displayed was off-set either to the right or left of the centre line. By this means an azimuth error of $\pm 7^{o}$ off the correct heading was simulated. As indicated in the Introduction this simple method of simulating azimuth error led inevitably to some distortion in the apparent perspective of the off-set portion. The condition of zero azimuth error was simulated by displaying the 4.8" x 3.6" portion so that the target was laterally central within it. Figure 5.0.1 illustrates the way the photograph was mounted for each of these conditions.

FIGURE 5.0.1

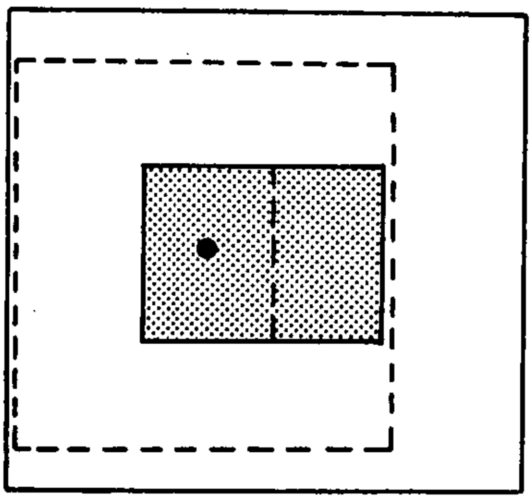
Method of mounting photographs to simulate heading errors.



Heading to left of target.



Heading straight for target.



Heading to right of target.

NOTE The position of the photograph behind the mask is shown by the dotted outline. The shaded area shows the displayed portion of the photograph on which are indicated the target spot and the simulated aircraft track.

6. EXPERIMENTAL PROCEDURE

The nature of the navigational error simulated in this experiment differed from that simulated previously. The preliminary training of the unskilled subjects was therefore slightly different. Otherwise the experimental procedure was similar to that described in detail for Experiment 1. A brief description is given below.

Each subject was tested individually and the session lasted approximately 3 hours. Preliminary written tests of intelligence, personality and memory were carried out. The nature of the experiment was then explained to the subject in detail. Training in map-reading and explanation of the photographic and navigational parameters involved followed. The subject was told that the situation simulated was that of an aircraft, altitude 2000 ft., two miles away from the target with a possible azimuth error of $\pm 7^{\circ}$ from its true course. The appropriate map area with which the subject needed to familiarise himself was shown by means of a transparent overlay. A series of sample maps and photographs was presented.

The subject was instructed in the operation of the display and recording apparatus and eight targets were presented for further practice. After each of the first four presentations the subject was told whether or not he had correctly located the target and if not was given a further opportunity to do so. No knowledge of results was given subsequently.

Finally, the four test targets were presented in random order under the appropriate azimuth error conditions as shown in Appendix 1. In each case the subject was required to study the map and then locate the target in the photographic display as rapidly as possible. He then indicated the confidence of his judgment on the seven-point scale and pointed out the position of the target. The experimenter recorded whether or not he was correct.

7. EXPERIMENTAL RESULTS

The results of this experiment are reported in considerably less detail than those of previous experiments since the statistical analyses indicated that the experiment was too limited to demonstrate reliably any effect on detection performance due to azimuth error. The raw data on detection probabilities, search times and confidence levels are shown in this section together with the brief analyses carried out on them. The raw data on map times have been included only for the sake of completeness as previous work showed that they bore no relationship to the other measures made. No analyses have been carried out on these data.

The analyses of variance shown in the following sections were intended only to determine whether performance under conditions of no azimuth error was significantly different from that under the error conditions, i.e. no distinction was made between the two different error conditions, + 7° and - 7°. However, further partitioning of the data enabling each error condition to be compared separately with the non-error conditions, was also carried out but it yielded no useful results. Differences between the two error conditions were non-significant for each of the three performance measures.

7.1 Detection probability

The raw data on detection probabilities is shown in Table 7.1.1. It can be seen that two of the four targets were detected correctly at each presentation. Thus, any possible effect of azimuth error on detection probability would only be apparent for the other two targets, the more difficult ones. The analysis of variance carried out on the raw data is shown in Table 7.1.2. This shows clearly that there is no significant overall effect due to azimuth error. The effect of target differences in highly significant, as had been found in previous experiments.

No Logit analysis was carried out on the detection probability data as the results obtained from the conventional analysis indicated that it would not be worthwhile.

TABLE 7.1.1

Correct and incorrect identifications by 12 unskilled subjects

TARGETS	AZIMUTH ERROR			
	-7°	0°		$+7^{\circ}$
3	1	1	1	1
	1	1	1	1
	1	1	1	1
14	1	1	1	1
	1	1	1	1
	1	1	1	1
15	1	1	0	0
	0	0	0	0
	0	0	0	0
13	1	1	1	0
	1	1	0	0
	0	1	0	0

1 = correct identification

0 = incorrect identification

TABLE 7.1.2

Analysis of variance on detection probability data shown in Table 7.1.1

Source	DF	S.S.	M.S.	V.R.	Significance
Azimuth error (A)	1	0.10	0.10	0.99(b)	N.S.
Targets (T)	3	6.00	2.00	18.18(b)	$p < 0.001$
A x T	3	0.26	0.09	0.82(a)	N.S.
Residual (a)	40	4.32	0.11(a)		
Pooled residual (b) (Residual (a) + A x T)	43	4.58	0.11(b)		
TOTAL	47	10.68			

7.1.1 Azimuth error

Detection probabilities for each condition of azimuth error are shown in Table 7.1.3

TABLE 7.1.3

Mean detection probability for each condition

	Azimuth error		
	-7°	0°	$+7^{\circ}$
Mean detection probability	0.75	0.71 (0.83) (0.58)	0.50
Number of readings on which each value is based	12	24 (12) (12)	12

The differences between detection probability values shown in this table are non-significant. Although the difference between the value for the -7° error and the $+7^{\circ}$ appears relatively large it was not significant when compared with the random variation between the two identical non-error conditions. The values shown in brackets in Table 7.1.3 represent the means for the two sets of 12 readings for the non-error conditions. It can be seen that the difference between them is the same as that between the two error conditions.

The mean value of 0.71 for the condition of zero azimuth error can be compared with the mean value for the appropriate targets at range 2 miles obtained in Experiment I, which is somewhat lower, 0.63. A possible explanation of this is that the present experiment involved no range error and was thus likely to be simpler for unskilled subjects to learn in a relatively brief training period. In addition the target position was at approximately the same level on the display for each presentation and this considerably reduced the amount of search required.

7.1.2 Targets

The effect of target differences on detection probability is highly significant, as shown by the analysis of variance. Table 7.1.4 gives the mean detection probabilities, arranged in rank order, for each of the targets.

TABLE 7.1.4

Mean detection probabilities for targets

Target	Detection probability
3 and 14	1.00
13	0.50
15	0.17

The rank order of these four targets corresponds closely with tnat found in previous experiments.

7.2 Search time

Search time, which was automatically recorded, was the time in seconds required by a subject to view the display before making a response indicating that he thought he had located the target. The raw data on search times are shown in Table 7.2.1 and the analysis of variance carried out on these data in Table 7.2.2.

TABLE 7.2.1

Search time data from 12 unskilled subjects

		AZIMUTH ERROR			
		-7°	0°		$+7^{\circ}$
TARGETS	3	6.6	7.2	3.2	18.0
		24.6	3.2	1.6	7.6
		6.6	8.0	2.8	9.8
	14	5.0	2.2	2.4	1.2
		14.2	2.2	1.0	3.6
		1.6	1.2	0.6	3.8
	15	19.8	18.2	$\underline{95.4}$	$\underline{11.8}$
		$\underline{25.2}$	$\underline{27.8}$	$\underline{16.0}$	$\underline{13.4}$
		$\underline{4.0}$	$\underline{11.2}$	$\underline{29.0}$	$\underline{11.4}$
	13	5.6	6.6	20.2	$\underline{3.6}$
		7.6	6.4	$\underline{9.2}$	$\underline{7.0}$
		$\underline{68.8}$	13.6	$\underline{11.4}$	$\underline{2.2}$

Values underlined relate to incorrect decisions.

All times are shown in seconds.

TABLE 7.2.2

Analysis of variance on search time data shown in Table 7.2.1

Source	DF	S.S.	M.S.	V.R.	Significance
Azimuth error (A)	1	6.46	6.46	- (b)	N.S.
Targets (T)	3	2,727.13	909.04	3.74(b)	$p < 0.05$
A x T	3	1,319.76	439.92	1.92(a)	N.S.
Residual (a)	40	9,145.13	228.62(a)		
Pooled residual (b) (Residual (a) + A x T)	43	10,464.89	243.37(b)		
TOTAL	47	13,198.48			

It can be seen from this table that the effect of azimuth error is non-significant. However, as found previously target differences are significant. There is no significant interaction between the two factors.

7.2.1 Azimuth error

The mean search times for each condition of azimuth error are shown in Table 7.2.3

TABLE 7.2.3

Mean search times for each condition

	Azimuth error		
	-7°	0°	$+7^{\circ}$
Mean search time (seconds)	15.8	12.5 (9.0) (16.0)	7.8
Number of readings on which each value is based	12	24 (12) (12)	12

Differences between the search time values shown in this table were non-significant compared with the random variation in the data. In addition there was no significant difference between the mean of the 2 mile range search times for the four targets concerned found in Experiment 1 and the corresponding mean search time for the 0° azimuth error condition in the present experiment.

7.2.2 Targets

The mean search times for the four targets are shown in rank order in Table 7.2.4.

TABLE 7.2.4

Mean search time for targets

Target	Mean search time (seconds)
14	3.3
3	8.3
13	13.7
15	23.6

It can be seen that the rank order of the targets according to mean search times corresponds very closely with that found for detection probabilities indicating that, as found previously, high detection probability tends to be associated with low search time and vice versa.

7.3 Confidence level

After each target detection a confidence level judgment was recorded. This was a subjective judgment made by the subject on a seven-point scale of the confidence he had in the correctness of his judgment. High values were associated with high confidence of a correct judgment. The raw data on these scores are shown in Table 7.3.1 and the analysis of variance on these data in Table 7.3.2.

TABLE 7.3.1

Confidence level data from 12 subjects

		AZIMUTH ERROR			
		-7°	0°		$+7^{\circ}$
TARGETS	3	7	6	7	6
		4	7	7	7
		5	7	7	7
	14	7	7	7	7
		5	7	7	7
		7	4	7	7
	15	3	$\underline{2}$	$\underline{4}$	$\underline{6}$
		$\underline{5}$	$\underline{2}$	$\underline{2}$	$\underline{4}$
		$\underline{4}$	6	$\underline{3}$	$\underline{4}$
	13	7	5	6	$\underline{6}$
		6	$\underline{2}$	4	$\underline{4}$
		$\underline{5}$	6	$\underline{7}$	$\underline{6}$

Values underlined relate to incorrect judgments.

TABLE 7.3.2

Analysis of variance on confidence level data shown in Table 7.3.1

Source	DF	S.S.	M.S.	V.R.	Significance
Azimuth error (A)	1	1.02	1.02	-	N.S.
Targets (T)	3	61.23	20.41	13.36(b)	$p < 0.001$
A x T	3	0.56	0.19	-	N.S.
Residual (a)	40	65.17	1.63		
Pooled residual (b) (Residual (a) + A x T)	43	65.73	1.53		
TOTAL	47	127.98			

It can be seen from this table that azimuth error has no significant effect on confidence level but, as in previous experiments, target differences are highly significant.

7.3.1 Azimuth error

Table 7.3.3 shows the mean confidence level for each error condition.

TABLE 7.3.3

Mean confidence level for each condition

	Azimuth error		
	-7°	0°	$+7^\circ$
Mean confidence level	5.4	5.4	5.9

There are no significant differences between these values and furthermore, the value for the zero error condition does not differ significantly from the relevant mean values for these targets at range 2 miles extracted from Experiment I.

7.3.2 Targets

Table 7.3.4 shows the mean confidence levels for each of the four targets in rank order.

TABLE 7.3.4

Mean confidence levels for targets

Targets	14	3	13	15
Mean confidence level	6.6	6.4	5.3	3.8

The mean confidence level for Target 15, the most difficult of the four targets, was significantly lower than those for Targets 3 and 14, the easiest targets. The rank order of the targets according to mean confidence level is identical to that according to search times shown in Table 7.2.4, and detection probabilities, shown in Table 7.1.4.

7.4 Map-briefing times

Subjects were allowed as much time as they required to brief themselves on the appropriate area of map before attempting to detect the target. The times taken for map-briefing were recorded and are shown in Table 7.4.1. They are included only for the sake of completeness and no detailed analysis has been carried out on them as previous work showed that they bore no relation to the other three performance measures recorded. The overall mean value, 78.9 seconds, was very similar to those found in previous experiments.

TABLE 7.4.1

Map-briefing times

		AZIMUTH ERROR			
		-7°	0°		$+7^{\circ}$
TARGETS	3	25.6	101.4	105.6	43.4
		38.0	49.6	65.0	187.6
		58.6	31.4	56.6	33.8
	14	129.6	50.4	42.0	35.2
		230.0	52.2	56.0	87.8
		76.2	35.2	42.6	44.0
	15	73.6	45.0	51.4	112.0
		153.0	180.6	82.4	61.4
		132.0	153.0	42.2	75.6
	13	85.6	61.6	119.6	108.2
		42.8	39.0	64.2	40.2
		55.8	189.8	44.6	95.8

All times shown in seconds.

7.5 Intelligence and personality scores

Each subject that took part in this experiment was assessed for intelligence and personality by means of Heim's A.H.5 high-grade intelligence test and Eysenck's personality inventory which gives a measure on an extraversion-intraversion scale (E) and a neuroticism scale (N). The means and standard deviation values of these scores for the group of 12 subjects are shown in Table 7.5.1, together with the population norms.

TABLE 7.5.1

Mean and standard deviation values of the IQ, E and N scores

	12 Unskilled subjects (students)		Population norms	
	Mean	s.d.	Mean	s.d.
Heim's A.H.5 test score	41.2	6.6	39.1	8.3
E.P.I. score				
E	16.3*	2.8*	11.1	4.5
N	11.4	4.7	10.0	5.0

* The asterik indicates values significantly different (5% level) from the population norms.

It can be seen from Table 7.5.1 that only in the extraversion-introversion (E) scores do the group tested show characteristics different from those of the corresponding population. It can be seen that the student group tested tended to be more extraverted than the general student population. This had been found also in the second of this series of expэriments but there was no evidence to suggest that performance was in any way related to E scores. In view of the limited scope of this experiment and the disappointing results obtained no attempt was made to correlate performance with the personality.

8. DISCUSSION

It is clear from the results of this experiment that the simulated azimuth error had no significant effect on detection performance, as measured by detection probability, search time and confidence level. These results are disappointing, particularly as the flight trials and dynamic simulation studies outlined in the Introduction show that under such conditions off-set errors do lead to a significant deterioration in detection performance. It is therefore worth considering the reasons for the failure of this particular experiment and the wider question of the suitability of this static stimulation technique for studying off-set errors.

The failure of this experiment to demonstrate any significant effect of the simulated azimuth error on detection performance can be attributed at least in part to the severe limitation of the experimental material. In particular the small number of test targets, the absence of range uncertainty and the relatively small azimuth error simulated contributed to the failure.

Since each subject could only see each target once the use of only four test targets limited the amount of data which could be obtained from a subject and also limited the number of conditions which could be tested. Furthermore, of the four targets used, two were readily detectable and were correctly detected at each presentation whether or not they were off-set. It would have been preferable to use more difficult targets in this experiment but the choice of targets was dictated by their suitability for displaying under off-set conditions, as explained in Section 3.

The most serious effect of the small number of targets was that it was not possible to include range as a factor in the experimental design. As there was no variation in range, all targets being presented at range of two miles, they appeared at approximately the same level on the display. Thus, since the subjects may have learned to expect this the target detection task tended to become one of searching along a line rather than searching the whole display. Therefore, it was considerably easier than it would have been if range uncertainty had been included. This difference is reflected by the higher overall detection probability recorded for the four targets at 2 miles range in the present experiment than in Experiment I, which involved range uncertainty.

Another limitation of this experiment was that the maximum degree of angular off-set which could be simulated was small relative to the 30° field of view and there was therefore a large amount of overlap between the terrain shown in the central and the off-set conditions. Thus the initial task of geographic orientation was probably not seriously affected by the off-set. Furthermore, there were only three positions in which the target could occur, i.e. central or displaced to fixed positions on the right or left of the display. Subjects may have become aware of this and thus uncertainty in target position would have been reduced still further.

It is likely therefore that the necessarily limited scope of this experiment could account for its lack of success. In view of this the possibility of using static simulation techniques for studying off-set errors need not necessarily be abandoned. The basis cause of the failure of this experiment, i.e. the inadequate number of targets and too little uncertainty in the target position, could be overcome if suitable experimental material were available. It would be necessary to allow for the introduction of range uncertainty and for simulating greater degrees of target off-set. In addition, for comparison with the dynamic data reported by Heap (1965) and Wyman, Rawlings and Sturm (1965) it might be preferable to simulate parallel off-track errors, rather than angular off-sets as was necessary in the present experiment.

Although dynamic simulation studies may provide a more realistic task, the use of static techniques can prove valuable for studying some aspects of the task which cannot be so readily controlled and measured in a dynamic situation. One instance of this is the study of eye-movements, which is particularly relevant to the problems of geographic orientation and target detection under various conditions of navigational uncertainty. It is likely that the patterns of search used in the present experiment under conditions of lateral uncertainty were different from those used under conditions of range uncertainty in Experiments I and II. (Summaries of these experiments are given in Appendix I). The mean times taken to search the display in the three experiments were in the range 12 - 15 seconds. Taking 0.25 seconds as an average fixation time (Michon and Kirk, 1962), these search times would allow for approximately 50 - 60 fixations. However, there is at present no information as to the distribution of these fixations or the types of search patterns used.

It is known that even if the target has an equal probability of appearing anywhere on the display, subjects do not distribute their fixations equally over the whole area. For instance, White and Ford (1960) report that subjects instructed to search for a target that could appear anywhere in a 30° unstructured field tended to concentrate their fixations on a roughly circular band midway between the centre and the periphery. However, the pattern of eye fixations made when the target appears in a complex structured field is likely to be different from that in an unstructured field, particularly if the background structure gives some information of the likely position of the target.

Enoch (1959) investigated the eye fixations made by skilled observers viewing aerial photographs of varying scale and verticality. It was found that there was an initial orientation phase during which a characteristic pattern of eye movements and fixations was made. For a particular observer this pattern remained remarkably constant regardless of the target or the scale and content of the photograph, although different observers showed different characteristic patterns. At the end of the orientation phase the observer moved on to a specific search phase using any clues he might have gained from the initial search. If he had not gained any such clues the second search phase was devoted to expanding the basic pattern of the initial phase. One disturbing result found in this study was that if the target was not in close relation to the features initially interpreted as clues the observer tended to ignore the remainder of the display (sometimes more than half its area) and declare that the target was not there.

Enoch also found that there was a marked concentration of fixations at the centre of the display, while the peripheral regions were essentially ignored. This finding was independent of display size, quality and content and of the generality of the problem given the observer. He recommends 9° as being the optimum display size if the target size is such that it can only be detected foveally. For displays smaller than this search patterns change markedly and a much higher proportion of fixations fall outside the display. For displays larger than 9° coverage becomes increasingly less uniform. However, it is emphasised that this value relates to static displays and would not necessarily apply to dynamic displays.

These interesting findings indicatd that the study of search patterns in relation to various types of navigational uncertainty could provide valuable information. Preferably such an investigation should include the study of search patterns under conditions of range uncertainty and lateral target off-set both separately and combined. Since eye movements can be more easily interpreted if they are related to a static display static simulation techniques are particularly suitable for some aspects of this work but dynamic simulation would also be required.

Thus, although it must be concluded that this particular experiment was not successful in demonstrating any significant effect due to the simulated azimuth error, it is nevertheless possible that if suitable experimental material were obtained, this technique could be used in association with dynamic techniques, for a more extensive study of navigational errors and corresponding visual search patterns.

9. REFERENCES

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APPENDICES

APPENDIX I

Since this report includes a number of references to previous experiments carried out in this series summaries of these two experiments are shown on the following pages for convenient reference.

EXPERIMENT I

SUMMARY

A static simulation technique was used in this target detection experiment to investigate the effect of navigational uncertainty, range to target and target difficulty on four measures of performance. These were detection probability, search time, confidence level of decision and map-briefing time. The experiment was based on a 7 x 7 (targets x conditions) Latin Square design. Seven skilled pilots and navigators, and 21 students of comparable ability, as assessed by intelligence and personality tests, acted as subjects.

The results showed that none of the performance measures considered were affected by navigational uncertainty. For unskilled subjects detection probability and search time were significantly related to range. The relation was linear. As range increased from one to four miles detection probability decreased and search time increased. There were significant differences between the targets for each measure of performance. When the targets were ranked according to each of these measures significant associations were found between the rankings. Targets which had high detection probabilities tended to have short search times and high confidence levels associated with them. The converse was also true.

The performance of skilled subjects was very similar to that of the unskilled subjects, but the former took significantly less time in map-briefing and in searching for the targets.

In the discussion sections the general suitability of the experimental technique is assessed and the results considered in relation to further work at present being carried out.

EXPERIMENT II

SUMMARY

This report describes the second of a series of experiments investigating performance at a statically simulated target detection task. The main aim was to determine whether detection performance was affected by a reduction in apparent display size, i.e. by reducing the angular subtense of the display at the observer's eye. This was done by keeping the actual display size constant (4.8" x 3.6") and increasing the viewing distance from 13" to 21" and to 30", giving corresponding angular subtense values of $21^{\circ} \times 15\frac{3}{4}^{\circ}$, $13^{\circ} \times 9\frac{3}{4}^{\circ}$ and $9^{\circ} \times 7^{\circ}$.

Data relating to the 13" viewing distance were taken from Experiment 1, the first experiment in this series. Data for the 21" and 30" viewing distances were obtained in the present experiment from two groups of 9 unskilled subjects who underwent preliminary training and practice. At each viewing distance the experimental design was based on a Latin square of targets and range conditions.

The results showed that the effect of viewing distance on the three main performance measures, i.e. detection probability, search time and confidence level was statistically non-significant. However, there was a tendency for performance to deteriorate as viewing distance increased, particularly at the 30" distance.

The general trends found in the present experiment, e.g. effect of range on performance, relative difficulty of targets, correlations between high detection probability, low search time and high confidence level, etc. were in close agreement with those found in Experiment 1.

The implications of the results and their relevance to the operational situation are considered in the discussion.

APPENDIX II

This appendix shows the detailed schedule of targets and azimuth error conditions used in this experiment. The particular target and condition combinations assigned to each of the 12 subjects were presented in random order as shown.

Experimental schedule of targets and azimuth error conditions presented to each subject

Subject number	1		2		3		4		5		6		7		8		9		10		11		12	
	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
	3	$+7^\circ$	13	0°	3	0°	15	$+7^\circ$	13	0°	15	0°	3	0°	15	-7°	15	-7°	15	0°	13	-7°	3	0°
	15	-7°	14	$+7^\circ$	13	$+7^\circ$	13	-7°	3	$+7^\circ$	14	0°	15	$+7^\circ$	3	0°	13	$+7^\circ$	14	$+7^\circ$	15	0°	14	-7°
	14	0°	15	0°	14	-7°	3	0°	14	-7°	13	$+7^\circ$	14	0°	13	0°	3	0°	3	-7°	14	0°	13	0°
	13	0°	3	-7°	15	0°	14	0°	15	0°	3	-7°	13	-7°	14	$+7^\circ$	14	0°	13	0°	3	$+7^\circ$	15	$+7^\circ$

T = Target C = Condition of azimuth error

Azimuth error conditions:

-7° indicates heading 7° to the left of the target.

0° indicates heading directly at the target.

$+7^\circ$ indicates heading 7° to the right of the target.