PART IV

VISUAL AND TELEVISUAL DETECTION STUDIES

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PART IV

A STUDY OF TARGET DETECTION PERFORMANCE IN RELATION TO THE SIGNAL/NOISE RATIO OF THE TELEVISION DISPLAY SYSTEM

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SUMMARY

This report describes the fourth in a series of experiments investigating performance at a statically simulated target detection task. The main purpose of the present experiment was to study the effect of visual noise on three measures of performance, detection probability, search time, and confidence level. Target photographs were displayed on a television monitor screen on which 'flat, white' electronic noise was superimposed. Four conditions of signal/noise ratio were studied: 14, 19, 24 and 30 dbs. The photographs displayed were taken obliquely, from an altitude of 2000 ft. at ranges of 1, 2, 3 and 4 miles from each of twelve targets.

In the main experiment 32 unskilled subjects were exposed to the four conditions of signal/noise ratio and the four conditions of range. A more limited experiment was carried out with eight skilled subjects who were exposed to the four conditions of range but only two conditions of signal/noise ratio (14 and 24 dbs).

The results showed that, for unskilled subjects, a decrease in signal/noise ratio resulted in a significant deterioration in detection probability and confidence level, but it had no effect on search time. Decrease in range resulted in significant increases in detection probability and confidence level and a significant decrease in search time. Target differences and, in particular, differences between large and small targets had a significant effect on all three performance measures. As would be expected, more favourable performance was associated with the large targets. The results for skilled subjects showed similar trends but the overall mean search time was significantly higher than that for the unskilled subjects. Summary tables of the main results are shown on the following pages.

These results are discussed in relation to the findings of other workers and their relevance to operational conditions is considered.

SUMMARY OF THE MAIN RESULTS FOR UNSKILLED SUBJECTS

	DETECTION PROBABILITY	SEARCH TIME	CONFIDENCE LEVEL
OVERALL MEANS	0.46	11.1 seconds	4.7
SIGNAL/NOISE RATIO (N)	Significant effect ($p < 0.001$) Mean values range from 0.38 (14 dbs) to 0.55 (30 dbs). Relationship between S/N ratio and detection probability is linear. Highly significant fall in detection probability between 24 and 19 dbs. (33-37)	No significant effect. Mean values range from 10.8 secs. (14 dbs) to 11.4 secs. (30 dbs), but show no consistent trend. (81-82)	Significant effect ($p < 0.025$) Mean values range from 4.4 (14 dbs) to 4.8 (24 dbs). There is a significant linear relationship between confidence level and S/N ratio. Variation within S/N ratios is almost entirely due to the low value for the 14 dbs level. (101-104)
RANGE (R)	Significant effect ($p < 0.001$) Mean values range from 0.60 (1 mile) to 0.36 (4 miles). Relationship between range and detection probability is linear. (38-43)	Just fails to reach significance. ($0.05 < p < 0.10$) Mean values range from 10.0 secs. (1 mile) to 12.7 secs. (4 miles). Relationship between range and search time is linear. (82-85)	Significant effect ($p < 0.001$) Mean values range from 5.1 (1 mile) to 4.3 (4 miles). Relationship between range and confidence level is linear. (105-107)
TARGETS (T)	Significant effect ($p < 0.001$) Mean values range from 0.84 for Target 9 to 0.09 for Target 6. Highly significant difference between large and small targets. Mean for large targets: 0.68 Mean for small targets: 0.24 (44-49)	Significant effect ($p < 0.005$) Mean values range from 5.4 secs. for Target 14 to 15.8 secs. for Target 5. There is a highly significant difference between large and small targets. Mean for large targets: 9.0 secs. Mean for small targets: 13.2 secs. (86-90)	Significant effect ($p < 0.001$) Mean values range from 3.9 for Target 6 to 6.2 for Target 14. Highly significant difference between large and small targets. Mean for large targets: 5.2 Mean for small targets: 4.2 (108-112)
DIFFERENCES BETWEEN SKILLED AND UNSKILLED SUBJECTS.	No significant differences.	Mean search times were significantly higher for the skilled subjects. Overall mean for the skilled subjects is 15.8 secs., as compared with 11.1 secs. for the unskilled subjects.	No significant differences.

NOTE The numbers at the bottom right-hand corner of each cell are the numbers of the relevant pages of the report.

SUMMARY TABLE OF INTERACTION EFFECTS FOR UNSKILLED SUBJECTS

	DETECTION PROBABILITY	SEARCH TIME	CONFIDENCE LEVEL
N x R High/Low S/N ratios x R	No significant interaction Detection probability decreases linearly with range for both high and low S/N ratios in a similar manner, i.e. the two regression lines do not deviate significantly from parallel. (50-54)	No significant interaction No further analyses were carried out since the main S/N ratio effect was also not significant. (76)	No significant interaction No further analyses were carried out since in this case it was not appropriate to partition S/N ratios into high and low levels. (113)
N x T N x Target size	No significant interaction. Detection probability increases linearly with S/N ratio for both large and small targets in a similar manner; the two regression lines do not deviate significantly from parallel. Detection probabilities are significantly lower for small targets at each S/N ratio. (55-60)	No significant interaction No further analyses were carried out since the main S/N ratio effect was also not significant. (76)	Significant interaction ($p < 0.01$) i.e. the twelve targets are differently affected by S/N ratio. For large targets confidence levels increase with increasing S/N ratio in a non-linear manner. For small targets S/N ratio has no significant effect on confidence level. Large targets have significantly higher confidence levels at each S/N ratio. (114-119)
R x T R x Target size	Significant interaction ($p < 0.001$) i.e. the twelve targets are differently affected by range. Detection probability decreases linearly with range for both large and small targets, but the regression lines are significantly non-parallel and tend to converge towards longer ranges. Detection probabilities are significantly lower for small targets at each range. (61-66)	Significant interaction ($p < 0.01$) i.e. the twelve targets are differently affected by range. For large targets search times increase linearly with range. For small targets this effect does not reach significance but there is no evidence that the two regression lines deviate significantly from parallel. Search times are significantly lower for large targets at each range. (90-95)	Significant interaction ($p < 0.001$) i.e. the twelve targets are differently affected by range. Confidence levels decrease linearly with increasing range for both large and small targets in a similar way, i.e. the two regression lines do not deviate significantly from parallel. Confidence levels are significantly lower for small targets at each range. (120-124)

NOTE The numbers at the bottom right-hand corner of each cell are the numbers of the relevant pages of the report.

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INDEX

1. INTRODUCTION 1

2. PURPOSE OF EXPERIMENT 13

3. EXPERIMENTAL DESIGN 14

3.1 Unskilled subjects 14

3.2 Skilled subjects 15

4. DISPLAY AND RECORDING APPARATUS 16

5. EXPERIMENTAL MATERIALS 23

6. EXPERIMENTAL PROCEDURE 24

6.1 Unskilled subjects 24

6.2 Skilled subjects 25

7. EXPERIMENTAL RESULTS 26

7.1 Detection probability 27

7.2 Search times 76

7.3 Confidence levels 96

7.4 Map-briefing times 125

7.5 Relationship between detection performance and psychometric measures 131

7.6 Summary of results 135

8. DISCUSSION 140

8.1 The effect of signal/noise ratio on detection performance... 141

8.2 The effect of range on detection performance 149

8.3 Target differences 151

8.4 Interaction effects 158

8.5 Differences between skilled and unskilled subjects 164

8.6 Relationship between psychometric measures and detection performance 167

8.7 Comparison of the results with those found from dynamic experiments 168

8.8 Further work 172

9. REFERENCES 176

APPENDICES

Appendix I 178

Appendix II 181

Appendix III 184

Appendix IV 186

ILLUSTRATIONS

FIGURE 4.0.1 General view of the experimental area 18

FIGURE 4.0.2 Marconi 321 camera mounted to televise the photographic display 19

FIGURE 4.0.3 Equipment used for calibration, generation and attenuation of electronic noise 20

FIGURE 4.0.4 Television monitor seen through the viewing tunnel with map display mounted beside it 21

FIGURE 4.0.5 Diagrammatic representation of television circuit. 22

FIGURE 7.1.1 The effect of signal/noise ratio on detection probability 36

FIGURE 7.1.2 The effect of range on detection probability 41

FIGURE 7.1.3 A comparison of the effect of range on detection probability under conditions of photographic display and television display 43

FIGURE 7.1.4 Mean detection probabilities for the twelve targets 46

FIGURE 7.1.5 The effect of range on detection probability for high S/N ratios and low S/N ratios 53

FIGURE 7.1.6 The effect of signal/noise ratio on detection probabilities for large and small targets 58

FIGURE 7.1.7 The effect of range on detection probability for large targets and small targets 65

FIGURE 7.1.8 The effect of range on detection probability for large and small targets under conditions of high S/N ratio and low S/N ratio 70

FIGURE 7.2.1 The effect of range on search time 85

FIGURE 7.2.2 Mean search times for the twelve targets 89

FIGURE 7.2.3 The effect of range on search time for small targets and large targets 93

FIGURE 7.3.0 The effect of signal/noise ratio on confidence level 103

FIGURE 7.3.1 The effect of range on confidence level 107

FIGURE 7.3.2 Mean confidence levels for the twelve targets 111

FIGURE 7.3.3 The effect of signal/noise ratio on confidence level for large targets and small targets 117

FIGURE 7.3.4 The effect of range on confidence level for large targets and small targets 123

1. INTRODUCTION

The detection and recognition of terrain features, either as navigational fix-points or as military targets, is of vital importance during high-speed, low-level flight. The difficulty of the target acquisition task depends on a number of factors including aircraft speed and altitude, vibration effects, meteorological conditions, target size and conspicuity, the nature of the terrain and the type of briefing information. These factors, and the interactions between them, give rise to a situation of considerable complexity. This complexity is greatly increased if a television viewing system is interposed between the observer and the terrain.

The use of this two-dimensional display mode to represent the outside world inevitably results in a partial loss of three-dimensional cues. These cues are of importance in the interpretation of terrain structure and in the judgment of distance, both of which are of direct relevance to target acquisition tasks. If, as is usually the case, a black and white television display is used the loss of colour effects is a particularly important factor. For instance, it has long been known that the atmospheric attenuation of colour, and the increasingly blue appearance of objects as their distance from the observer increases, are interpreted by the eye as significant distance cues (Leonardo da Vinci, 1585). Thus in these respects the television display mode is inherently inferior, as a source of outside world information, to a direct view of the terrain.

Furthermore, the nature of the television system introduces other factors that may adversely affect performance. For instance, the camera field of view is relatively restricted, and contrast and resolution degraded. It is also possible that visual noise, originating in the television system, will give rise to unwanted signals which appear superimposed on the display, thus partially masking it. All these factors are liable to have a detrimental effect on performance and this may be accentuated if the size, viewing distance or orientation of the display relative to the observer is unfavourable.

Although training in the use of television displays may reduce the detrimental effect of these factors, target acquisition tasks carried out by means of a television system are likely to be considerably more difficult than the same tasks carried out by direct view of the terrain. In general, therefore, performance levels will be lower especially under adverse conditions such as in poor visibility, or at very high speeds. However, it should be noted that in one respect a television viewing system may have a favourable effect on performance. Reducing the field of view of the camera results in magnification of the apparent size of the target as seen on the television display. This tends to lead to increased recognition ranges, although it may also decrease the overall probability of correct recognition (Rusis and Snyder, 1965).

In spite of the complexities involved television has become increasingly important as a means of guiding air-to-ground missiles. It is therefore necessary to investigate the many interacting factors which affect the observer's performance although, clearly, only a limited number of factors can be included in a single experiment. The present experiment, the fourth in a series of visual and televisual detection studies, is primarily concerned with the effect of visual noise on detection performance. The importance of this particular factor arises from the need to specify the characteristics, in terms of the signal/noise ratio of the display system, required to achieve an acceptable level of performance. Designing and producing systems incorporating very high signal/noise ratios is likely to involve considerable expense and technical difficulty. This is not justified if only marginal improvements in performance are associated with the increased signal/noise ratio. However, if the signal/noise ratio is too low performance may fall below the required level. In order to avoid a specification that is either unnecessarily high, or not high enough, for the task involved it is essential to know how performance varies with signal/noise ratio. It is also important to be able to predict the extent to which performance is liable to deteriorate if the signal/noise ratio falls temporarily below the specified value through malfunctioning of the equipment or external interference.

A large amount of work, both theoretical and practical, has been directed towards the formulation of a signal detection theory which can be used to predict the detectability of signals in the presence of noise. However, this work is of little direct relevance to the present study of the effect of noise on the televisual detection of ground targets since the theory can only be applied quantitatively to situations in which both the distribution of noise intensities and the distribution of signal + noise intensities are known. It is assumed that both these give rise to levels of activity in the nervous system which are normally distributed with equal variances. It is then possible to derive a measure of signal detectability, d', which is the difference between the means of the noise and signal + noise distributions, divided by their standard deviation. Thus the value of d' relates to the degree of overlap between these distributions.

If the observer is presented with a signal which he perceives as falling within this critical overlap region he must adopt a strategy in order to decide whether or not to report a signal. This strategy will depend on whether he is more willing to make omissive or commissive errors. On the basis of this he selects a criterion value, below which he rejects the disturbance as noise and above which he accepts it as a signal. If his criterion value is such that most of the overlap region falls below it then he is relatively unlikely to make commisive errors but he may omit to report genuine signals. Conversely, if his criterion value is such that the overlap region largely occurs above it then he is relatively unlikely to make omissive errors but may report as signals disturbances that are, in fact,noise.

If the probabilities of correct detection, of commissive errors and of omissive errors are determined for a particular observer in a given situation it is possible to calculate the value of d', and also the criterion value selected by the observer. His response to the physical world, as measured by the actual noise and signal + noise characteristics of the display system can then be evaluated. There are many references to fundamental studies in this field (see, for instance, Swets, 1964, Broadbent and Gregory, 1963) but these need not be considered in detail here since the basic requirements of signal detection theory are not met by the task studied in the present experiment. In this experiment visual noise originating in the television system appeared superimposed on the display. The noise was measured relative to the known peak white in the video signal and thus in this respect the signal/noise ratio of the display system could be calculated.

However, a different type of noise arises from the nature of the terrain itself, which forms a structured background for the target. In this background some features may give valuable clues as to the exact position of the target. These 'lead-in' features can be regarded as useful signals. In addition, there are many minor features which cannot be related to map information and give no indication of target position. These features constitute useless and unwanted information and must therefore be regarded as noise although this noise is of a very different type from that originating in the electronics of the display system. In this experiment no attempt has been made to distinguish in a quantitative manner between the terrain features that can be regarded as signals and those which are unwanted noise. Furthermore, in no case is a display presented in which the target is not present, although in some cases it was extremely difficult to detect.

The situation in the present experiment is therefore one in which the target occurs against a structured terrain, consisting partly of useful signals and partly of unwanted noise, and both target and background are degraded by the visual noise arising in the television system. Studies of the effect of visual noise on the detection and recognition of target objects which, as in this case, cannot at present be completely specified in quantitative terms, as required by signal detection theory, must be based on experimental techniques. Reported work in this field is largely concerned with the effect of visual noise or disturbance on the recognition of target patterns.

Van de Geer and Levelt (1963), for instance, carried out an experiment in which patterns were presented as rapid sequences of dots on a screen under either 'noise-free' conditions, or 'noisy' conditions in which the position of each dot was displaced by a random normal deviate from its correct position, thus distorting the pattern. It was found that this disturbance was detrimental to pattern recognition. Patterns which were relatively 'noise-proof', i.e. detected almost equally well under 'noise-free' and 'noisy' conditions, tended to be those which had the greatest degree of spread, e.g. square, helix and star, whereas patterns which were predominantly linear were more readily confused under the disturbed conditions. The critical factor determining whether a pattern would be affected by the disturbance appeared to be the average distance travelled by the dot between successive frames. In the 'noise-proof' patterns this was relatively large whereas in the vulnerable patterns it was low.

The noisy conditions studied in this experiment represented a disturbance of the pattern from its true form, rather than the superimposition of visual noise such as might occur in a television system. In another study (Coules, Duva and Ganem, 1960) it was also found that there was an interaction between noise and pattern form. Judgments of the complexity of 20 irregular shapes were obtained under varying conditions of superimposed visual noise of the kind that might occur in a television system. It was found that form differences and noise level both affected the complexity ratings and furthermore there was an interaction between these two factors, the effect of noise being different for different forms.

Crook and Coules (1959) found that visual noise resulted in deterioration of performance in form identification on a simulated television display. This deterioration under noisy conditions was thought to be due to reduced contrast between form and background and a degradation of contours. In a similar investigation of radar displays Bowen et al (1959) found that noise and distortion were more serious than blur in degrading recognition of geometric symbols.

A different type of experiment was carried out by French (1954) who studied the recognition of dot patterns in relation to a simple measure of target-to-noise ratio. In this experiment the subject was required to recognise 'target' patterns of light dots embedded in visual noise consisting of randomly scattered light dots. Recognition of these patterns was studied as a function of the number of target dots (ranging from 2 to 9) and the number of noise dots (ranging from 1 to 8). The results indicated that increasing the complexity of the target pattern by progressively increasing the number of target dots improved recognition performance. On the other hand increasing the number of noise dots produced a progressive decrement in recognition of the target. In general it was found that recognition performance improved as the ratio of the number of target dots to the number of noise dots increased to a target-to-noise ratio of approximately 3:1. Beyond that there was little improvement in recognition performance.

The general conclusion that can be drawn from these, and other similar experiments, is that in a situation involving the recognition of target patterns against a uniform background, performance tends to deteriorate as the amount of visual noise or disturbance on the display increases. However, it is not possible from experiments of this type to predict quantitatively the recognition performance associated with a particular level of noise unless the nature of the task is closely similar to that actually studied experimentally. Although experiments of the kind described above could in some cases be used to predict the performance of observers required to recognise target patterns appearing against a plain background, for instance on a radar screen, they cannot be regarded as directly applicable to a situation in which the target appears against a background containing other objects.

Erickson (1966) studied the recognition of a target pattern (a rounded cross) against a static background containing 62 non-target objects (kernels of pop-corn). Recognition of the target was studied under three conditions: noise-free, 'fast' noise, which changed 26 times/second, and 'slow' noise, which changed 5.2 times/second. The display was produced by projecting a cine-film showing the target against a grey background containing the non-target objects. The television-type visual noise was superimposed on the appropriate films by double exposure and special printing, the 'fast' noise changing each frame and the 'slow' noise changing every five frames. Thus the observer viewed a display showing a static target, against a background containing static non-target objects, on which either rapidly or slowly changing visual noise might be superimposed. The exposure time was 11 seconds and the target appeared randomly in one of thirty possible positions. After preliminary tests of visual acuity and response time Erickson measured the search times required for the observers, 22 Navy pilots, to locate the target under the three conditions.

The results of this experiment indicated that after a 10 second search time the probability of detecting the target was 0.94 under noise-free conditions, 0.85 under conditions of 'fast' noise and 0.78 under conditions of 'slow' noise. One possible explanation that Erickson suggests to account for these results is that the 'slow' noise might interfere with the natural frequency of eye-movements. Since fixations tend to change every 0.20 to 0.40 seconds (Michon and Kirk, 1962, White and Ford, 1960) while an observer is searching for a target it could be that this fixation frequency is disturbed by the 'slow' noise which changed every 0.19 seconds. Thus the natural search patterns might be distorted with a resulting decrease in recognition rate.

The background of non-target objects used in this study represents a closer approach to the 'real' world than studies involving only plain backgrounds. Nevertheless there is still a great gulf between laboratory investigations of this type and the task involved in airborne television navigation, in which the observer may gain valuable information as to the location of the target from the structure of the surrounding terrain. For instance, if a small target such as a bridge, can be exactly located on a map, and its position in relation to larger and more conspicuous features noted, it may be possible to determine the exact position of the target in the television display by reference to these features. Thus the observer may be able to correctly locate the target with the aid of the additional information gained from the surrounding terrain features, although it might otherwise be below the threshold of recognition. In such cases it may be that the extent to which these conspicuous terrain features become unrecognisable in the presence of visual noise has a more serious effect on target detection performance than degradation of the target itself. Such effects would not be apparent from studies of abstract targets against backgrounds which, although they may contain non-target objects or patterns, are unrelated to the target.

Relatively few reports are available which relate directly to the airborne detection of ground targets against a background terrain in the presence of visual noise, but one such investigation is reported by Kause (1965). The experiment was intended to study the effect of contrast, resolution and signal/noise ratio in an airborne target detection situation simulated statically by means of 45° oblique aerial photographs displayed on a television monitor screen. Two 'looks' at each of nine target areas were shown to the 20 engineers and 4 image interpreters who acted as subjects in this experiment. The first look, simulating a 40,000 ft. line-of-sight was presented under conditions of moderate vs. high contrast, low (2 lines/mm) vs. high (4 lines/mm) resolution and noise present (constant 2 volt noise) vs. noise absent, (a total of 8 conditions). The subject was required to locate the general area ($\pm$ 500 ft.) in which the target was situated. He was then, after a short delay, shown a second display simulating a 12,000 ft. line-of-sight in which he was required to locate and designate the target (± 50 ft.). This second look was presented under the same conditions of signal/noise and resolution as the first look but contrast was improved by one step. It should be noted that the apparatus was such that contrast and signal/noise ratio were unfortunately confounded, i.e. a change in contrast resulted in a change in signal/noise ratio. The contrast, resolution and noise levels were determined in relation to the operational situation under investigation.

For briefing purposes a high quality target photograph, of scale slightly less than that of the second look, was provided. The target was pointed out to the observer and he was allowed up to 5 minutes to familiarise himself with the target characteristics and the surrounding area. The ground size of seven of the targets ranged from 27 ft. to 107 ft; the remaining two targets were relatively large, 315 ft. and 392 ft.

The main results found from this study were:

(a) The overall proportion of correct responses for the high altitude condition was 57% and for the low altitude condition was 71%. Mean decision time in each case was 7 seconds.

(b) Increased signal/noise ratio and increased resolution improved operator performance. Contrast increase, with high resolution, produced an improvement in operator performance; contrast increase, with low resolution produced a decrement.

(c) Decreased signal/noise ratio was more serious under optimal conditions of contrast and resolution than under degraded conditions of contrast and resolution.

(d) Correct responses were higher when viewing low altitude imagery with a high signal/noise ratio and high resolution than when both these variables were simultaneously degraded.

(e) For the low altitude condition considerably better performance was associated with the two relatively large targets than with the seven smaller ones.

The overall conclusion that Kause draws from this exploratory study is that, after observers have been extensively and rigorously trained for the task, the detection rate for large military targets in the operational situation should closely approach 100%, even under moderately severe conditions of picture degradation such as those he studied.

In this study the visual complexity of the real world, as viewed by television, is accurately reproduced in the experimental situation and thus, in this respect, the results are closely applicable to operational conditions. The targets studied by Kause were ground features, mostly small buildings, which could be exactly located on a target photograph. Targets of a similar type were studied in the present experiment but maps were used to provide briefing information. However, in other situations, it may be necessary for the observer to search for small targets, such as army vehicles, whose position is not necessarily related to any particular terrain feature shown on a map, or photograph of the target area. The observer's task in such cases is basically one of searching for a small target shape against a complex and highly structured background, which gives no information as to target position. The results found by Kause would probably be very over-optimistic if applied to a situation of this type since the effect of visual noise on detection performance is likely to be extremely detrimental. The apparent size of such a target on the screen is very small and it could possibly be completely or partially obliterated by successive elements of noise.

It is likely that in this situation even a relatively low level of noise might make target detection impossible, particularly if other relevant parameters, for instance, contrast or resolution, are also unfavourable. Decreasing the camera field of view, and thus effectively magnifying the target, could facilitate detection under such conditions but this would tend to increase the difficulty of overall geographic orientation since the extent of the terrain shown in the display would be decreased. For these small and potentially mobile targets it is difficult to predict the effect of visual noise on detection performance. However, it seems likely that to achieve a reasonable detection rate all display parameters, including signal/noise ratio, must be highly favourable.

One extremely important factor which has not been considered in the experiments described above is the effect of aircraft speed and the way that this might interact with visual noise effects. In both the experiment carried out by Kause and the one described in the present report no attempt was made to simulate the dynamic aspects of the airborne situation. In each case the simulation technique involved the use of static aerial photographs. Although there is some evidence to suggest that the results of static experiments, in terms of the probability of detection at a given range, are comparable with those found in flight trials, dynamic experiments would yield more reliable information. Either cine-film simulation techniques or actual flight trials could be the basis of such experiments, according to whether greater experimental control or greater realism was thought to be more important. Without dynamic studies it is not possible to predict quantitatively how aircraft speed interacts with the display signal/noise ratio, or even whether there is such an interaction. It seems likely, however, that a deterioration in picture quality would be more detrimental at higher speeds when there is less time to detect and recognise targets and important terrain features. It would also be of interest to investigate dynamically and in more detail, the effect of visual noise on the detection of different types of targets, particularly very small ones, but such an experimental program would involve considerable expense and effort.

The present experiment represents an attempt to study by a comparatively simple technique the effect of visual noise, as measured by the signal/noise ratio of the display system, on the detection of a variety of ground targets. Target contrast and apparent size were related to range as in the real situation but other display parameters were kept constant at a relatively favourable level. Although the noise effect was the main subject of the investigation the effects of range and of target size have also been analysed. Both skilled and unskilled subjects took part in the experiment and the performance of the two groups was compared.

This study was the fourth in a series of static simulation experiments (Parkes, 1967) intended to investigate various parameters involved in the visual and televisual detection of ground targets during high-speed, low-level flight. In the previous experiments the target displays had been viewed under conditions of direct photographic presentation, which were completely free of electronic noise. The present television experiment enabled comparisons to be made of detection performance under the two modes of presentation. The principal aim, however, was to provide detailed information relating to televisual detection performance in the presence of noise, under conditions which were directly relevant to the operational situation.

2. PURPOSE OF THE EXPERIMENT

The main aims of this experiment can be summarised as follows:

(i) To determine whether detection performance, as measured by detection probability, search time and confidence level, was significantly affected by the signal/noise ratio of the television system used to display the target photographs. The four values of signal/noise ratio studied were 14, 19, 24 and 30 dbs.

(ii) To investigate the effect of range, and of differences between the twelve individual targets, on detection performance under conditions of television presentation, and to compare the results with those found previously under conditions of photographic presentation.

(iii) To analyse the differences in detection performance due to differences between the group of six small targets and the group of six large or conspicuous targets. In particular it was of interest to determine whether the two groups of targets were differently affected by the conditions of signal/noise ratio and range investigated.

(iv) To compare the performance of unskilled subjects (students) with that of skilled subjects (pilots and navigators). Since only eight skilled subjects were available the separate experiment in which they took part was inevitably relatively limited in scope and only two signal/noise ratios (14 and 24 dbs) were investigated.

3. EXPERIMENTAL DESIGN.

In this experiment the performance of both unskilled and skilled subjects was studied. However, since only eight skilled aircrew were available to take part, no attempt was made to carry out a single experiment involving both groups of subjects. Instead two separate experiments were carried out, each on a scale appropriate to the number of subjects available. Inevitably the experiment with skilled subjects had to be relatively limited in scope but it was nevertheless intended to provide suitable data for comparison purposes.

3.1 Unskilled subjects

The design of this experiment was intended to provide as much information as possible, compatible with the amount of time available about the following factors:

Signal/noise ratio	4 levels	14, 19, 24 and 30 dbs.
Range	4 levels	1, 2, 3 and 4 miles.

Although a number of extra sets of target photographs were included in this experiment the maximum number of targets that could be used to test the 16 conditions was twelve. Furthermore, restrictions similar to those noted in previous experiments had to be taken into account. Thus:

(a) No subject could see a target more than once.

(b) Each subject had to see each condition of signal/noise ratio and each condition of range an equal number of times.

Since only twelve targets were available to test the sixteen conditions it was clearly not possible for each subject to be exposed to each condition as in previous experiments. Sixteen subjects (students) were therefore allocated to the 12 x 16 (targets x conditions) matrix in such a way that each was exposed to each range condition three times and to each condition of signal/noise ratio three times. Thus a subject saw each of the twelve targets under a different combination of conditions.

The order of presentation of the target and condition combinations to each subject was randomised.

This experimental design, which is given in detail in Appendix II, was orthogonal with respect to the range conditions and the signal/noise ratio conditions separately, but was not orthogonal with respect to the 16 conditions of range and signal/noise ratio combined. However, this was not a serious drawback since the experiment was not intended to investigate subject differences and in the analysis of the results each reading was treated as independent. Two groups of sixteen unskilled subjects took part in this experiment, i.e. the matrix was replicated twice, giving two readings in each cell.

3.2 Skilled subjects

Since only eight skilled subjects were available this experiment was restricted to eight conditions, these consisting of combinations of the four range levels but only two levels of signal/noise ratio, 14 and 24 dbs. All twelve targets were used to test these conditions. Eight subjects were allocated to the 12 x 8 (targets x conditions) matrix in such a way that each subject was exposed to each range condition three times and each signal/noise ratio six times. The order of the twelve presentations to each subject was randomised. Like that for unskilled subjects, this experimental design was orthogonal with respect to the range and signal/noise ratio conditions separately, but not when they were combined. Owing to the shortage of subjects it was not possible to replicate this matrix, full details of which are given in Appendix II.

4. DISPLAY AND RECORDING APPARATUS

The display and recording apparatus used in previous experiments was considerably modified for use in the present experiment. The aim of this modification was to interpose a television viewing system between the observer and the photographic display i.e. instead of looking directly at the display, as in previous experiments, the observer viewed the display on a television monitor with visual noise added. The map display and recording apparatus, which printed out map time, search time and the confidence level of the observer's judgment, remained essentially the same as described for earlier experiments. A general view of the experimental area is shown in Figure 4.0.1.

The photographs were magnetically mounted on a metal slide at the back of the display box, as previously. However, in the present experiment the front portion of the viewing tunnel was removed. The photographic display, suitably illuminated from within the display box, was televised from a distance of about 13" by a Marconi 321 camera, as shown in Figure 4.0.2. The television picture was displayed on a monitor with the addition of appropriate amounts of 'flat, white' electronic noise. This noise, of bandwidth 5mc, was derived from a B.B.C. noise generator and added into the video signal via an attenuator. The circuit impedences were checked to be 75 Ω to ensure the validity of the calibration of the generator. This was calibrated to deliver 1 mW of noise (5mc) into 75 Ω. The signal/noise ratios used were 14, 19, 24 and 30 dbs r.m.s. noise relative to the measured peak white in the video signal. The excellent compensating circuitry of the 321 camera resulted in the peak white being constant over all the target photographs used in spite of large variations in scene content. The black levels on the display were also acceptably constant so that no adjustment of either the display or the camera was necessary for each target presentation. The equipment used for generation, attenuation and calibration of the electronic noise is shown in Figure 4.0.3.

The $6\frac{1}{2}$" television monitor had a 4 : 3 aspect ratio and measured approximately $5\frac{1}{4}$" x 4". The monitor screen was inclined at 30^{0} to the vertical and arranged so that the observer viewed it through the front portion of the original viewing tunnel used in previous experiments. When the subject's head was correctly positioned against the fore-head and chin rests the viewing distance was 21". The map display box was set up alongside the television display as shown in Figure 4.0.4. A diagrammatic representation of the television circuit is shown in Figure 4.0.5. The 'start' and 'stop' switches for recording the time spent viewing the display were mounted, together with the series of seven switches for indicating confidence level, below the viewing tunnel where they could be conveniently reached by the seated subject.

Although considerable changes had been made in the apparatus the subject's task was essentially the same as in previous experiments, i.e. to detect a given target in the display after familiarising himself with an appropriate area of the map. The only difference was that in this case the display was a televised view, rather than a direct view, of an aerial photograph. The method of operating the apparatus was identical to that used previously.

The time spent by the subject viewing the map was automatically recorded when he closed the map box. When he pressed the 'start' button the television display appeared on the screen and he was required to detect the target as rapidly as possible. He pressed the 'stop' button when he had done so and this recorded the time he had taken. He then indicated the extent to which he was confident in the correctness of his judgment by operating the appropriate one of the series of seven switches. Finally, he used the pointer to point out the target on the display. This was checked by the experimenter. At the end of each cycle the experimenter changed the map and the photograph. To prevent the subject from gaining prior knowledge of the S/N ratio he was subsequently to be exposed to the attenuator was not reset until after he had completed the map-briefing task in each cycle.

FIGURE 4.0.1
General view of experimental area.

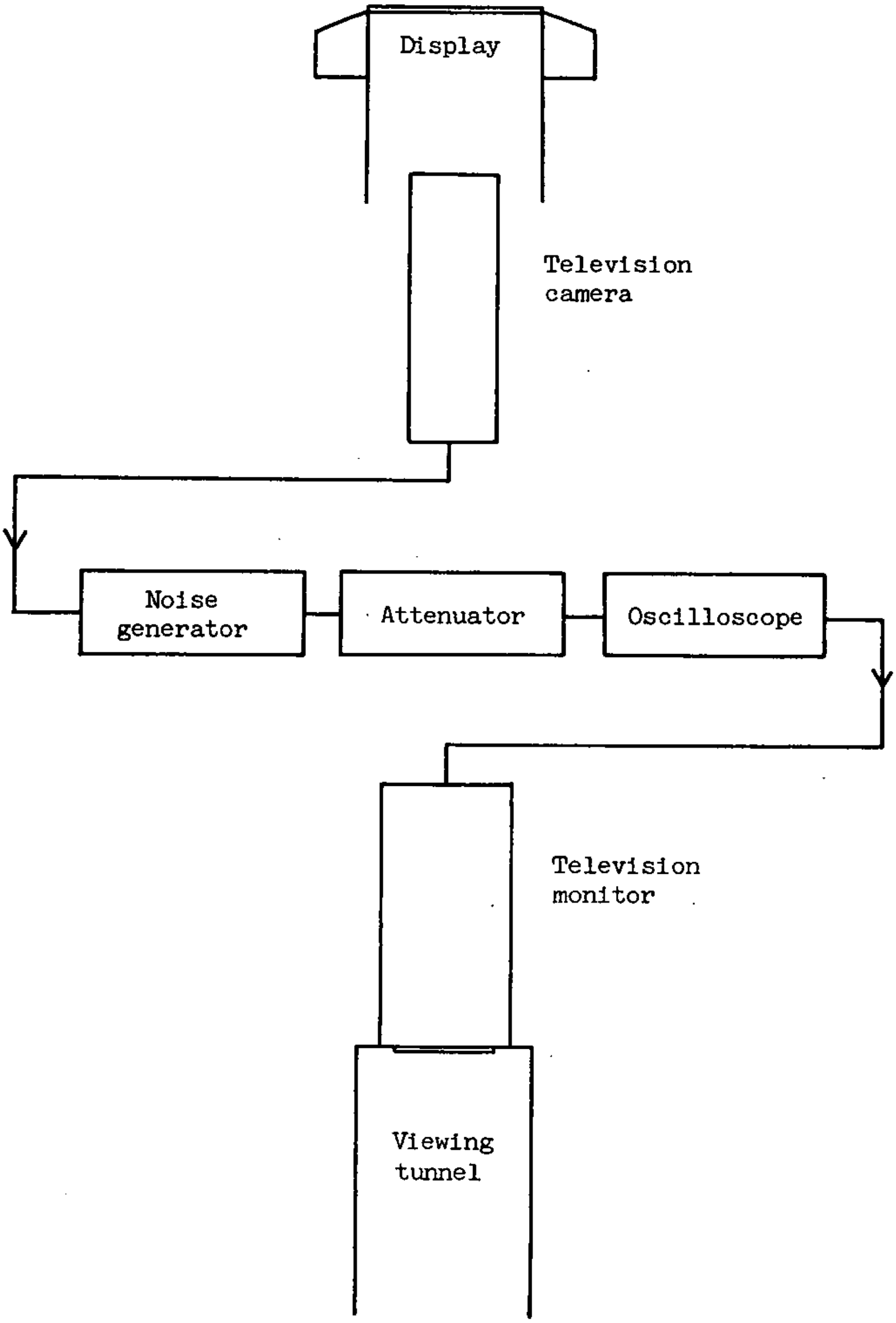
FIGURE 4.0.2
Marconi 321 camera mounted to
televise photographic display.

FIGURE 4.0.3
Equipment used for calibration, generation and attenuation of electronic noise.

FIGURE 4.0.4
Television monitor seen through the viewing tunnel with the map display mounted beside it.

FIGURE 4.0.5

Diagrammatic representation of television circuit



5. EXPERIMENTAL MATERIALS

The maps and photographs used in this experiment were those used in previous experiments in this series together with a number of additional ones. It was necessary to use this additional material because of the large number of experimental conditions to be tested. (See Section 3, Experimental Design). However, the four extra sets of photographs, and the corresponding maps, related to the same type of targets and terrain as those used originally, e.g. buildings, bridges, stations, etc. in Southern England. These brought the total number of targets available for training and test purposes to 22.

The experimental material has been described in detail in the first of this series of reports (Parkes, 1967) and so only a brief description is given here. The photographic material consisted of a series of 8" x 8" aerial photographs taken from an altitude of 2,000 ft. with a camera field of view of $50^{\circ} \times 50^{\circ}$. For display purposes these photographs were masked so that only a central portion 4.8" (horizontally) and 3.6" (vertically) was shown representing a camera field of $30^{\circ} \times 22\frac{1}{2}^{\circ}$. In each case the horizon appeared $\frac{1}{4}$" below the top of the displayed portion, the depression angle of the camera being 10°. For each of the 22 targets there were four photographs taken at ranges of 4, 3, 2 and 1 mile respectively along an approach route.

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 4" x $\frac{1}{2}$" was marked along the approach route. This represented the limits of the simulated uncertainty in the aircraft position corresponding to the $\pm$ 2 mile condition of navigational uncertainty in range and $\pm \frac{1}{4}$ mile in off-set. This was associated with a nominal range to target of 2 miles.

6. EXPERIMENTAL PROCEDURE

The training and test procedures used in this experiment were adapted to suit the television display mode but were otherwise very similar to those described in detail for Experiment I. A brief description is given below.

6.1 Unskilled subjects

Each subject was given a preliminary test of intelligence (Heim's A.H.5 test) and personality (Eysenck Personality Inventory). These were given as group tests and carried out separately from the main experimental session. In addition each subject was given an individual test of memory (forward and reverse digit-span). These three tests took approximately $1\frac{1}{4}$ hours altogether.

The experimental session was carried out individually and took approximately 2 hours. Subjects were first given some practice in map reading, with particular reference to ground features of importance in aerial navigation. This was followed by an explanation of the photographic and navigational parameters involved. The appropriate search area with which the subject was required to familiarise himself was shown on the map by a transparent overlay during initial training. This search area corresponded to a navigational uncertainty of $\pm$ 2 miles in range and $\pm \frac{1}{4}$ mile in off-set, an altitude of 2,000 ft. and a camera field of view of 30°. The subject was shown a series of three sample maps and the corresponding sets of photographs and asked to identify the conspicuous features and the target in each. He was then shown how to operate the display and recording apparatus, and a series of four targets, one at each range was shown for further practice. After each presentation the subject was told whether or not he had correctly located the target and, if not, was given a further opportunity to do so. Each photograph was initially displayed on the monitor under a different noise condition but, after he had detected the target, the subject was shown the same display under each of the other three noise conditions. Thus, during the presentation of these four targets the subject was able to become familiar with each noise condition. Four targets were then presented for further practice, one at each range and one at each noise level. In these and subsequent presentations no knowledge of results was given and each target was presented under a single noise condition.

The final test run consisted of twelve targets presented under randomly ordered conditions of range and noise, according to the experimental schedule (see Appendix II). 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 then turn to the television display, which appeared on the screen when he pushed the 'start' button, 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 briefing time.

6.2 Skilled subjects

The procedure followed in testing the skilled subjects was the same as that outlined for the unskilled subjects except for the following modifications:

(a) Preliminary training in map-reading was omitted since it was unnecessary for skilled aircrew.

(b) Since the experimental design for the skilled subjects involved only two levels of S/N ratio the training related only to those levels (14 and 24 dbs). Otherwise, since not all the skilled subjects were experienced in television navigation, this part of the training was similar to that given to unskilled subjects.

(c) Intelligence and personality tests were given as individual tests after the experimental session, rather than as group tests.

7. EXPERIMENTAL RESULTS.

In the statistical analysis of the results obtained from this experiment each of the main factors tested is considered in relation to the four basic performance measures 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 factors is systematically considered. The main emphasis, however, is on the effect of signal/noise ratio on performance. For convenience cross-referenced summary tables are given in the final section (Section 7.6).

In each case the data from the 32 unskilled subjects have been analysed separately from those relating to the 8 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 treatment.

In the statistical analysis of the results the raw data for the unskilled subjects were treated as though each of the 384 values in the 12 x 16 (targets x conditions) matrix, which was replicated twice, were independent. This assumption, which was also made in previous experiments, was thought to be reasonable although each subject contributed twelve values to the matrix. A similar assumption was made about the independence of the values in the matrix of raw data for the skilled subjects. No attempt has been made to investigate differences between subjects within either the unskilled or the skilled group. These subject differences were of relatively slight importance since the primary purpose of the experiment was to investigate the effect of the conditions tested on the performance of the two subject groups. However, the relationship between an individual's performance and his scores on the psychometric tests used has been evaluated (see Section 7.5).

7.1 Detection probability

The raw data obtained from the unskilled subjects is shown in Table 7.1.1 and those from the skilled subjects in Table 7.1.2. The overall detection probability for the skilled subjects, who were exposed only to noise levels of 14 and 24 dbs., was 0.44 and the corresponding value for unskilled subjects was 0.46. The overall value for the unskilled subjects, relating to all four noise levels, was 0.47.

It can be seen in Tables 7.1.1 and 7.1.2 that the values in the matrix are restricted to 0, indicating an incorrect detection, or 1, which represents a correct detection. The data were thus not entirely suitable for analysis by conventional techniques. In spite of this a conventional analysis of variance was carried out on each set of readings. For the data relating to unskilled subjects the results were then compared with those obtained from a more sophisticated technique, Logit analysis. This is considered in a later section. For skilled subjects not enough data were available to make this further analysis worthwhile.

The analysis of variance on the data from unskilled subjects is shown in Table 7.1.3. It can be seen that the three main factors tested, S/N ratio, ranges and targets are all highly significant. Furthermore, the interaction between ranges and targets is highly significant. In Table 7.1.4, which shows the corresponding analysis for the skilled subjects, ranges and targets are again highly significant, but the effect of noise just fails to reach the 5% significance level. However, this result is not surprising in view of the fact that in this case only two S/N ratios were tested. Thus in Table 7.1.4 there is only one degree of freedom associated with this factor, which, together with the limited number of subjects used, could account for the low significance of the effect.

In the following sections the effect of each of the main factors is considered in greater detail, and comparisons made between the performance of unskilled and skilled subjects. For unskilled subjects the interaction effects between the main factors have also been further analysed. Although only one of these effects reaches significance in the overall analysis of variance shown in Table 7.1.3 the detailed analyses (shown in Sections 7.1.4 - 7.1.7) were thought to be worthwhile in view of the interest of the results obtained. These analyses were not carried out for skilled subjects owing to the relatively small amount of data available.

TABLE 7.1.1

Correct and incorrect identifications by unskilled subjects

Ranges (miles)	S/N ratio (dbs)	TARGETS											
		3	14	17	16	15	13	1	20	10	6	5	9
1	14	1	1	0	1	0	0	0	1	1	0	0	1
		0	1	1	0	0	0	0	0	1	0	0	1
	19	1	1	1	1	1	0	0	1	1	0	0	1
		1	1	1	1	0	1	0	0	1	0	0	1
	24	1	1	1	1	1	0	0	1	1	0	1	1
		1	1	1	1	1	0	0	1	1	0	0	1
	30	1	1	1	1	0	0	0	0	1	0	1	1
		0	1	1	1	1	0	1	1	1	0	1	1
2	14	1	1	0	1	0	0	0	0	0	0	0	1
		1	1	0	1	0	0	1	1	0	0	1	1
	19	1	1	0	1	0	0	0	1	0	0	0	0
		1	0	1	1	1	0	0	1	0	0	1	0
	24	1	1	0	1	0	0	0	1	0	0	1	1
		1	1	0	1	0	0	1	1	1	0	0	1
	30	1	1	0	1	0	1	1	1	0	0	1	1
		1	0	0	0	0	1	0	1	1	0	1	1
3	14	0	1	0	1	1	0	0	0	0	1	0	1
		0	1	0	0	1	0	0	0	0	0	0	1
	19	0	1	0	0	1	0	0	1	1	0	0	1
		1	1	0	0	0	0	0	0	0	0	0	0
	24	1	1	1	0	0	1	0	1	0	0	0	1
		1	1	0	0	0	0	0	1	0	0	0	1
	30	1	1	1	1	0	0	0	0	0	0	0	1
		1	1	0	1	1	0	0	1	0	1	0	1
4	14	1	1	0	1	0	0	0	1	0	0	0	0
		0	0	0	1	0	1	0	0	0	0	0	1
	19	1	0	0	1	1	0	0	1	0	0	0	0
		0	0	0	0	0	0	0	0	0	0	0	1
	24	1	0	0	0	0	0	0	1	0	0	1	1
		1	0	0	1	1	0	0	1	1	1	1	1
	30	1	0	0	1	0	1	0	0	0	0	0	1
		1	1	1	1	1	1	0	0	0	0	0	1

1 = correct identification   0 = incorrect identification

TABLE 7.1.2

Correct and incorrect identifications by skilled subjects

Range (miles)	S/N ratio (dbs)	TARGETS											
		3	14	17	16	15	13	1	20	10	6	5	9
1	14	0	1	0	1	0	1	0	1	1	0	0	1
	24	1	1	1	1	1	1	0	1	1	0	0	1
2	14	1	1	0	1	0	0	0	1	0	0	1	0
	24	1	1	1	1	0	1	1	1	1	0	0	1
3	14	0	1	0	1	0	0	0	1	0	0	0	0
	24	0	1	0	0	0	0	0	0	0	0	0	1
4	14	0	1	0	1	0	0	0	0	0	0	0	1
	24	1	0	0	0	1	0	1	0	0	0	1	1

1 = correct identification

0 = incorrect identification

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
S/N ratio (N)	3	2.68	0.89	5.93(b)	$p < 0.001$
Ranges (R)	3	3.55	1.18	7.87(b)	$p < 0.001$
Targets (T)	11	25.05	2.28	15.20(b)	$p < 0.001$
N x R	9	0.93	0.10	- (b)	N.S.
N x T	33	5.51	0.17	1.13(b)	N.S.
R x T	33	13.64	0.41	2.73(b)	$p < 0.001$
N x R x T	99	16.14	0.16	1.07(a)	N.S.
Residual	192	28.00	0.15(a)		
Pooled residual (Residual + R x N x T)	291	44.14	0.15(b)		
TOTAL	383	95.49			

TABLE 7.1.4

Analysis of variance on the data for skilled subjects shown in Table 7.1.2

Source	D.F.	S.S.	M.S.	V.R.	Significance
S/N ratio (N)	1	0.67	0.67	3.82(b)	($p < 0.10$)
Range (R)	3	2.88	0.96	5.49(b)	$p < 0.005$
Targets (T)	11	6.12	0.56	3.19(b)	$p < 0.005$
N x R	3	0.58	0.19	1.08(a)	N.S.
N x T	11	2.83	0.26	1.44(a)	N.S.
R x T	33	4.62	0.14	- (a)	N.S.
Residual	33	5.92	0.18(a)		
Pooled residual (Residual + N x R, N x T, R x T)	80	13.96	0.17(b)		
TOTAL	95	23.62			

7.1.1. The effect of S/N ratio on detection probability

The overall mean detection probabilities for each S/N ratio are shown in Table 7.1.5.

TABLE 7.1.5.

Mean detection probability for each S/N ratio

	S/N ratio (dbs)			
	14	19	24	30
Unskilled subjects	0.38	0.39	0.54	0.55
Skilled subjects	0.36	-	0.53	-

It is clear from this table that the values relating to skilled subjects agree closely with the corresponding values for the unskilled subjects and in each case detection probability decreases with decreasing S/N ratio. For the unskilled subjects the main part of this degradation in detection probability appears to take place between the 19 and 24 dbs levels. The difference in detection probability between these levels is highly significant as shown in Table 7.1.6.

TABLE 7.1.6

Differences between detection probability means at each S/N ratio

S/N ratio (dbs)	14	19	24	30
14	-	0.01	0.16**	0.17**
19			0.15**	0.16**
24				0.01

** Significant at 1% level, one-tail test

It can also be seen in Table 7.1.6 that for unskilled subjects differences in detection probability between the two higher S/N ratios

(24 and 30 dbs) and between the two lower S/N ratios (14 and 19 dbs) are extremely small. The difference between the two values obtained for skilled subjects, relating to the 14 and 24 dbs levels, is significant at the 5% level, on a one-tail test.

Table 7.1.7 shows the total variation due to S/N ratios partitioned into three components:

(i) Variation arising from differences between the high S/N ratios (24 and 30 dbs) and the low S/N ratios (14 and 19 dbs).

(ii) Variation arising from differences within the two high S/N ratios.

(iii) Variation arising from differences within the two low S/N ratios.

TABLE 7.1.7

Partition of S/N ratio variation

Source	D.F.	S.S.	M.S.	V.R.	Significance
S/N RATIOS*	3	2.68	0.89	5.93	$p < 0.001$
Between high S/N ratios and low S/N ratios	1	2.67	2.67	17.79	$p < 0.001$
Within high S/N ratios	1	0.005	0.005	-	N.S.
Within low S/N ratios	1	0.005	0.005	-	N.S.
RESIDUAL*	291	44.14	0.15		

* Values taken from analysis of variance shown in Table 7.1.3

This analysis shows clearly that almost the whole of the variation in detection probability due to S/N ratio is accounted for by the highly significant variation between the high S/N ratios and the low S/N ratios. Variation within high and low S/N ratios is negligible. The effect of range on detection probability under conditions of high and low S/N ratio is considered in Section 7.1.4.

These results confirm that in this experiment the deterioration in detection probability takes place almost entirely between the 19 and 24 dbs levels. Since no readings relating to S/N ratios between those two values are available, it is not possible to define the exact relationship between detection probability and S/N ratio in this region. However, a regression analysis carried out on the data for all four S/N ratios (unskilled subjects only) suggests that the relationship between detection probability and S/N ratio is basically a linear one within the 14 - 30 dbs range investigated. This analysis is shown in Table 7.1.8.

TABLE 7.1.8

Regression analysis of S/N ratio variation

Source	D.F.	S.S.	M.S.	V.R.	Significance
S/N RATIOS*	3	2.68	0.89	5.93	$p < 0.001$
Linear regression	1	2.23	2.23	14.86	$p < 0.001$
Deviation about linear regression	2	0.45	0.23	1.53	N.S.
RESIDUAL*	291	44.14	0.15		

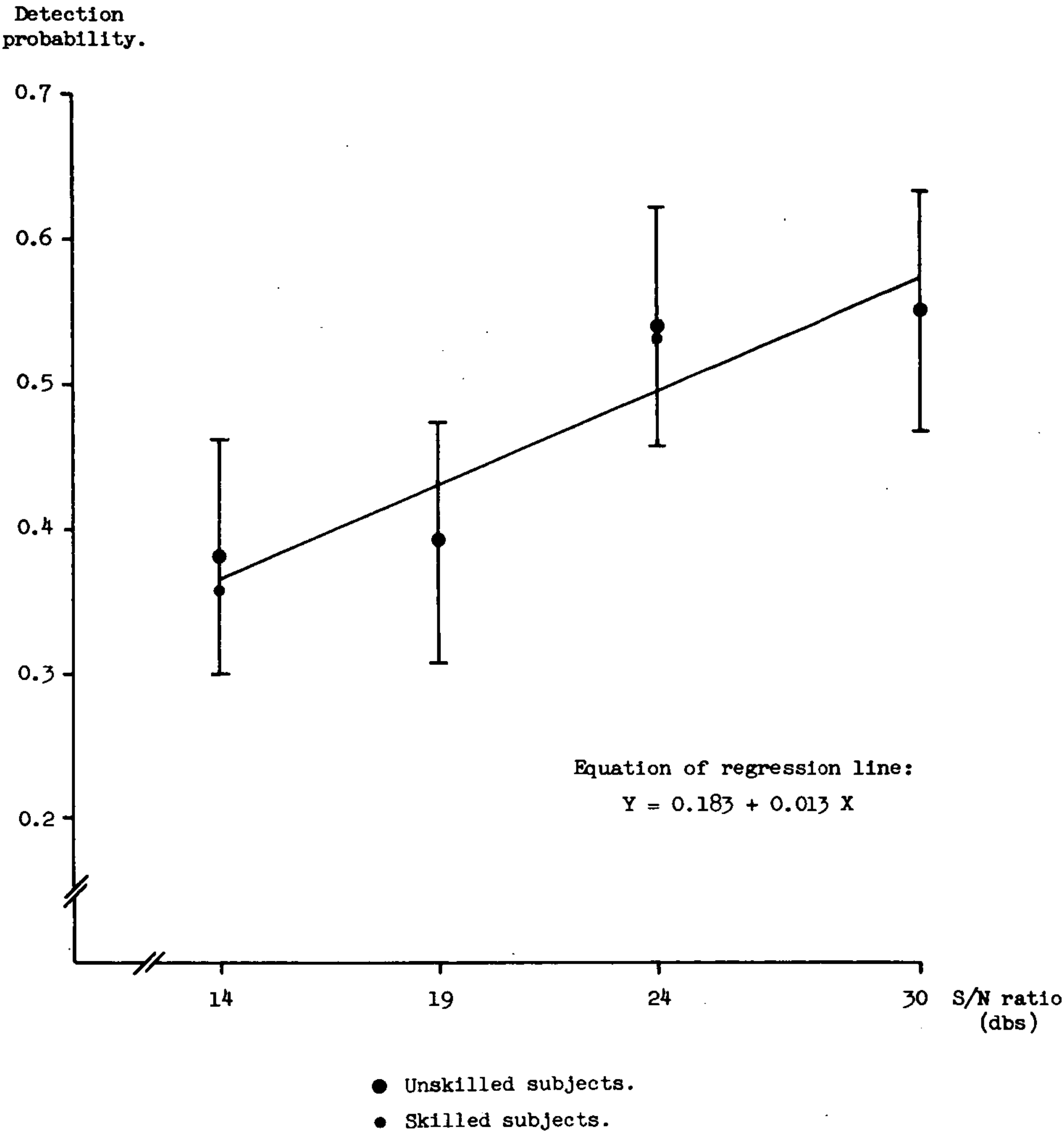
* Values taken from analysis of variance shown in Table 7.1.3

As can be seen in Table 7.1.8 a large proportion of the variation due to S/N ratios is accounted for by linear regression. The regression line is shown in Figure 7.1.1, together with the actual mean probability values for unskilled subjects and the associated 95% confidence limits. The two corresponding detection probability values for skilled subjects are also shown, although these were not included in the calculation of the regression line.

The remaining variation due to S/N ratios is accounted for by deviation about the linear regression. This deviation is not statistically significant. These results are very similar to those found

FIGURE 7.1.1

The effect of signal/noise ratio on detection probability.



NOTE The regression line is based only on the values relating to unskilled subjects.

from the Logit analysis of these data, (Section 7.1.8). This analysis showed that the linear effect of S/N ratio was highly significant but the quadratic component was not significant. A comparison of observed and expected detection probabilities in each cell suggested that the fit of the model might be improved by the introduction of a cubic effect of S/N ratio. This would probably give rise to a curve showing upper and lower asymptotes.

Seven targets used in the present experiment had been studied under conditions of photographic presentation in Experiment I. By extracting appropriate data it was possible to compare the overall detection probability associated with the 30 dbs S/N ratio television display with that for photographic presentation. The relevant values were 0.57 (30 dbs) and 0.63 (photographic). The difference between them was not significant which suggests that increasing the S/N ratio above 30 dbs would be unlikely to result in a significant improvement in detection probability. There was also no significant difference in detection probability between the 24 dbs S/N ratio display and the photographic display. This indicates that, in spite of the apparent linearity of the data within the 14 - 30 dbs range of S/N ratios studied, the two higher levels, 24 and 30 dbs, are approaching an upper asymptote and little further improvement in detection probability would be observed if the S/N ratio were increased. However, it is not feasible to investigate this possibility further without obtaining additional data in the 14 - 30 dbs range and for higher S/N ratios.

The two main conclusions that can be drawn from the data obtained in the present experiment are:

(a) There is a highly significant fall in overall detection probability between the 24 and 19 dbs levels of S/N ratio.

(b) Within the 14 - 30 dbs range of S/N ratios investigated there is no evidence that the relationship between detection probability and S/N ratio is non-linear, although the form of the data, and comparison with data obtained under conditions of photographic presentation, suggest an upper asymptote. The deviation of the mean values about the regression line accounts for the fact that the difference in detection probability between the 24 and 19 dbs levels is highly significant whereas differences between the 14 and 19 dbs and the 24 and 30 dbs levels are very small. However, this deviation is not significant whereas the linear regression component is significant.

7.1.2 The effect of range on detection probability

The analysis of variance shown in Tables 7.1.3 and 7.1.4 for unskilled subjects and skilled subjects respectively both show that detection performance is significantly affected by range. Table 7.1.9 shows the mean detection probabilities for each range and for each group of subjects. Since the skilled group were only exposed to S/N ratios of 14 and 24 dbs the corresponding data has been extracted from the complete data for the unskilled group for comparison purposes.

TABLE 7.1.9

Mean detection probabilities for each range

	Range (miles)				N*
	1	2	3	4	
Unskilled subjects	0.60	0.50	0.39	0.36	96
Unskilled subjects (S/N ratios 14 and 24 dbs only)	0.56	0.50	0.38	0.39	48
Skilled subjects	0.63	0.59	0.21	0.34	24

*N = Number of readings on which each value is based.

For the unskilled subjects detection probability decreases with increasing range. This decrease is also apparent for the skilled subjects except that the value for the 3 miles range detection probability is lower than would be expected. However, these values are based on only one quarter as many readings as those for skilled subjects and are therefore likely to be less reliable. Differences in detection probabilities for skilled subjects and unskilled subjects (S/N ratios 14 and 24 dbs only)were shown by t-tests to be non-significant at each range.

Differences between mean detection probabilities for ranges are shown in Table 7.1.10 for each group of subjects. The levels of significance shown relate to one-tail t-tests since previous work had indicated that, as would be expected, detection probability decreases with increasing range.

TABLE 7.1.10

Significance of differences between range means

	Unskilled subjects				Skilled subjects			
Range (miles)	1	2	3	4	1	2	3	4
1	-	0.10*	0.21**	0.24**	-	0.04	0.42**	0.29**
2		-	0.11*	0.14**		-	0.38**	0.25*
3			-	0.03			-	-0.13

* Significant at 5% level   ** Significant at 1% level

It can be seen that for unskilled subjects range differences greater than 1 mile, i.e. differences between 1 and 3 miles, 2 and 4 miles and 1 and 4 miles, result in highly significant differences in detection probabilities. Single mile differences result in non-significant or less significant detection probability differences. Similar results are found for the skilled subjects although these are slightly distorted by the apparently anomalous value for the 3 mile range.

A regression analysis was carried out on the detection probability data for ranges. Only data relating to unskilled subjects were included in this analysis, the results of which are shown in Table 7.1.11.

TABLE 7.1.11

Regression analysis of range variation

Source	D.F.	S.S.	M.S.	V.R.	Significance
RANGE*	3	3.55	1.18	7.87	$p < 0.001$
Linear regression	1	3.33	3.33	22.27	$p < 0.001$
Deviation about linear regression	2	0.22	0.11	-	N.S.
RESIDUAL*	291	44.14	0.15		

*Values taken from analysis of variance Table 7.1.3

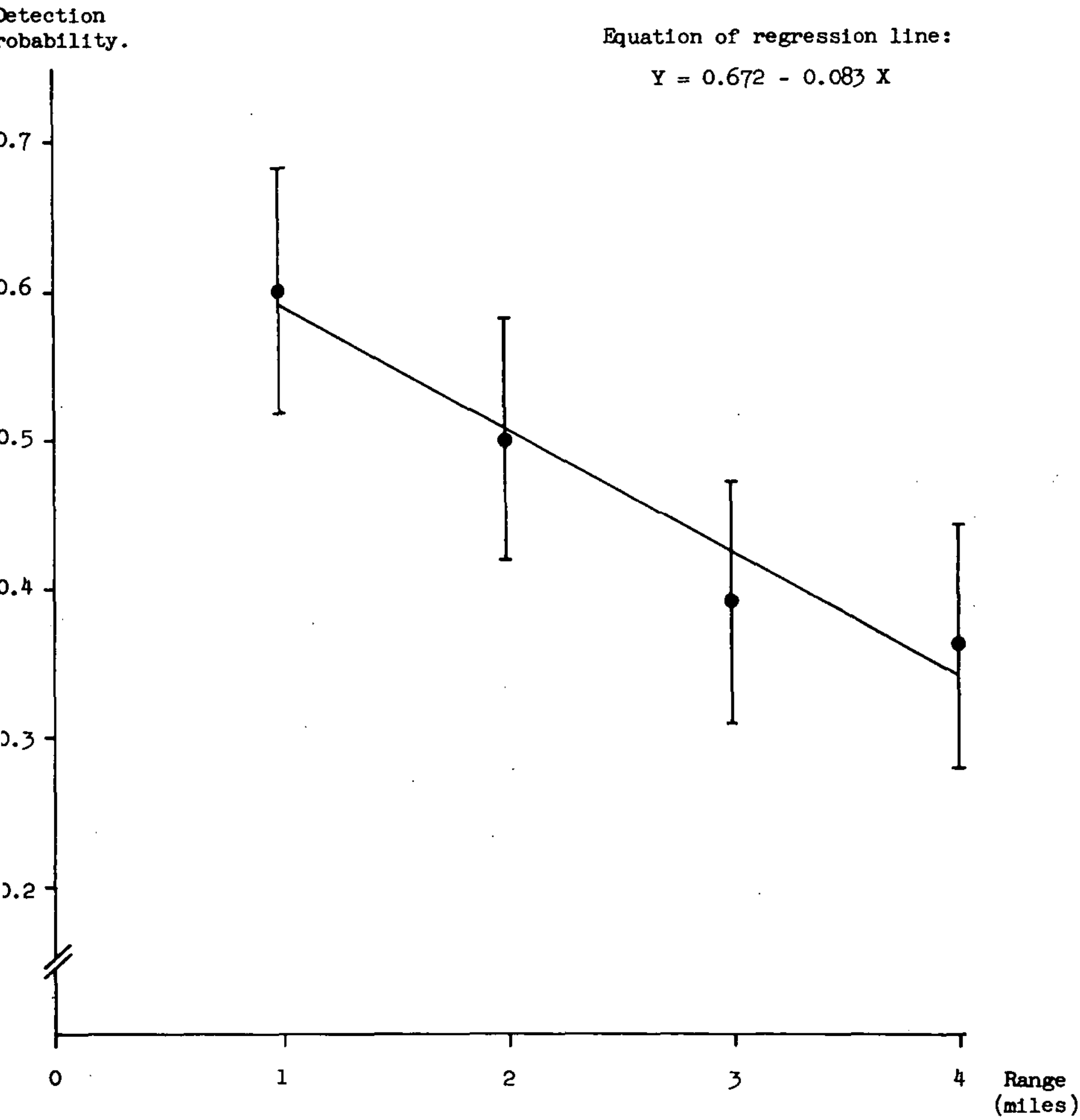
It can be seen from this analysis that the linear regression of detection probability on range is highly significant. Deviation about this linear regression is non-significant. These results are in good agreement with those found in previous experiments.

The mean detection probability values for unskilled subjects at each range, together with the associated 95% confidence limits are shown in Figure 7.1.2. The regression line relating detection probability to range is also shown.

Since the data obtained in previous experiments related to direct photographic presentation and those in this experiment to the television mode of presentation, it was of interest to compare the detection probability results obtained. The data obtained in Experiment I were most suitable for comparison purposes but they were restricted to seven targets and the regression line could only be calculated on the basis of three range values (1 - 3 miles). The corresponding data have been extracted from the raw data obtained in the present experiment and mean detection probabilities calculated for each range. These values are shown in Table 7.1.12, together with the corresponding data from Experiment I.

FIGURE 7.1.2

The effect of range on detection probability.



NOTE The regression line and detection probability values shown relate only to unskilled subjects.

TABLE 7.1.12

Mean detection probabilities at each range under conditions of photographic and television presentation

	Range (miles)			N	Overall mean
	1	2	3		
Photographic presentation	0.74	0.62	0.53	42	0.63
Television presentation	0.61	0.50	0.41	56	0.51
Differences	0.13*	0.12*	0.12*		0.12**

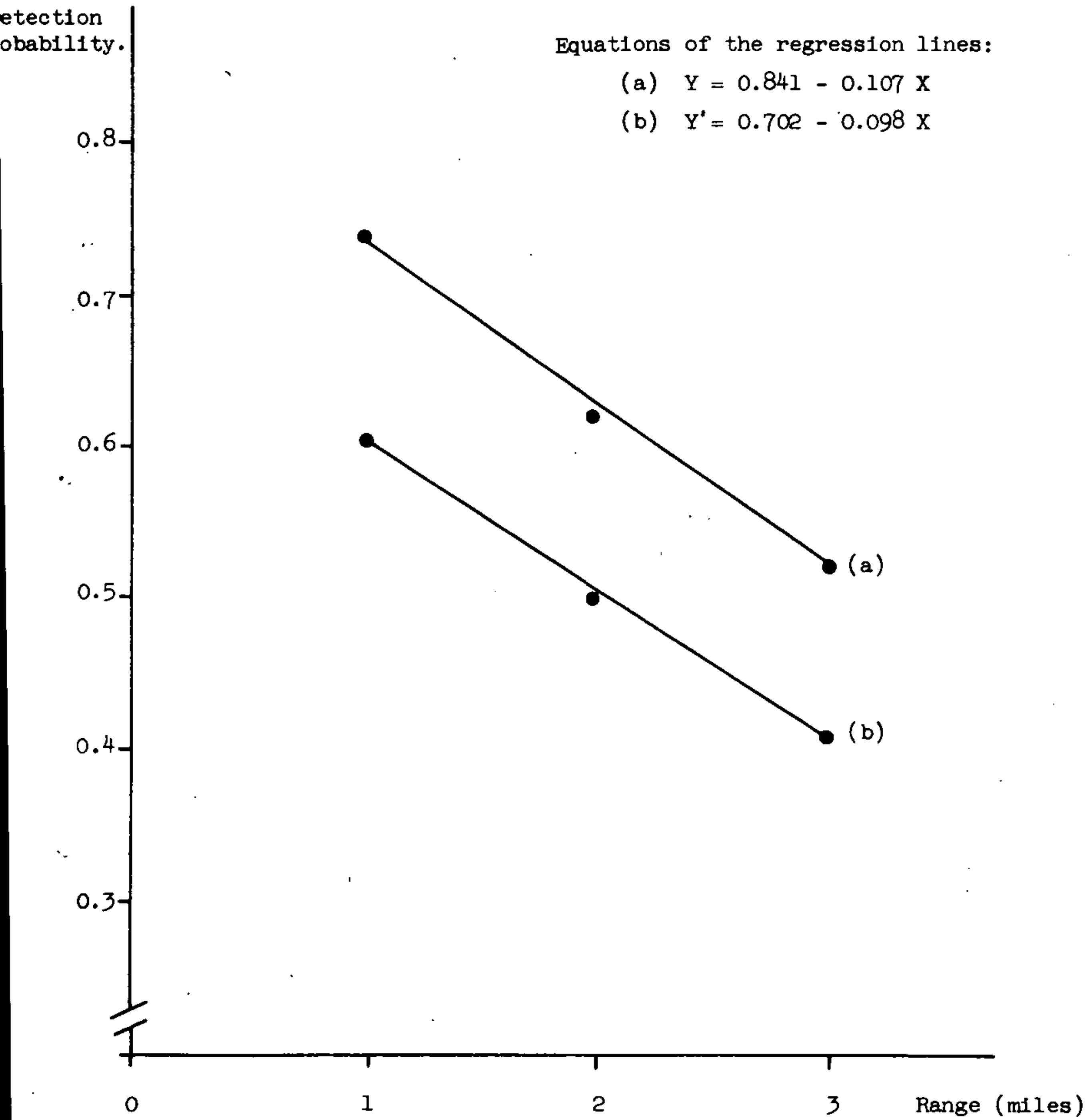
N = Number of readings on which each value is based.
* Significant at the 5% level, one-tail test.
** Significant at the 1% level, one-tail test.

It can be seen in Table 7.1.12 that, both overall and at each range, television presentation resulted in significantly lower detection probabilities than photographic presentation. The mean value of 0.51 relating to television presentation could be divided into two further values. The first, 0.56, related to high signal/noise ratios and was not significantly different from that for photographic presentation. The second, 0.45, related to low signal/noise ratios and was significantly lower than that for photographic presentation.

Figure 7.1.3 shows the mean detection probability values for each type of presentation and the corresponding regression lines. The values relating to television presentation have been averaged over all S/N ratios and the regression line, although based on data for only three ranges and seven targets, is similar to that shown in Figure 7.1.2 which relates to the complete set of data. It can be seen that television presentation results in detection probabilities approximately 0.12 lower than photographic presentation at each range. There is no significant difference between the gradients of the two regression lines and thus there is no evidence of an interaction between range and presentation mode.

FIGURE 7.1.3

A comparison of the effect of range on detection probability under conditions of (a) photographic display and (b) television display.



NOTE Both regression lines relate to unskilled subjects.

7.1.3 The effect of target differences on detection probability

Mean detection probabilities for each of the twelve targets are shown in Table 7.1.13, together with the rank order. These values relate only to unskilled subjects.

TABLE 7.1.13

Mean detection probabilities for targets

Target	Mean detection probability	Ranking
9	0.84	1
3	0.78	2
14	0.75	3
16	0.72	4
20	0.63	5
10	0.38	6½
15	0.38	6½
17	0.34	8
5	0.31	9
13	0.22	10
1	0.13	11
6	0.09	12

It can be seen that there is a wide variation between target detection probabilities, ranging from 0.84 for Target 9, an airfield, to 0.09 for Target 6, a small road/river bridge.

In the case of skilled subjects the mean detection probabilities for targets related only to the 14 and 24 dbs. S/N ratio levels. It was therefore not possible to make a direct comparison between these values and those shown in Table 7.1.13 for unskilled subjects which relate to all four S/N ratio levels. However, when appropriate values, i.e. those relating only to the 14 and 24 dbs. levels, were extracted from the raw data for unskilled subjects and compared with the target mean detection probabilities for skilled subjects, it was found that the differences between the two sets of values were non-significant for each of the twelve targets.

Furthermore, there was a high degree of correlation (Kendall's tau $= 0.71$, $p < 0.005$) between the target rankings for skilled subjects and the corresponding rankings for unskilled subjects. Thus it was clear that unskilled and skilled subjects did not differ significantly in their ability to detect individual targets.

For unskilled subjects target detection probabilities were further analysed by determining the differences between each pair of values shown in Table 7.1.13. These differences, together with the associated significance levels, are shown in Table 7.1.14. Examination of this table shows that the twelve targets can be conveniently divided into three groups. In general, although there is slight overlap, differences in detection probabilities within each group are non-significant but differences between groups are significant at the 5% or 1% levels, as shown diagrammatically in Figure 7.1.4.

TABLE 7.1.14

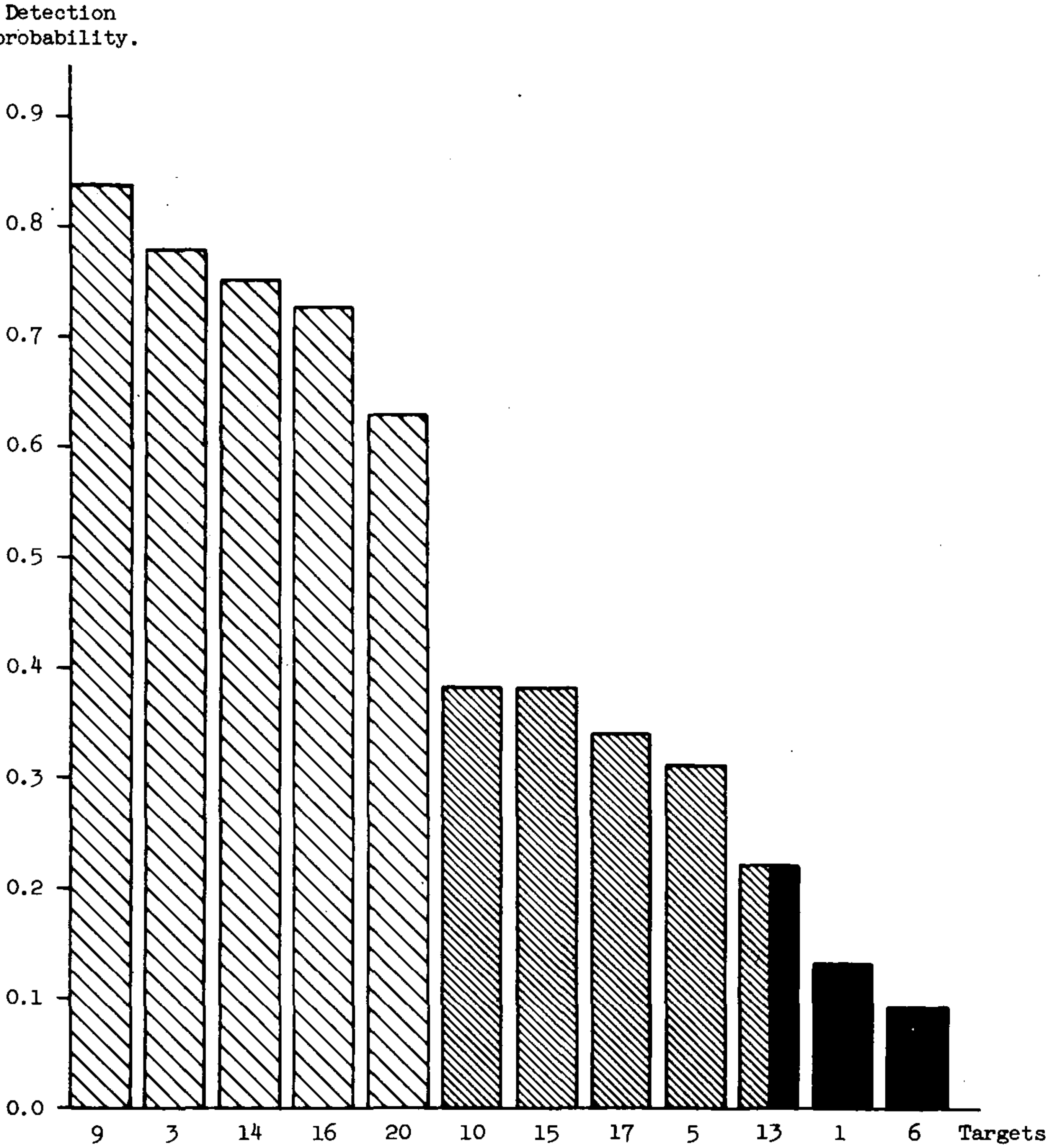
Differences between detection probability means for targets.

TARGETS	9	3	14	16	20	10	15	17	5	13	1	6
9		.06	.09	.12	$\underline{.21}$	$\underline{\underline{.46}}$	$\underline{\underline{.46}}$	$\underline{\underline{.50}}$	$\underline{\underline{.53}}$	$\underline{\underline{.62}}$	$\underline{\underline{.71}}$	$\underline{\underline{.75}}$
3			.03	.06	.15	$\underline{\underline{.40}}$	$\underline{\underline{.40}}$	$\underline{\underline{.44}}$	$\underline{\underline{.47}}$	$\underline{\underline{.56}}$	$\underline{\underline{.65}}$	$\underline{\underline{.69}}$
14				.03	.12	$\underline{\underline{.37}}$	$\underline{\underline{.37}}$	$\underline{\underline{.41}}$	$\underline{\underline{.44}}$	$\underline{\underline{.53}}$	$\underline{\underline{.62}}$	$\underline{\underline{.66}}$
16					.09	$\underline{\underline{.34}}$	$\underline{\underline{.34}}$	$\underline{\underline{.38}}$	$\underline{\underline{.41}}$	$\underline{\underline{.50}}$	$\underline{\underline{.59}}$	$\underline{\underline{.63}}$
20						$\underline{.25}$	$\underline{.25}$	$\underline{.29}$	$\underline{\underline{.32}}$	$\underline{\underline{.41}}$	$\underline{\underline{.50}}$	$\underline{\underline{.54}}$
10							.00	.04	.07	.16	$\underline{.25}$	$\underline{\underline{.29}}$
15								.04	.07	.16	$\underline{.25}$	$\underline{.29}$
17									.03	.12	$\underline{.21}$	$\underline{.25}$
5										.09	.18	$\underline{.22}$
13											.09	.13
1												.04
6												

Differences which are significant at the 5% level are indicated by single underlining and those significant at the 1% level by double underlining.

FIGURE 7.1.4

Mean detection probabilities for the twelve targets.



NOTE The different types of shading indicate statistically significant differences between the detection probabilities for the targets. A combination of shadings (Target 13) indicates that the target is not significantly different from those shaded with either of the single shadings.

To compare target detection probabilities found under conditions of photographic presentation in Experiment I with those found under television presentation in the present experiment it was necessary to extract the appropriate data, i.e. those relating to the original seven targets and three ranges (1 - 3 miles) from the raw data shown in Table 7.1.1. The two sets of values, those in Experiment I and those extracted from the present experiment, are shown in Table 7.1.15. All data relate to unskilled subjects.

TABLE 7.1.15

Target detection probabilities under conditions of photographic and television presentation

	TARGETS							Overall mean
	14	16	3	17	13	15	1	
Photographic presentation (Experiment I)	1.00	0.94	0.67	0.67	0.50	0.33	0.28	0.63
Television presentation	0.92	0.67	0.79	0.42	0.17	0.38	0.17	0.50
Differences	0.08	0.27*	-0.12	0.25*	0.33**	-0.05	0.11	0.13**

* Significant at 5% level ** Significant at 1% level

It can be seen in Table 7.1.15 that the difference between overall mean detection probabilities for photographic and television presentation is highly significant, the television display being associated with lower detection probabilities. However, only three individual targets are significantly affected. For the remaining four targets television presentation and photographic presentation do not give rise to significantly different detection probabilities. There is no obvious explanation as to why these three particular targets should be significantly affected and the others apparently not affected.

The analysis of variance on the detection probability data for unskilled subjects shows that variation arising from target differences accounts for a relatively large proportion of the total variation. This is reasonable in view of the wide differences between the twelve targets studied and particularly the differences in target size. This parameter was chosen as an appropriate basis for dividing targets into two groups, and thus partitioning the total variation due to targets. The first group consisted of the six small targets, e.g. bridges, small buildings, and the second group consisted of three large targets, e.g. an airfield, and three smaller targets which could be included in the large target group because they were adjacent to large conspicuous features, recognition of which greatly facilitated target detection, e.g. a station adjacent to a large pond. Full details of the two groups of targets are shown in Appendix III. As would be expected there is a close relationship between detection probability and target size and the six large targets were the first six in the detection probability rankings for unskilled subjects shown in Table 7.1.13.

Table 7.1.15 shows the total variation due to targets divided into three components:

(a) Variation between small targets and large targets, (i.e. that due to target size)

(b) Variation within small targets

(c) Variation within large targets

TABLE 7.1.16

Partition of target variation

Source	D.F.	S.S.	M.S.	V.R.	Significance
TARGETS*	11	25.05	2.28	15.20	$p < 0.001$
Target size	1	18.38	18.38	122.53	$p < 0.001$
Within small targets	5	2.21	0.44	2.93	$p < 0.025$
Within large targets	5	4.46	0.89	5.93	$p < 0.001$
RESIDUAL*	291	44.14	0.15		

* Values taken from analysis of variance shown in Table 7.1.3.

It can be seen in Table 7.1.16 that the variation arising from the highly significant effect due to target size accounts for a high proportion of the total variation due to targets. The remaining variation is due to variation within the six small targets and within the six large targets. These two values are both significant but they are not significantly different from each other, i.e. there is no evidence to suggest that the variation within small targets is different from that within large targets.

Since the difference between large and small targets accounts for such a high proportion of the total variation due to targets it was of interest to consider the effect of S/N ratio and range on small and large targets separately. These effects are considered in Sections 7.1.5 and 7.1.6 respectively.

7.1.4. S/N ratio x range interaction

The analysis of variance shown in Table 7.1.3 on the detection probability data for unskilled subjects indicates that there is no significant interaction between range and signal/noise ratio, i.e. that each signal/noise ratio condition is affected in a similar way by the range values tested. The partition of the total variation due to the N x R interaction into linear and deviation components is shown in Table 7.1.17.

TABLE 7.1.17

Regression analysis of N x R interaction

Source	D.F.	S.S.	M.S.	V.R.	Significance
N x R*	9	0.93	0.10	-	N.S.
Linear regression	1	0.54	0.54	3.60	($p < 0.10$)
Deviation	8	0.39	0.05	-	N.S.
RESIDUAL*	291	44.14	0.15		

* Values taken from analysis of variance shown in Table 7.1.3

It can be seen in this table that the linear regression component of the N x R interaction does not quite reach the 5% level of significance. However, since $p < 0.10$, there appears to be a tendency for the regression lines of detection probability on range to be non-parallel. This suggests that the different S/N ratios are differently affected by range. The deviation of the mean values about the regression lines is non-significant.

Since the variation due to difference between the two high S/N ratios (30 and 24 dbs) and the two low S/N ratios (19 and 14 dbs) accounted for almost the whole of the total variation due to S/N ratios (see Table 7.1.7) it was of interest to determine whether these two levels were differently affected by range. The mean detection probabilities for unskilled subjects at each range under conditions of high and low S/N ratio are shown in Table 7.1.18.

TABLE 7.1.18

Mean detection probabilities for ranges under conditions of high and low S/N ratio

	Range (miles)				Number of readings on which each value is based
	1	2	3	4	
High S/N ratios (30 & 24 dbs)	0.69	0.56	0.46	0.48	48
Low S/N ratios (19 & 14 dbs)	0.52	0.44	0.31	0.25	48
Differences	0.17*	0.12	0.15*	0.23**	

* Significant at 5% level, one-tail test.
** Significant at 1% level, one-tail test.

The differences between detection probabilities under the high and low S/N ratio levels were significant at each range except for 2 miles which just failed to reach the 5% level.

To determine whether there was any interaction between high and low S/N ratios and range the N x R variation was partitioned into three components as shown in Table 7.1.19.

TABLE 7.1.19

Partition of N x R interaction

Source	D.F.	S.S.	M.S.	V.R.	Significance
N x R*	9	0.93	0.10	-	N.S.
R x (between high and low S/N ratios)	3	0.15	0.05	-	N.S.
N x R (within low S/N ratios)	3	0.64	0.21	1.40	N.S.
N x R (within high S/N ratios)	3	0.14	0.05	-	N.S.
RESIDUAL*	291	44.14	0.15		

* Values taken from analysis of variance shown in Table 7.1.3

All three components were found to be non-significant indicating that there was no interaction between S/N ratio and range, either within low S/N levels or within high S/N levels, and also that there was no interaction between high and low S/N levels and range. Further analysis showed that the linear regression component of this last factor was also non-significant. It was clear therefore that there was no difference between the effect of range on detection performance under conditions of high S/N ratio and low S/N ratio. Thus the two regression lines shown in Figure 7.1.5, which illustrates graphically the data given in Table 7.1.18, do not deviate significantly from parallel. These two regression lines were calculated separately for the two sets of means in Table 7.1.18. The linear regression and deviation components of the range variation in each case are shown in Table 7.1.20.

TABLE 7.1.20

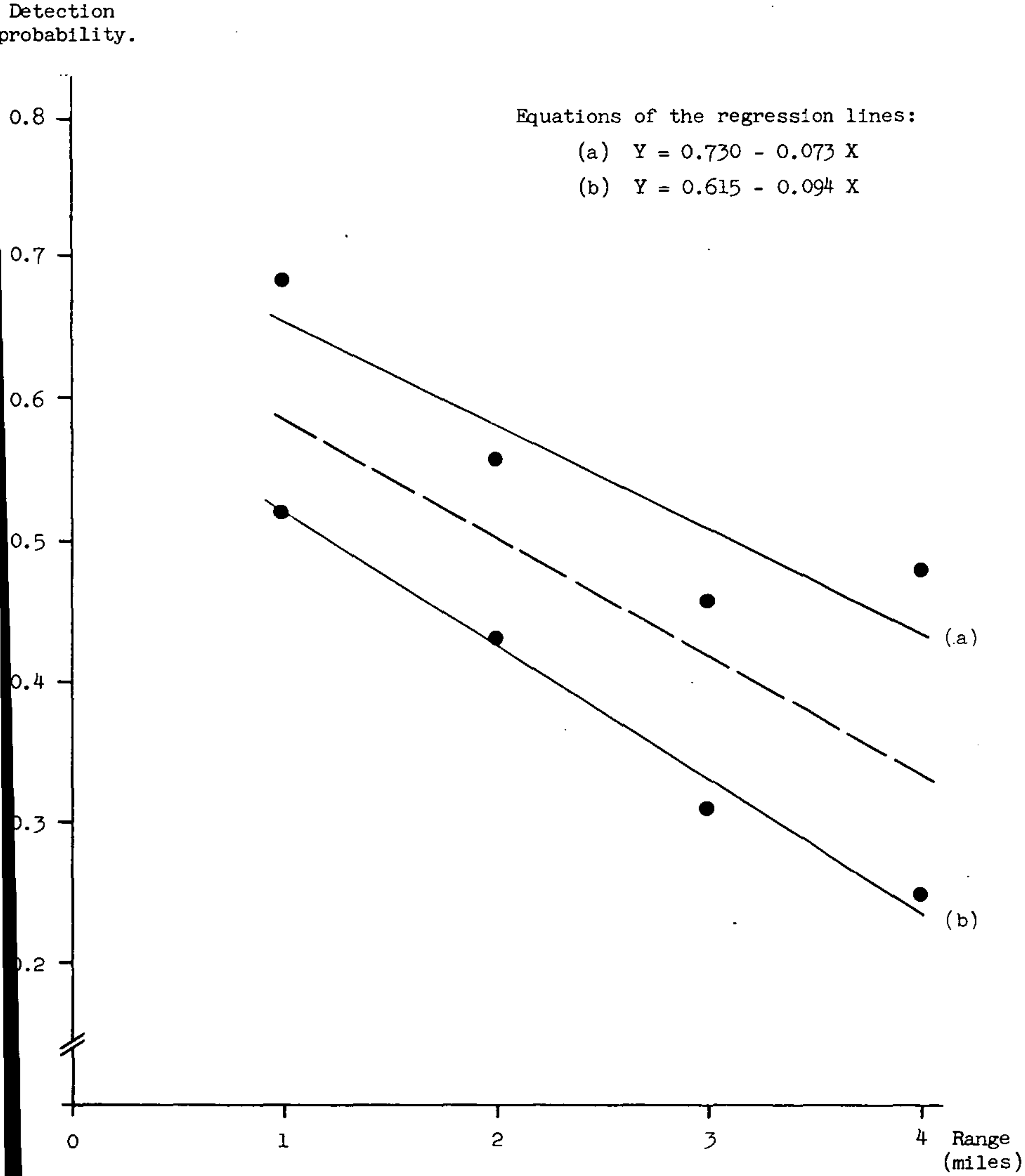
Linear regression and deviation components of range variation under conditions of high and low S/N ratio.

Source	D.F.	S.S.	M.S.	V.R.	Significance
Range (within low S/N ratios)	3	2.14	0.71	4.73	$p < 0.01$
Linear regression	1	2.11	2.11	14.07	$p < 0.001$
Deviation	2	0.03	0.02	-	N.S.
Range (within high S/N ratios)	3	1.56	0.52	3.47	$p < 0.05$
Linear regression	1	1.28	1.28	8.53	$p < 0.01$
Deviation	2	0.28	0.14	-	N.S.
RESIDUAL*	291	44.14	0.15		

* This value has been taken from the analysis of variance on the complete data shown in Table 7.1.3. The residual mean square values from the two separate analyses (high S/N levels and low S/N levels) were not significantly different and therefore it was appropriate to use the overall value shown.

FIGURE 7.1.5

The effect of range on detection probability for (a) high S/N ratios and (b) low S/N ratios.



NOTE The broken line is the regression line relating to all S/N ratios. The 95% confidence limits of the mean values shown are ± 0.11

For both high S/N and low S/N conditions the linear regression component is highly significant and the deviation component is non-significant. However, the deviation component is considerably larger for the high S/N ratios than for the low S/N ratios, i.e. there is greater deviation of the mean values about the regression line for high S/N ratios as can be seen in Figure 7.1.5.

Thus the overall conclusions that can be derived from the data given in Table 7.1.18 and Figure 7.1.5 are that:

(a) Detection probability decreases linearly with increasing range under both high and low S/N conditions.

(b) The two regression lines for detection probability on range under high and low S/N conditions, are not significantly different in gradient.

(c) Detection probabilities are significantly lower at each range (except 2 miles) under conditions of low S/N than under conditions of high S/N, the mean decrement being 0.17.

7.1.5 S/N ratio x targets interaction

The interaction between S/N ratio and targets is not significant in the analysis of variance shown in Table 7.1.3, i.e. individual targets are not differently affected by the S/N ratios. The partition of the total variation due to the N x T interaction into linear regression and deviation components is shown in Table 7.1.21.

TABLE 7.1.21

Regression analysis of N x T interaction

Source	D.F.	S.S.	M.S.	V.R.	Significance
N x T*	33	5.51	0.17	1.13	N.S.
Linear regression	1	1.17	1.17	7.80	$p < 0.01$
Deviation	32	4.34	0.14	-	N.S.
RESIDUAL*	291	44.14	0.15		

* Values taken from analysis of variance shown in Table 7.1.3

It can be seen that the linear regression component is highly significant. This indicates that the regression lines of detection on S/N ratio for each of the twelve targets are significantly non-parallel, i.e. that there is a significant interaction between the twelve regression lines. The deviation of the mean values about these lines is non-significant.

The twelve targets could, as described in Section 7.1.3, be divided into two groups, large targets (6) and small targets (6). The difference between these groups accounted for a high proportion of the total variation due to targets (see Table 7.1.16). Table 7.1.22 shows the mean detection probability values for small and large targets under each condition of S/N ratio, i.e. the twelve mean values for each S/N ratio, which relate to the overall N x T interaction, have been reduced to two values for each S/N ratio, representing means for the six large targets and the six small targets.

TABLE 7.1.22

Mean detection probabilities for small and large targets at each S/N ratio

	S/N ratio (dbs)				Number of readings on which each value is based
	14	19	24	30	
Large targets (6)	0.61	0.59	0.81	0.73	48
Small targets (6)	0.15	0.19	0.27	0.37	48
Differences	0.46**	0.40**	0.54**	0.36**	

** Significant at 1% level, two-tail test.

It can be seen that differences between the mean detection probabilities for large and small targets are highly significant at each S/N ratio level. To determine whether there was any interaction between S/N ratio and target size the total variation due to the overall N x T interaction was partitioned into three components as shown in Table 7.1.23.

TABLE 7.1.23

Partition of N x T interaction

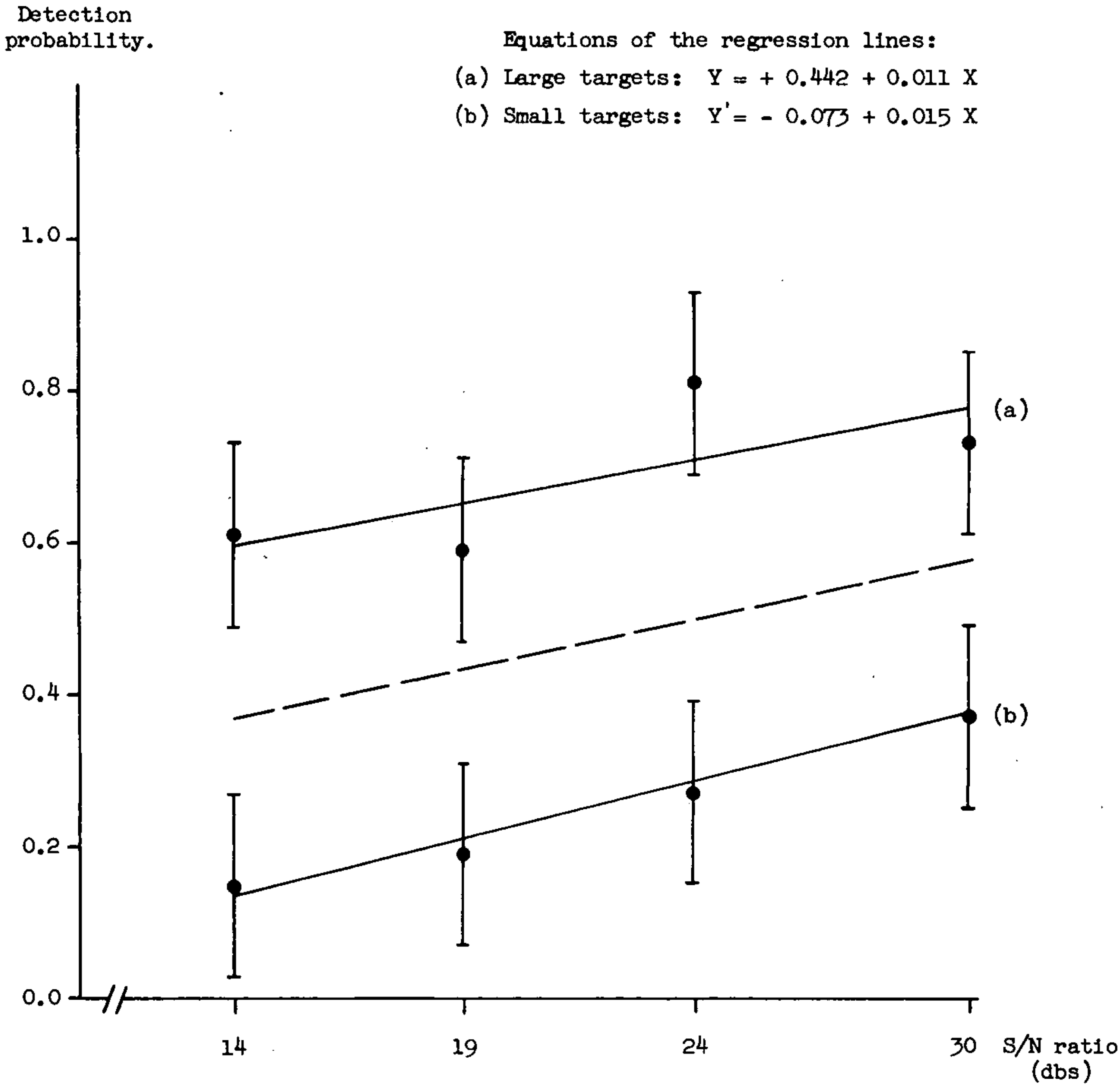
Source	D.F.	S.S.	M.S.	V.R.	Significance
N x T*	33	5.51	0.17	1.13	N.S.
N x Target Size	3	0.48	0.16	1.07	N.S.
N x T (within small targets)	15	1.68	0.11	-	N.S.
N x T (within large targets)	15	3.35	0.22	1.47	N.S.
RESIDUAL*	291	44.14	0.15		

* Values taken from analysis of variance shown in Table 7.1.3.

All three components of the N x T interaction were found to be non-significant indicating that there was no interaction between S/N ratios and targets within either the small target or the large target groups and also that there was no interaction between S/N ratio and target size, i.e. no N x ' between small and large targets ' interaction. Further analysis showed that the linear regression component of this factor was also non-significant indicating that there was no difference between the effects of decreasing S/N ratio on large targets and on small targets. Thus, the two regression lines shown in Figure 7.1.6, which illustrates graphically the data given in Table 7.1.22, do not deviate significantly from parallel. These two regression lines were determined by calculating the total variation due to ranges separately for the two sets of data relating to large and small targets. The sums of squares due to linear regression and the equations to the regression lines could then be determined. The linear regression and deviation components of the S/N ratio variation in each case are shown in Table 7.1.24.

FIGURE 7.1.6

The effect of signal/noise ratio on detection probabilities for large and small targets.



NOTE The broken line is the regression line relating to all targets.

TABLE 7.1.24

Linear regression and deviation components of the S/N ratio variation for small and large targets

Source	D.F.	S.S.	M.S.	V.R.	Significance
S/N ratio (within small targets)	3	1.48	0.49	3.29	$p < 0.025$
Linear regression	1	1.45	1.45	9.67	$p < 0.005$
Deviation	2	0.03	0.02	-	N.S.
S/N ratio (within large targets)	3	1.68	0.56	3.73	$p < 0.025$
Linear regression	1	0.82	0.82	5.47	$p < 0.025$
Deviation	2	0.86	0.43	2.87	N.S.
RESIDUAL*	291	44.14	0.15		

* This value has been taken from the analysis of variance on the complete data shown in Table 7.1.3. The residual mean square values from the two separate analyses (large targets and small targets) were not significantly different and therefore it was appropriate to use the overall value shown.

For both large and small targets it can be seen that detection performance is significantly affected by S/N ratio. In each case the linear regression component is significant and the deviation component is non-significant, i.e. for both large and small targets the relationship between detection probability and S/N ratio is a linear one and the deviation of the mean values about the regression lines is not significant. However, as can be seen in Table 7.1.24 and graphically in Figure 7.1.6, this deviation is relatively much greater for large targets than for small targets.

The overall conclusions which can be drawn from this analysis of the effect of S/N ratios on small and large targets are:

(a) Detection probability increases linearly with increasing S/N ratio for both small targets and large targets

(b) The regression lines of detection probability on S/N ratio for large targets and for small targets do not differ significantly in gradient, i.e. there is no evidence of an interaction between S/N ratio and target size.

(c) Detection probabilities are significantly lower for small targets than for large targets at each level of S/N ratio investigated.

7.1.6 Ranges x targets interaction

The analysis of variance on the detection probability data for unskilled subjects given in Table 7.1.3 shows that there is a significant interaction between ranges and targets, i.e. that individual targets are differently affected by the range conditions. This interaction can be divided into a linear regression component and a deviation component as shown in Table 7.1.25.

TABLE 7.1.25

Regression analysis of R x T interaction

Source	D.F.	S.S.	M.S.	V.R.	Significance
R x T*	33	13.63	0.41	2.73	$p < 0.001$
Linear regression	1	4.63	4.63	30.86	$p < 0.001$
Deviation	32	9.00	0.28	1.87	$p < 0.01$
RESIDUAL*	291	44.14	0.15		

* Values taken from analysis of variance shown in Table 7.1.3.

This analysis shows that the interaction between ranges and targets has a highly significant linear component, i.e. that the regression lines of detection probability on range for the twelve targets individually are non-parallel. This indicates that the targets are differently affected by increasing range. However, the deviation component of the R x T interaction is also significant. Therefore the deviation of the mean values about the corresponding regression lines must also be taken into account. Thus the analysis of this interaction reveals a somewhat confused situation.

However, the picture can be greatly clarified if the targets are considered in two groups, large targets and small targets, rather than individually. Table 7.1.26 shows the mean detection probabilities at each range for large targets and small targets.

TABLE 7.1.26

Mean detection probabilities for large and small targets at each range

	Range (miles)				N
	1	2	3	4	
Large targets	0.87	0.75	0.58	0.52	48
Small targets	0.33	0.25	0.19	0.20	48
Differences	0.54**	0.50**	0.39**	0.32**	

N = Number of readings on which each value is based.
** Significant at 1% level, two-tail test.

Differences between the mean detection probabilities for large and small targets were highly significant at each range. However there appears to be a tendency for this difference to decrease with increasing range, i.e. there appears to be some interaction between target size and range. This was confirmed by further analysis of the R x T interaction. The total variation due to this interaction was partitioned into three components as shown in Table 7.1.27.

TABLE 7.1.27

Partition of R x T interaction

Source	D.F.	S.S.	M.S.	V.R.	Significance
R x T*	33	13.63	0.41	2.73	$p < 0.001$
R x Target size	3	0.77	0.26	1.73	N.S.
R x T (within small targets)	15	6.30	0.42	2.80	$p < 0.001$
R x T (within large targets)	15	6.56	0.44	2.93	$p < 0.001$
RESIDUAL*	291	44.14	0.15		

* Values taken from analysis of variance shown in Table 7.1.3.

It can be seen in this table that the R x T interaction is significant within both small targets and large targets, i.e. within each group different targets are differently affected by range. The interaction between range and target size does not reach the 5% level. However, when this interaction is partitioned into a linear regression and a deviation component, as shown in Table 7.1.28, it was found that the linear regression component was significant and the deviation component was not significant.

TABLE 7.1.28

Regression analysis of R x Target size interaction

Source	D.F.	S.S.	M.S.	V.R.	Significance
R x Target size	3	0.77	0.26	1.73	N.S.
Linear regression	1	0.75	0.75	5.00	$p < 0.05$
Deviation	2	0.02	0.01	-	N.S.
RESIDUAL*	291	44.14	0.15		

* Value taken from analysis of variance shown in Table 7.1.3.

The significance of the linear regression component of the R x Target size interaction indicates that large and small targets are differently affected by increasing range. It can be seen in Figure 7.1.7 which shows graphically the data given in Table 7.1.26 that the regression lines of detection probability on range for large and small targets are not parallel. The significance of the linear regression component of the R x Target size interaction indicates that the gradients of the two regression lines are significantly different. The two lines tend to converge towards longer ranges, i.e. as range increases the difference between large and small targets becomes less marked. The equations to the regression lines were obtained by determining the variation due to linear regression of detection probability on range for large and small targets separately as shown in Table 7.1.29.

TABLE 7.1.29

Linear regression and deviation components of the range variation for small and large targets

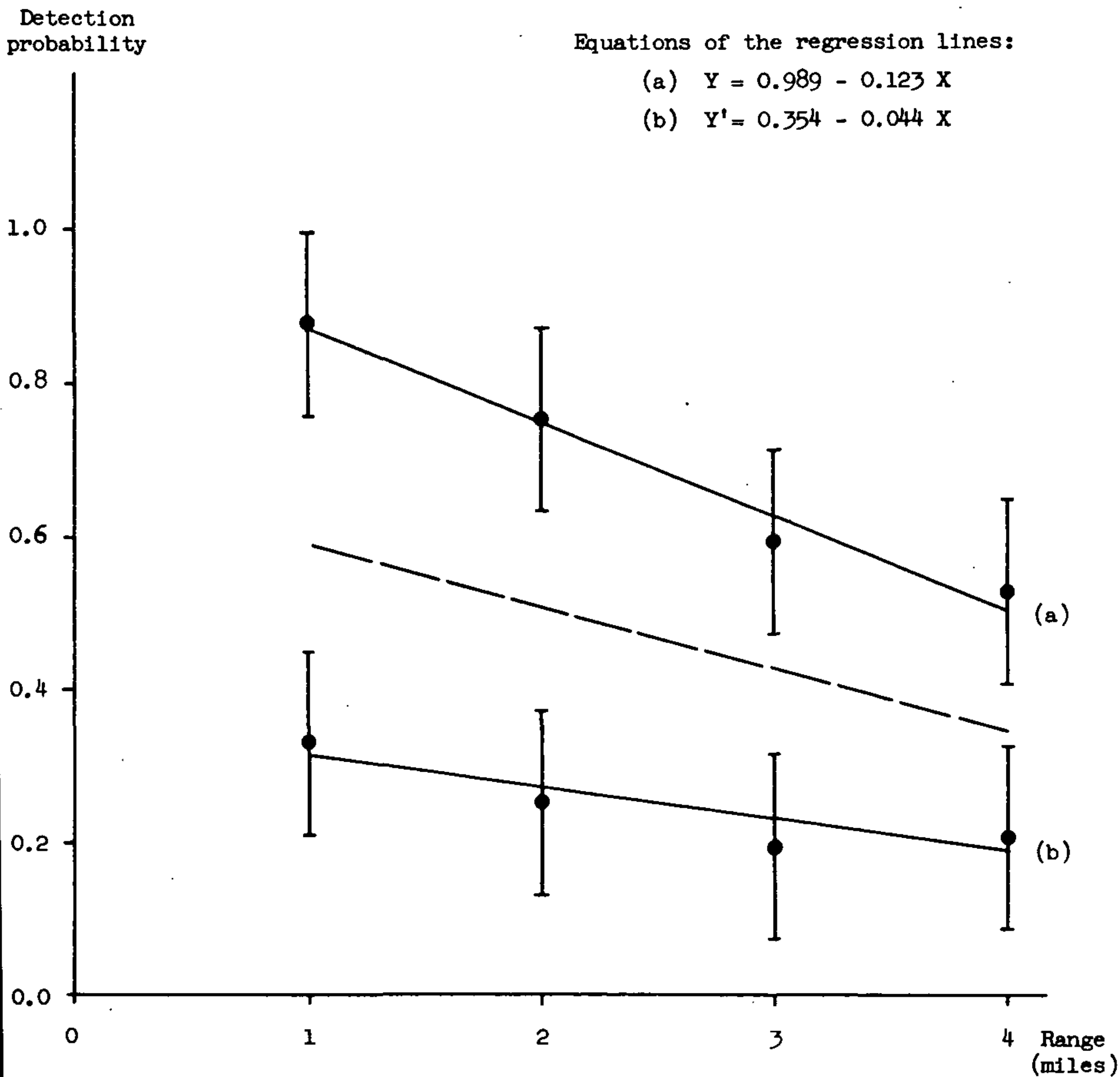
Source	D.F.	S.S.	M.S.	V.R.	Significance
Range (within small targets)	3	0.60	0.20	1.33	N.S.
Linear regression	1	0.46	0.46	3.07	$p < 0.10$
Deviation	2	0.14	0.07	-	N.S.
Range (within large targets)	3	3.72	1.24	8.27	$p < 0.001$
Linear regression	1	3.62	3.62	24.14	$p < 0.001$
Deviation	2	0.10	0.05	-	N.S.
RESIDUAL*	99	44.14	0.15		

* This value has been taken from the analysis of variance on the complete data shown in Table 7.1.3. The residual mean square values from the two separate analyses (large targets and small targets) were not significantly different and therefore it was appropriate to use the overall value shown.

It can be seen from this table that the range effect for small targets is relatively slight and the linear regression component for this factor fails to reach the 5% significance level. This is illustrated by the low gradient of the regression line for small targets shown in Figure 7.1.7. Furthermore, the deviation of the mean values about this line, although non-significant, is relatively greater than for the large targets. For large targets the range effect and the corresponding linear regression component are highly significant and the deviation component is extremely small.

FIGURE 7.1.7

The effect of range on detection probability for (a) large targets and (b) small targets.



NOTE The broken line is the regression line relating to all targets.

The overall conclusions which can be drawn from this analysis of the effect of range on detection probability for small and large targets are:

(a) Detection probability decreases linearly with increasing range for large targets and for small targets although for the latter this effect does not quite reach the 5% significance level.

(b) The regression lines of detection probability on range for large targets and for small targets have significantly different gradients and tend to converge towards longer ranges.

(c) Detection probabilities are significantly lower for small targets than for large targets at each range.

7.1.7 S/N ratios x ranges x targets interaction

The variation due to triple interaction between ranges, S/N ratios and targets is not significant in the analysis of variance on the data for unskilled subjects shown in Table 7.1.3. However, when this variation is partitioned into linear regression and deviation components the linear component is highly significant as shown in Table 7.1.30.

TABLE 7.1.30

Regression analysis of N x R x T interaction

Source	D.F.	S.S.	M.S.	V.R.	Significance
N x R x T	99	16.14	0.16	1.07	N.S.
Linear regression	1	5.25	5.25	35.00	$p < 0.001$
Deviation	98	10.89	0.11	--	N.S.
RESIDUAL	291	44.14	0.15		

The significance of the linear regression component indicates that the effect of range on detection probability is different for different combinations of target and S/N ratio, i.e. that the regression lines of detection probability on range plotted separately for each target and S/N ratio (48 lines altogether) are significantly non-parallel. However, the deviation of the mean values about the corresponding regression line is non-significant.

This complex interaction was simplified in the same way as the other interactions, i.e. targets were divided into large and small target groups rather than treated individually, and the four S/N ratios were reduced to two levels, high and low. The mean detection probabilities under each of the 16 resultant conditions are shown in Table 7.1.31.

TABLE 7.1.31

Mean detection probabilities at each range for small and large targets under high and low S/N conditions

	Range (miles)				N	Overall mean
	1	2	3	4		
Small targets						
High S/N ratio	0.46	0.29	0.21	0.33	24	0.32
Low S/N ratio	0.21	0.21	0.17	0.08	24	0.17
Large targets						
High S/N ratio	0.92	0.83	0.71	0.63	24	0.77
Low S/N ratio	0.83	0.67	0.46	0.42	24	0.60

N = Number of readings on which each value is based

In Table 7.1.31 differences between the mean values given must reach 0.19 to be significant at the 5% level and 0.27 to be significant at the 1% level. It can be seen that, in general, the differences between values relating to small targets and the corresponding ones relating to large targets are highly significant at each range. Differences between values relating to high S/N and low S/N only reach the 5% level of significance for ranges 1 and 4 miles for small targets, and ranges 3 and 4 miles for large targets. However, the differences between the four overall mean values shown, each of which are based on 96 readings, are all highly significant.

The total variation due to the R x N x T interaction could be divided into ten main components relating to the various interactions of range within and between large and small targets, and within and between high and low S/N ratios. However, only one of these components, that relating to the interaction between range, large and small targets, and high and low S/N ratios, is of importance. The variation due to this interaction is shown in Table 7.1.32.

TABLE 7.1.32

Partition of N x R x T interaction

Source	D.F.	S.S.	M.S.	V.R.	Significance
N x R x T*	99	16.14	0.16	-	N.S.
N (between high and low) x R x T (between large and small)	3	0.47	0.16	-	N.S.
Other components	96	15.67	0.16	-	N.S.
RESIDUAL*	291	44.14	0.15		

* Values taken from analysis of variance shown in Table 7.1.3

It can be seen that R x N (between high and low) x T (between small and large) interaction is non-significant, as is the overall effect of the remaining nine components. Further analysis showed that the linear regression component of the interaction was also non-significant. This indicates that the four regression lines shown in Figure 7.1.8 do not deviate significantly from parallel, i.e. that large and small targets, under high and low S/N ratio conditions, are affected in the same way by range.

Separate analyses were carried out on the data for each of these four conditions to determine the significance of the linear regression and deviation components of the range variation. The results of these analyses are shown in Table 7.1.33.

FIGURE 7.1.8

The effect of range on detection probability for large and small targets under conditions of high and low S/N ratio.

Equations of the regression lines:

Large targets

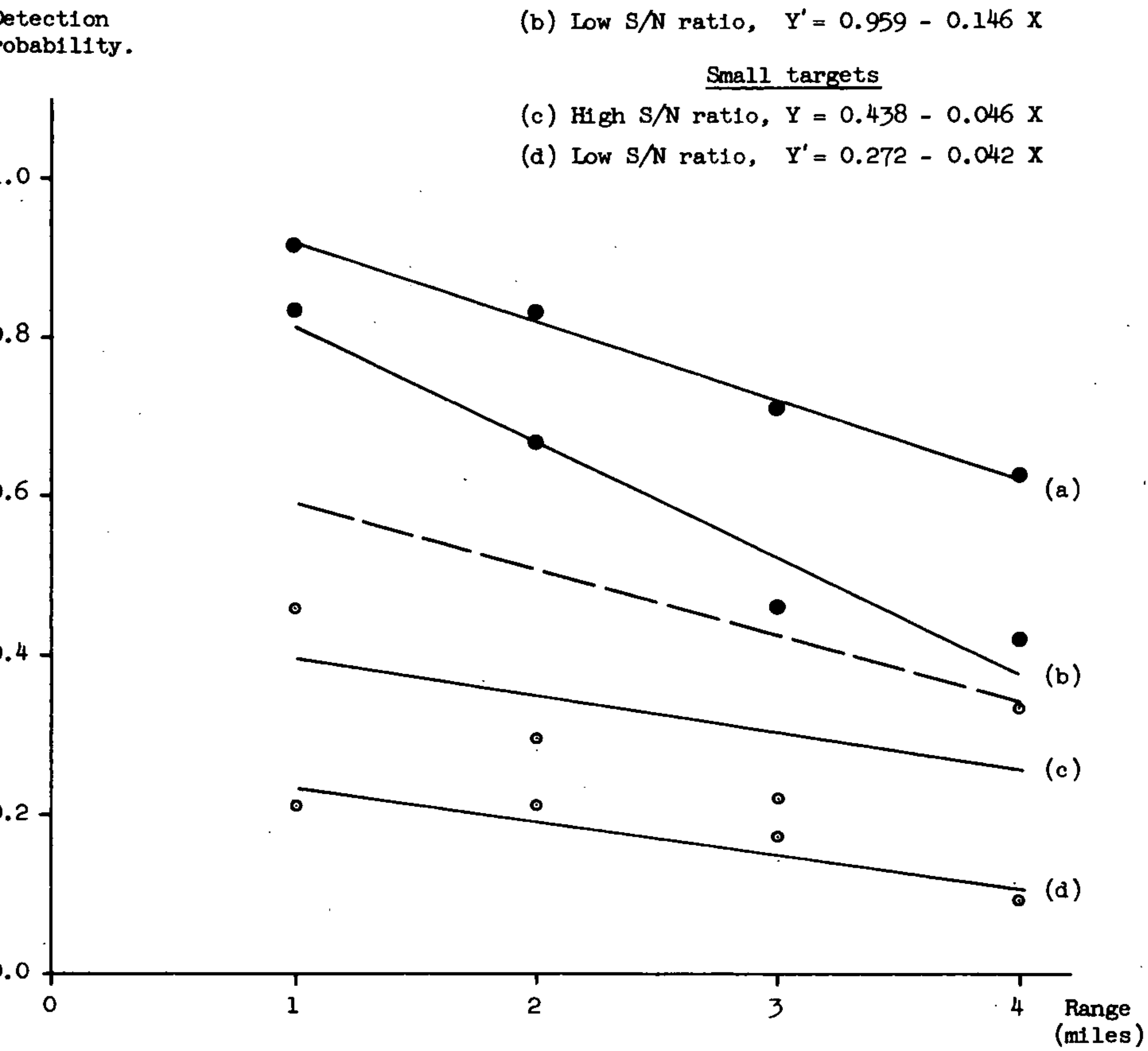
(a) High S/N ratio, $Y = 1.021 - 0.100\,X$

(b) Low S/N ratio, $Y' = 0.959 - 0.146\,X$

Small targets

(c) High S/N ratio, $Y = 0.438 - 0.046\,X$

(d) Low S/N ratio, $Y' = 0.272 - 0.042\,X$



NOTE The confidence limits of the mean values shown are ±0.16. Values shown ● are those for large targets and those shown ⊙ are for small targets.

The broken line is the regression line relating to all targets and S/N ratio conditions.

TABLE 7.1.33

Regression analysis on the range variation for small and large targets under conditions of high and low S/N ratio

Conditions	Source	D.F.	S.S.	M.S.	V.R.	Significance
Large targets High S/N ratio	Ranges	3	1.21	0.40	2.67	$p<0.05$
	Linear regression	1	1.20	1.20	8.00	$p<0.005$
	Deviation	2	0.01	0.01	-	N.S.
Large targets Low S/N ratio	Ranges	3	2.70	0.90	6.00	$p<0.001$
	Linear regression	1	2.27	2.27	15.13	$p<0.001$
	Deviation	2	0.43	0.22	1.47	N.S.
Small targets High S/N ratio	Ranges	3	0.78	0.26	1.73	N.S.
	Linear regression	1	0.25	0.25	1.67	N.S.
	Deviation	2	0.53	0.27	1.77	N.S.
Small targets Low S/N ratio	Ranges	3	0.25	0.08	-	N.S.
	Linear regression	1	0.21	0.21	1.40	N.S.
	Deviation	2	0.04	0.04	-	N.S.
	RESIDUAL*	291	44.14	0.15		

* Value taken from analysis of variance shown in Table 7.1.3, i.e. the variance ratios have been calculated relative to the overall residual variance for the complete data.

It can be seen from this table that for large targets under both high and low S/N ratio conditions there is significant linear regression of detection probability on range, i.e. regression lines (a) and (b) in Figure 7.1.8 have significant gradients. Furthermore, the deviation of the mean values about these regression lines is non-significant. For small targets the linear regression due to range is non-significant under conditions of both high and low S/N ratio, i.e. regression lines (c) and (d) both have non-significant gradients.

This result appears to be slightly anomalous since there is no evidence that the gradients of the four regression lines are significantly different. However, it can be seen in Figure 7.1.8 that regression lines (c) and (d) show a tendency for detection probability to decrease with increasing range, as would be expected. The fact that this effect does not reach the 5% significance level is most likely to be due to the subdivision of the original data into four parts. This results in each value being based on only one quarter as many readings with consequent reduction in significance levels. Had more readings been available the linear regression components would almost certainly have been significant (c.f. line (b) in Figure 7.1.7 which has a very similar gradient but is based on twice as many readings and only just fails to reach the 5% significance level. This line can be regarded as the mean of lines (c) and (d) in Figure 7.1.8). In each case the deviation components shown in Table 7.1.33 are non-significant, i.e. there is no evidence of a non-linear relationship between detection probability and range. The deviation of the mean values about line (c) is however relatively large as can be seen in Table 7.1.33 and Figure 7.1.8.

Since the gradient of line (b) in Figure 7.1.8 appeared to be slightly steeper than those for the other three lines a further analysis was carried out to determine whether, within the large target group, there was a significant interaction between range and high and low S/N ratios, which was not apparent in the overall data. However, this interaction did not reach significance when tested against the overall residual variation. As shown in Table 7.1.31, for large targets the difference in detection probabilities for high and low S/N ratios is non-significant at the 1 and 2 miles ranges, but significant at the 3 and 4 miles ranges. This indicates that there is some divergence between the lines. For small targets the regression lines were almost exactly parallel and there was no interaction between range and high and low S/N ratios.

The overall conclusions that can be drawn from this analysis of the triple interaction between high and low S/N ratios, ranges and large and small targets are that:

(a) There is no evidence that the four regression lines shown in Figure 7.1.8 differ significantly in gradient. There is also no evidence that, when considered separately, either the upper pair of lines, relating to large targets under high and low S/N ratios, or the lower pairs of lines, relating to small targets under high and low S/N ratios, deviate significantly from parallel.

(b) Detection probability decreases linearly with range for all four conditions although for small targets under both high and low S/N conditions the effect does not reach the 5% significance level.

(c) Detection probabilities associated with large targets are significantly higher at each range than the corresponding ones relating to small targets. Differences between detection probabilities at each range for high and low S/N ratios tend to be smaller and are not always significant. In particular, the difference is not significant for large targets at ranges 1 and 2 miles.

(d) Since this analysis involved dividing the data into four parts significance levels tend to be lower because of the small number of readings involved in each mean.

7.1.8 Logit analysis

The raw data on detection probabilities shown in Table 7.1.1 and 7.1.2 were not altogether suited to the conventional analysis of variance techniques used since there were only two responses in each cell and each response could only take one of two values, 0 or 1. As in previous experiments the results obtained from the conventional techniques were compared with those found from a more sophisticated technique, Logit analysis.

The model used in this method is 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 results of this analysis were in close agreement with those determined by the conventional techniques. The Logit analysis showed that the linear effects of S/N ratios and ranges were highly significant. It also showed that the quadratic components of these effects were non-significant, as was found by conventional techniques. However, a chi-square test, based on the observed and expected frequencies in each cell, suggested that there was some lack of goodness of fit of the model which could possibly have been improved by the introduction of a cubic effect of S/N ratio.

Differences between targets were also found to be highly significant in the Logit analysis. There was however a slight discrepancy between the two methods of analysis in that the Logit analysis indicated that even the largest gap between the ranked responses (that between Target 20 and Targets 15 and 10) was not significant whereas the conventional analysis indicated that this difference was significant at the 5% level.

Thus on the basis of the Logit analysis it was not possible to divide the targets clearly into groups although there were highly significant differences between the group of targets with the highest detection probabilities and those with the lowest. This discrepancy could have arisen from the fact that the Logit analysis was based on 192 cell totals relating to the number of correct detections out of 2, the maximum possible in each cell, whereas the conventional analyses of variance took account of variation between the individual cell readings.

In general the results obtained from the two methods of analysis agreed very closely, as was found in previous experiments. The Logit 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.

7.2 Search times

In this experiment the search time was taken to be the time required, in seconds, for the subject to view the television display before making a response indicating that he had located the target, whether correctly or incorrectly. Since a static method of simulation was used, these search times are not directly applicable to the airborne situation. However, analysis of the times is of interest in indicating the time required to locate the target under the different conditions studied.

Tables 7.2.1 and 7.2.2 show the search time data for unskilled and skilled subjects respectively. Analyses of variance were carried out on each of these sets of data and the results are shown in Table 7.2.3 and Table 7.2.4 respectively. It can be seen in Table 7.2.3 that for unskilled subjects target differences have a highly significant effect on search times but that the other main factors, signal/noise ratios and ranges, are non-significant. However, it should be noted that the range effect only just fails to reach the 5% level. Only one of the interactions, ranges x targets, is significant. This indicates that the twelve targets are differently affected by the range conditions.

For skilled subjects none of the main factors or the interactions are significant. This result is most likely to be due to the relatively small number of skilled subjects. For both groups of subjects the results of these analyses are closely similar to those found in Experiment I, (see Appendix I).

In the following sections each of the main effects is considered in greater detail and the significant interaction between ranges and targets is also further analysed. The remaining interactions (N x R, N x T and N x R x T) have not been analysed in detail as they are non-significant and, since the main effect due to S/N ratios is also non-significant, the partitioning of these interactions was not thought to be worthwhile.

TABLE 7.2.1

Search times for unskilled subjects.

Range (miles)	S/N ratio (dbs)	TARGETS 3	14	17	16	15	13	1	20	10	6	5	9
1	14	8.4 <u>12.4</u>	1.2 3.0	<u>7.2</u> 11.4	12.8 <u>23.0</u>	<u>7.4</u> <u>3.8</u>	<u>9.6</u> <u>12.2</u>	<u>3.2</u> <u>8.0</u>	2.2 <u>19.0</u>	11.6 11.2	<u>9.0</u> <u>7.2</u>	<u>34.4</u> <u>19.2</u>	2.8 2.4
	19	10.4 7.2	1.4 1.8	3.2 6.4	2.6 5.4	9.0 <u>10.0</u>	<u>10.8</u> 9.0	<u>14.6</u> <u>4.6</u>	4.0 <u>4.6</u>	5.6 17.0	<u>35.0</u> <u>10.8</u>	<u>14.0</u> <u>42.2</u>	2.6 2.8
	24	2.6 2.2	3.2 2.0	4.4 12.4	18.4 9.4	1.6 14.8	<u>8.2</u> <u>8.2</u>	<u>21.0</u> <u>5.0</u>	19.6 2.2	7.2 5.6	<u>10.8</u> <u>15.4</u>	25.8 <u>10.8</u>	4.4 6.4
	30	2.4 <u>33.2</u>	1.2 3.4	3.2 5.0	10.2 3.4	<u>15.4</u> 8.4	<u>14.4</u> <u>14.8</u>	<u>6.0</u> 7.4	<u>15.8</u> 11.4	7.8 6.8	<u>31.8</u> <u>6.2</u>	17.6 25.4	3.6 3.0
2	14	2.6 5.6	3.6 7.2	<u>5.8</u> <u>12.0</u>	8.2 13.0	<u>8.0</u> <u>10.8</u>	<u>15.2</u> <u>19.0</u>	<u>10.4</u> 27.0	<u>6.4</u> 7.2	<u>10.0</u> <u>14.2</u>	<u>3.4</u> <u>7.0</u>	<u>13.2</u> 4.2	5.8 8.4
	19	8.2 2.6	7.2 <u>6.0</u>	<u>29.6</u> 6.2	12.6 5.6	<u>5.6</u> 40.0	<u>23.2</u> <u>10.6</u>	<u>25.8</u> <u>11.6</u>	3.2 9.6	<u>7.2</u> <u>18.0</u>	<u>5.8</u> <u>9.8</u>	<u>6.6</u> 5.0	<u>13.8</u> <u>8.0</u>
	24	3.0 2.2	4.8 1.6	<u>33.8</u> <u>14.4</u>	6.2 9.4	<u>9.2</u> <u>6.8</u>	<u>26.4</u> <u>4.2</u>	<u>17.8</u> 13.8	7.4 4.2	<u>10.8</u> 5.6	<u>10.8</u> <u>16.4</u>	33.0 <u>6.2</u>	10.2 8.4
	30	6.2 8.0	3.8 <u>5.8</u>	<u>8.4</u> <u>16.6</u>	33.8 <u>10.0</u>	<u>18.0</u> <u>6.6</u>	7.0 13.8	9.2 <u>12.8</u>	15.0 2.4	<u>2.8</u> 10.6	<u>15.4</u> <u>17.6</u>	5.0 11.2	13.2 6.2
3	14	<u>6.6</u> 13.8	5.0 2.0	<u>5.8</u> <u>6.6</u>	5.8 <u>21.0</u>	5.0 4.4	<u>25.0</u> <u>4.2</u>	<u>5.0</u> <u>19.6</u>	<u>8.8</u> <u>10.0</u>	<u>20.4</u> <u>9.8</u>	6.4 <u>15.0</u>	<u>15.2</u> <u>28.4</u>	4.2 29.0
	19	<u>3.2</u> 9.8	11.4 5.0	<u>9.8</u> <u>8.2</u>	<u>3.6</u> <u>6.6</u>	4.6 <u>5.0</u>	<u>27.2</u> <u>9.2</u>	<u>12.4</u> <u>36.8</u>	14.4 <u>3.0</u>	7.6 <u>18.4</u>	<u>43.8</u> <u>6.0</u>	<u>14.4</u> <u>11.6</u>	14.2 <u>3.8</u>
	24	2.8 15.0	1.4 2.8	12.6 <u>9.8</u>	<u>4.8</u> <u>5.8</u>	<u>7.0</u> <u>6.4</u>	9.6 <u>11.8</u>	<u>10.8</u> <u>9.6</u>	7.2 12.6	<u>16.4</u> <u>9.6</u>	<u>6.2</u> <u>10.4</u>	<u>8.0</u> <u>11.6</u>	5.2 5.0
	30	7.0 4.8	4.2 4.8	15.0 <u>4.2</u>	1.0 7.2	<u>4.2</u> 8.8	<u>20.0</u> <u>7.0</u>	<u>25.8</u> <u>11.2</u>	<u>21.0</u> 10.8	<u>26.2</u> <u>13.0</u>	<u>27.8</u> 6.6	4.8 <u>18.2</u>	22.0 6.0
4	14	2.6 <u>6.0</u>	9.2 <u>10.4</u>	<u>12.2</u> <u>12.4</u>	22.4 3.8	<u>9.6</u> <u>20.2</u>	<u>6.6</u> 26.2	<u>4.0</u> <u>6.0</u>	18.2 <u>10.2</u>	<u>10.8</u> <u>9.8</u>	<u>18.4</u> <u>22.4</u>	<u>15.8</u> <u>5.6</u>	<u>12.4</u> 10.0
	19	20.6 <u>14.4</u>	<u>3.6</u> <u>6.2</u>	<u>21.0</u> <u>12.0</u>	4.0 <u>4.4</u>	5.2 <u>10.8</u>	<u>16.2</u> <u>6.0</u>	<u>42.0</u> <u>3.0</u>	9.8 <u>6.8</u>	<u>6.4</u> <u>25.4</u>	<u>16.0</u> <u>11.6</u>	<u>7.6</u> <u>14.2</u>	<u>18.0</u> 8.8
	24	4.0 6.6	<u>1.4</u> <u>32.6</u>	<u>32.2</u> <u>11.0</u>	<u>3.0</u> 13.6	<u>7.6</u> 7.6	<u>10.4</u> <u>7.6</u>	<u>11.4</u> <u>12.2</u>	20.2 8.4	<u>37.8</u> 5.0	<u>22.6</u> <u>27.0</u>	42.2 9.8	2.6 8.0
	30	6.0 4.8	<u>7.6</u> 6.8	<u>18.4</u> 26.2	4.6 11.8	<u>8.6</u> 10.0	5.4 7.0	<u>7.0</u> <u>18.0</u>	<u>21.2</u> <u>8.2</u>	<u>8.4</u> <u>6.6</u>	<u>29.6</u> <u>13.2</u>	<u>6.6</u> <u>17.6</u>	27.4 13.4

All values are given in seconds.
Values underlined relate to incorrect decisions.

TABLE 7.2.2

Search times for skilled subjects

Range (miles)	S/N ratio (dbs)	TARGETS											
		3	14	17	16	15	13	1	20	18	6	5	9
1	14	16.0	4.4	67.4	12.4	16.2	13.0	15.0	1.0	13.2	12.2	15.0	1.2
	24	3.6	3.8	15.6	16.0	11.6	6.6	2.4	5.6	3.8	25.8	32.0	3.0
2	14	4.4	2.8	29.2	9.4	30.2	9.6	18.0	18.0	23.0	2.2	35.2	14.8
	24	3.8	8.4	8.2	11.2	23.4	28.2	46.6	6.2	9.4	25.8	32.0	4.4
3	14	7.4	1.8	19.0	2.8	9.6	18.6	18.4	6.2	35.4	3.4	15.2	11.6
	24	23.4	3.6	15.8	23.0	2.8	14.4	22.6	20.0	8.2	6.6	4.0	34.0
4	14	15.6	16.4	33.0	4.2	33.8	11.8	22.4	32.4	39.4	15.0	19.6	5.2
	24	19.0	19.0	31.4	21.2	5.2	34.8	4.8	13.6	4.0	8.6	55.4	8.2

All values given in seconds
Values underlined relate to incorrect decisions

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
S/N ratio (N)	3	41.88	13.96	-	N.S.
Ranges (R)	3	377.85	125.95	2.18(b)	($p < 0.10$)
Targets (T)	11	3420.56	310.96	5.37(b)	$p \leq 0.005$
N x R	9	349.74	38.86	- (b)	N.S.
N x T	33	1752.63	53.11	- (b)	N.S.
R x T	33	3306.60	100.20	1.73(b)	$p < 0.01$
R x N x T	99	3868.92	39.08	- (a)	N.S.
Residual	192	12967.92	67.54(a)		
Pooled residual (Residual + R x N x T)	291	16836.84	57.86(b)		
TOTAL	383	28068.10			

TABLE 7.2.4

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

Source	D.F.	S.S.	M.S.	V.R.	Significance
S/N ratio (N)	1	17.51	17.51	- (b)	N.S.
Ranges (R)	3	672.84	224.28	1.16(b)	N.S.
Targets (T)	11	3199.97	290.91	1.50(b)	N.S.
N x R	3	181.93	60.64	- (a)	N.S.
N x T	11	2671.59	242.87	- (a)	N.S.
R x T	33	4142.69	125.54	- (a)	N.S.
Residual	33	8528.87	258.45(a)		
Pooled residual (Residual + N x R, N x T, R x T)	80	15525.08	194.06(b)		
TOTAL	95	19415.40			

7.2.1 The effect of signal/noise ratio on search times

For both unskilled and skilled subjects the effect of S/N ratio on search times was non-significant. The mean search times associated with each S/N ratio are shown in Table 7.2.5. All search time values are given in seconds.

TABLE 7.2.5

Mean search times at each S/N ratio

	S/N ratio (dbs)			
	14	19	24	30
Unskilled subjects	10.8	11.5	10.8	11.4
Skilled subjects	16.3		15.4	

It can be seen in this table that for unskilled subjects there is very little difference between the mean search times for the four S/N ratios. The differences between each pair of values were non-significant, which confirms the results of the analysis of variance. The differences between the two values obtained for skilled subjects was also non-significant.

The difference between the values for skilled and unskilled subjects was significant at the 5% level for the 14 dbs S/N ratio and was close to the 5% level for the 24 dbs S/N ratio. In each case the skilled subjects required a longer time to search the display than the unskilled subjects. This is an interesting result as in Experiment I, which also involved the use of skilled subjects, it was found that these subjects took significantly shorter time to search the display than did the unskilled subjects. Whereas the mean search time for unskilled subjects found in the present experiment is slightly less than that found in Experiment I, the mean value for the skilled subjects has almost doubled. It seems likely that this difference arises from differences in experience or motivation between the two groups of skilled subjects.

No regression analysis was carried out on the data for unskilled subjects shown in Table 7.2.5 since it can be seen in the analysis of variance in Table 7.2.3 that the variation due to S/N ratio is extremely small. Inspection of the mean search times at each S/N ratio suggests that the gradient of the regression line, and hence the sum of squares due to linear regression, would be very close to zero. Furthermore, there was clearly very little variation between high and low S/N ratios and this partition analysis was therefore not carried out.

7.2.2 The effect of range on search time.

The effect of range on search time was non-significant for skilled subjects and only reached the 10% level for unskilled subjects. The mean search time values at each range are shown in Table 7.2.6.

TABLE 7.2.6

Mean search times at each range.

	Range (miles)				N
	1	2	3	4	
Unskilled subjects	10.0	10.8	10.9	12.7	96
Skilled subjects	13.2	16.9	13.7	19.7	24

N = Number of readings on which each value is based.

It can be seen that for unskilled subjects the mean search time at range 4 miles is considerably higher than the values for ranges 1, 2 and 3 miles. There were significant differences between the mean search times for ranges 1 and 4 miles ($p < 0.01$) and 2 and 4 miles ($p < 0.05$). Otherwise all differences were non-significant. For the skilled subjects, who were exposed only to S/N ratios of 14 and 24 dbs, there were no significant differences between range means. Furthermore there is no consistent trend of search time increasing with range as found in previous experiments. However, these values were based on only one quarter as many readings as those for unskilled subjects and therefore are less likely to be reliable. A similar inconsistency was found in the detection probability values for skilled subjects at each range (see Section 7.1.2).

To compare the mean search times for skilled subjects with those for unskilled subjects it was again necessary to extract the appropriate data (i.e. that relating only to S/N ratios 14 and 24 dbs) from the complete data for unskilled subjects. Although the values relating to skilled subjects were higher than those relating to unskilled subjects at each range none of the differences reached significance. Two difference values, those for ranges 2 miles and 4 miles, were however very close to the 5% level.

A comparison was also made between mean search times at each range for the unskilled subjects in Experiment I, i.e. under conditions of photographic presentation, and those in the present experiment. The two sets of values are shown in Table 7.2.7. These values relate only to the original seven targets used in Experiment I and to ranges 1 - 3 miles.

TABLE 7.2.7

Mean search times at each range under conditions of photographic and television presentation

	Range (miles)			N	Overall mean
	1	2	3		
Photographic presentation	9.7	12.1	14.0	42	11.93
Television presentation	8.2	11.7	9.2	56	9.70
Differences	1.5	0.4	4.8**		2.23*

N = Number of readings on which each range mean is based.
* Significant at 5% level, two-tail test.
** Significant at 1% level, two-tail test.

It can be seen that the values relating to television presentation are not entirely consistent and also that the differences between photographic and television presentation are non-significant, except at range 3 miles. This is likely to be a chance discrepancy and little importance should be attached to it. This difference also contributes largely to the difference between the overall means for the two presentation modes. Again, the difference should not be taken too seriously, particularly as different groups of subjects were involved.

For unskilled subjects the range variation was further analysed by calculating the value of the linear regression component as shown in Table 7.2.8.

TABLE 7.2.8

Regression analysis of range variation

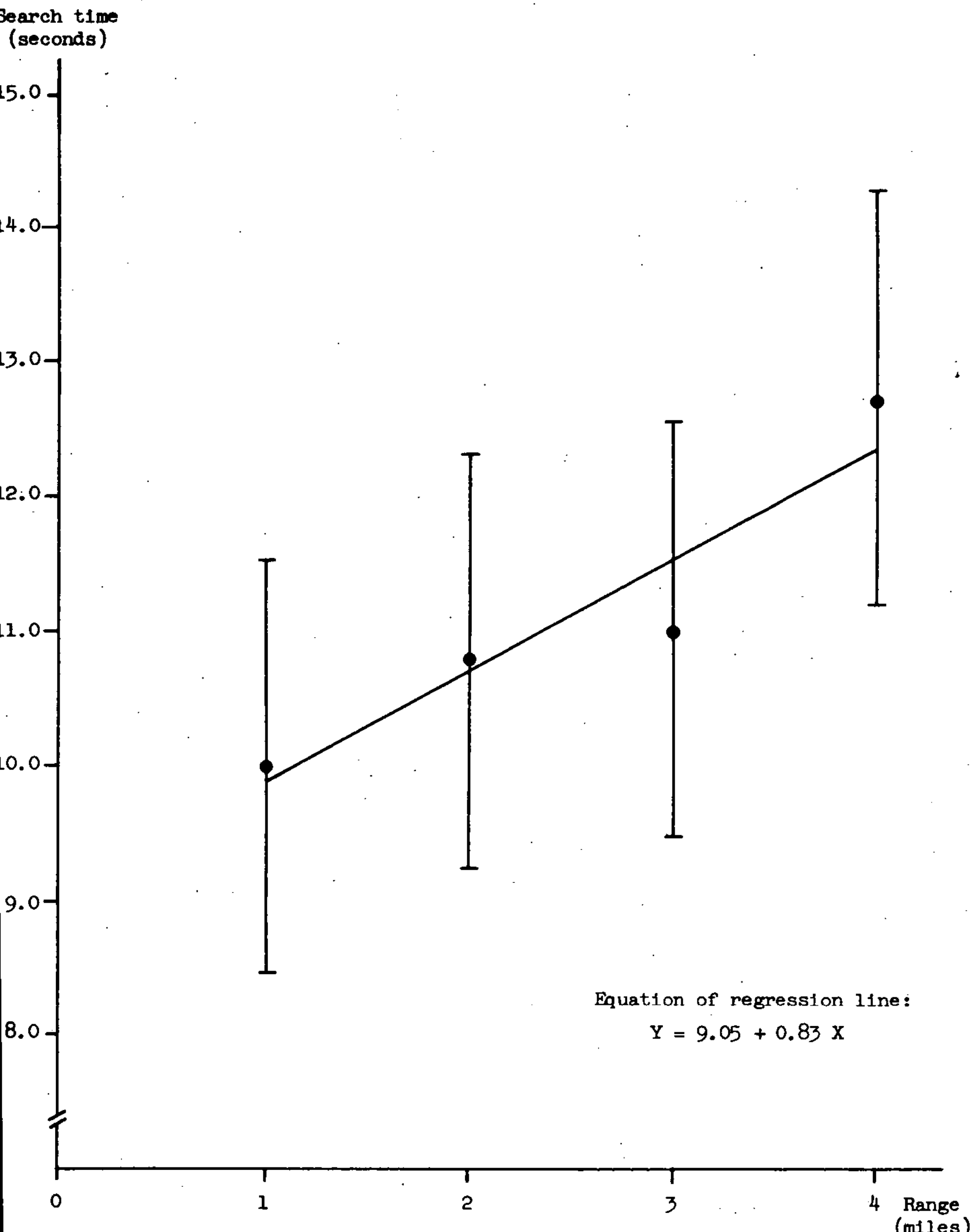
Source	D.F.	S.S.	M.S.	V.R.	Significance
RANGES*	3	377.85	125.95	2.18	($p < 0.10$)
Linear regression	1	330.67	330.67	5.72	$p < 0.025$
Deviation	2	47.1	23.55	-	N.S.
RESIDUAL*	291	16836.84	57.86		

*Values taken from analysis of variance shown in Table 7.2.3.

It can be seen from this table that the linear regression component of the range variation is highly significant, i.e. there is a basically linear relationship between range and search time. The regression line of search time on range is shown in Figure 7.2.1 together with the actual mean values for unskilled subjects. The deviation of these mean values about the regression line is non-significant, as also shown in Table 7.2.8.

FIGURE 7.2.1

The effect of range on search time.



NOTE This diagram relates only to unskilled subjects.

7.2.3 The effect of target differences on search times

The mean search times for targets are shown in rank order in Table 7.2.9. These values relate only to unskilled subjects.

TABLE 7.2.9

Mean search time for each of the twelve targets

Target	Mean search time	Ranking
14	5.36	1
3	7.66	2
9	9.12	3
15	9.39	4
16	9.61	5
20	10.15	6
10	11.99	7
17	12.41	8
13	12.69	9
1	13.53	10
6	15.48	11
5	15.79	12

It can be seen that there is a wide variation in mean search times. In general shorter search times are associated with larger targets. The rank order of the targets based on mean search times was compared with the rank order based on detection probabilities (see Table 7.1.13). It was found that there was a highly significant correlation between detection probability and search time (Kendall's tau = 0.73, $p < 0.001$), i.e. those targets which were associated with high detection probabilities tended to be associated also with low search times and vice versa.

For skilled subjects the mean search times tended to be higher for each target than those for unskilled subjects. However, when the values were compared with the appropriate data for unskilled subjects (i.e. that relating only to S/N ratios of 14 and 24 dbs), it was found that only in one case (Target 17) was this difference significant. Furthermore, there was a high degree of correlation between the rank orders of the targets according to mean search times for skilled and unskilled subjects (tau = 0.63, $p<0.01$). As for unskilled subjects, a correlation was found between high detection probability and low search time in the data for the skilled subjects (tau = 0.58, $p<0.01$).

Only in one case was a significant difference found between the mean search times for the original seven targets viewed under conditions of photographic presentation (Experiment I) and television presentation. This one instance was Target 15, for which the mean search time under conditions of television presentation was approximately half that found under conditions of photographic presentation.

Mean search times for the targets were further analysed by calculating the difference between each pair of values. These differences together with their associated significance levels are shown in Table 7.2.10. These values relate only to unskilled subjects.

TABLE 7.2.10

Differences between mean search times for targets

Targets	14	3	9	15	16	20	10	17	13	1	6	5
14		2.30	3.76	4.03	4.25	4.79	6.63	7.05	7.33	8.17	10.12	10.43
3			1.46	1.73	1.95	2.49	4.33	4.75	5.03	5.87	7.82	8.13
9				0.27	0.49	1.03	2.87	3.29	3.57	4.41	6.36	6.67
15					0.22	0.76	2.60	3.02	3.30	4.14	6.09	6.40
16						0.54	2.38	2.80	3.08	3.92	5.87	6.18
20							1.84	2.26	2.54	3.38	5.33	5.64
10								0.42	0.70	1.54	3.49	3.80
17									0.28	1.12	3.07	3.38
13										0.84	2.79	3.10
1											1.95	2.26
6												0.31
5												

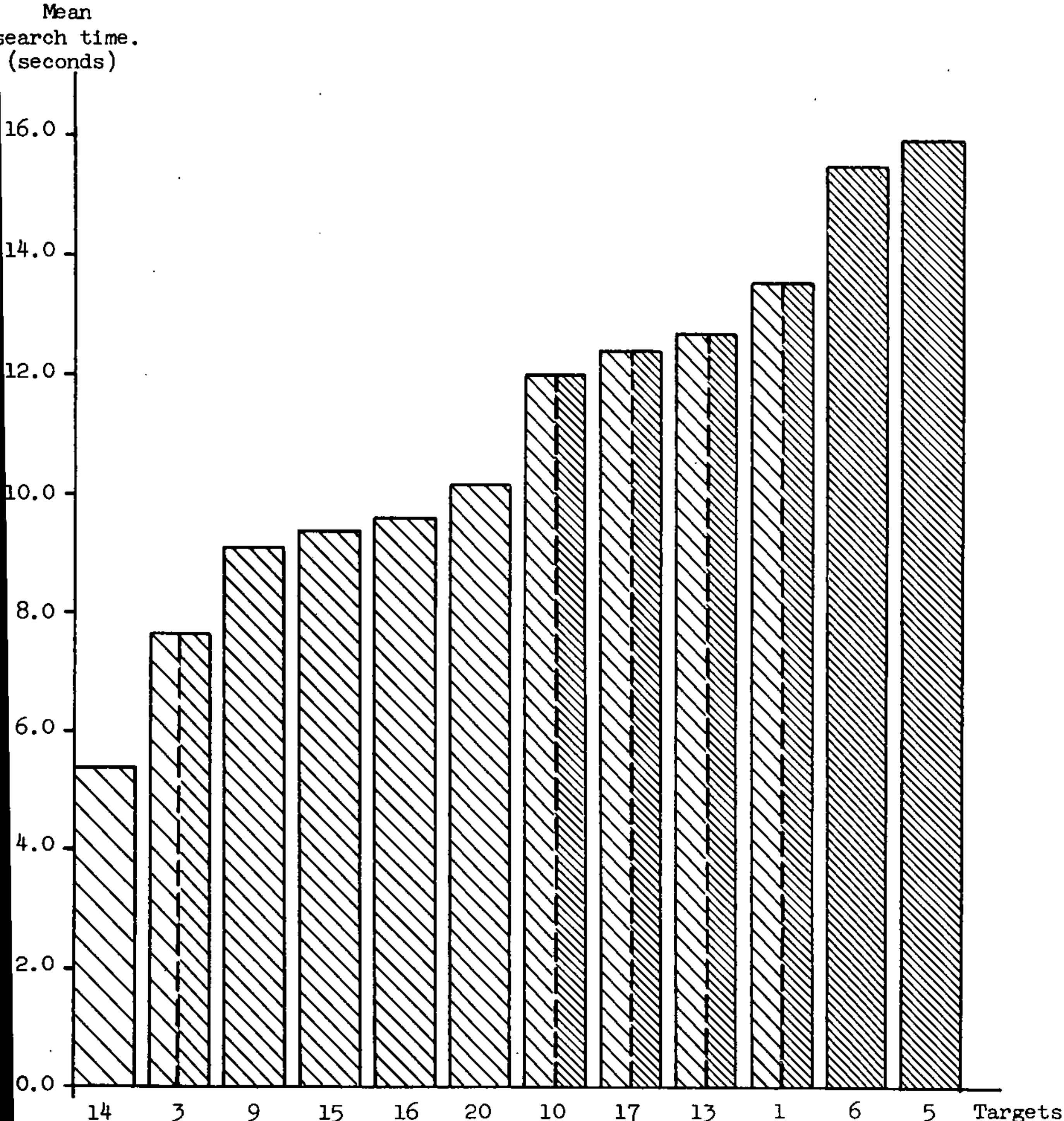
Differences which are significant at 5% level are shown by single underlining, and those which are significant at 1% level by double underlining.

It can be seen that the three easiest targets (Targets 14, 3 and 9) have significantly shorter search times than the three most difficult ones, (Targets 1, 6 and 5). Differences between the six remaining targets, which form the central group, are smaller and in general are not significant. Figure 7.2.2 shows the mean search times for each target in the form of a histogram and the main significant differences between targets are indicated by the shadings.

For the unskilled subjects target differences were further investigated by partitioning the total variation due to target differences, shown in the analysis of variance in Table 7.2.3, into three components representing the variation between large and small targets (i.e. that due to target size), and the variation within large targets and within small targets. This partition is shown in Table 7.2.11.

FIGURE 7.2.2

Mean search times for the twelve targets.



NOTE The different types of shading represent the main significant differences between the mean search times for the targets. A combination of shadings indicates that the targets are not significantly different from those shaded with either of the single shadings.

TABLE 7.2.11

Partition of target variation

Source	D.F.	S.S.	M.S.	V.R.	Significance
TARGETS*	11	3420.56	310.96	5.37	$p < 0.005$
Target size	1	1720.98	1720.98	29.74	$p < 0.001$
Targets (within small targets)	5	878.44	175.69	3.04	$p < 0.025$
Targets (within large targets)	5	821.14	164.23	2.84	$p < 0.025$
RESIDUAL*	291	16836.84	57.86		

*Values taken from analysis of variance shown in Table 7.2.3.

The most significant source of variation shown in Table 7.2.11 is the target size, i.e. variation due to differences between large and small targets. However, there is also significant variation due to differences between individual targets within the large and small target groups. The variation within the group of small targets is not significantly different from that within large targets. The interaction between target size and range is analysed in Section 7.2.4.

7.2.4 Ranges x target interaction

The analysis of variance on the search time data for unskilled subjects given in Table 7.2.3 shows that there is a significant interaction between ranges and targets, i.e. that individual targets are differently affected by the range conditions. This interaction can be divided into a linear regression and a deviation component as shown in Table 7.2.12.

TABLE 7.2.12

Regression analysis of R x T interaction

Source	D.F.	S.S.	M.S.	V.R.	Significance
R x T*	33	3306.60	100.20	1.73	$p < 0.01$
Linear regression	1	1200.87	1200.87	20.75	$p < 0.001$
Deviation	32	2105.73	65.80	1.14	N.S.
RESIDUAL*	291	16836.84	57.86		

* Values taken from the analysis of variance shown in Table 7.2.3.

This table shows that the linear regression component of the R x T interaction is highly significant, i.e. that the regression lines of search time on range for the twelve targets individually are significantly non-parallel. The deviation component of this interaction is non-significant and thus the mean values do not deviate significantly about the regression lines.

This interaction was simplified by dividing the targets into large and small target groups and considering the effect of range on each group rather than on each target individually. The mean search times at each range for the large and small target groups are shown in Table 7.2.13.

TABLE 7.2.13

Mean search times for large and small targets at each range

	Range (miles)				N
	1	2	3	4	
Large targets	7.52	8.03	9.46	10.92	48
Small targets	12.42	13.54	12.44	14.46	48
Differences	4.90**	5.51**	2.98*	3.54*	

N = Number of readings on which each value is based.
** Significant at 1% level, one-tail test.
* Significant at 5% level, one-tail test.

Differences between mean search times for large and small targets were significant at each range. There appeared to be some tendency for these differences to be smaller at longer ranges but the further analyses shown below indicated that this range x target size interaction was non-significant.

The total variation due to this interaction was divided into three components as shown in Table 7.2.14.

TABLE 7.2.14

Partition of R x T interaction

Source	D.F.	S.S.	M.S.	V.R.	Significance
R x T*	33	3306.60	100.20	1.73	N.S.
R x Target size	3	99.44	33.15	-	N.S.
R x T (within small targets)	15	2323.27	154.88	2.67	$p < 0.001$
R x T (within large targets)	15	883.89	58.93	1.02	N.S.
RESIDUAL*	21	16836.84	57.86		

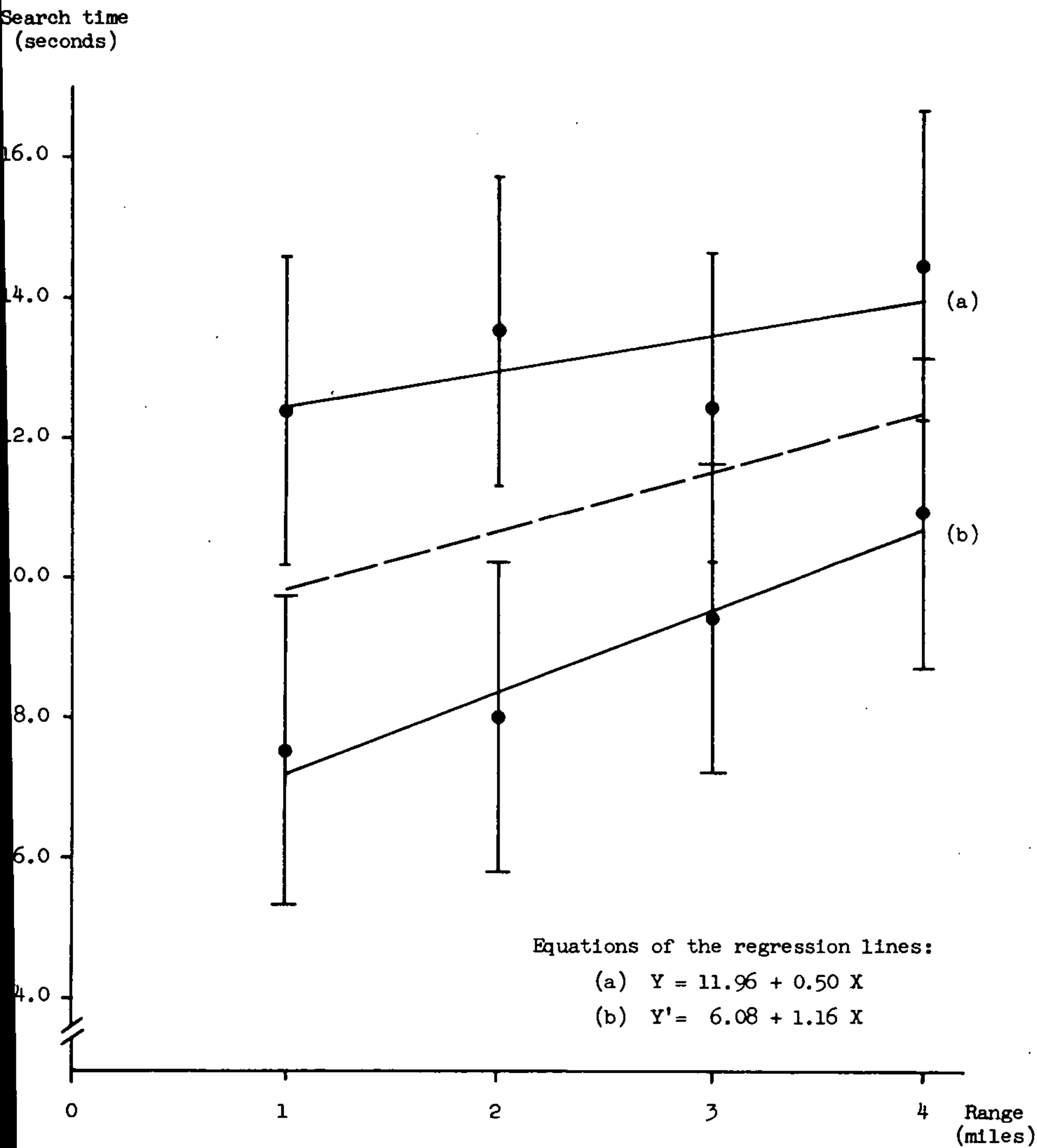
*Values taken from analysis of variance shown in Table 7.2.3.

This analysis shows that the interaction between range and target size is non-significant, i.e. that mean search times associated with the two groups of targets, large and small, are not differently affected by the range conditions. Within the group of small targets there is a highly significant interaction between ranges and targets, i.e. different small targets are differently affected by range. Within the large target group this interaction is non-significant.

A regression analysis carried out on the range x target size interaction showed that both the linear and the deviation components of the variation were non-significant. Thus, the two regression lines shown in Figure 7.2.3 do not deviate significantly from parallel. These regression

FIGURE 7.2.3

The effect of range on search time for
(a) small targets and (b) large targets.



NOTE The broken line is the regression line relating to all targets.

lines were calculated from the two sets of mean search times shown in Table 7.2.13, i.e. those for large and small targets, and analyses were also carried out to determine the significance of the linear regression and deviation components. These analyses are shown in Table 7.2.15.

TABLE 7.2.15

Regression analysis on the range variation for small and large targets

Source	D.F.	S.S.	M.S.	V.R.	Significance
Range (within small targets)	3	139.22	46.41	-	N.S.
Linear regression	1	60.85	60.85	1.05	N.S.
Deviation	2	78.37	39.18	-	N.S.
Range (within large targets)	3	337.40	112.47	1.94	N.S.
Linear regression	1	324.62	324.62	5.61	$p < 0.025$
Deviation	2	12.78	6.39	-	N.S.
RESIDUAL*	291	16836.84	57.86		

* Value taken from analysis of variance shown in Table 7.2.3. The residual mean square values determined from the separate analyses of variance on large and small targets were not significantly different and therefore it was appropriate to use the overall value shown.

This table shows that within small targets the overall range effect is non-significant, as are the linear regression and deviation components. Thus the gradient of line (a) in Figure 7.2.3 is non-significant and, although there appears to be some deviation of the mean values about the line, this is also non-significant. Within large targets the overall range effect is non-significant but the linear regression component is significant, i.e. line (b) in Figure 7.2.3 has a significant gradient.

As would be expected mean search time increases with increasing range. The deviation of the mean values about this line is negligible.

These results show the same type of anomaly as found in Section 7.1.7, i.e. two regression lines, one of which has a significant gradient and one of which does not, do not deviate significantly from parallel. The explanation of this again lies in the fact that there is a range effect in each case but for small targets this effect is slight and does not reach significance relative to the overall residual variation and the number of readings available. The most appropriate interpretation of these results is therefore that range does have an effect on search time and there is no evidence from these data that this effect is different for large and small targets.

7.3 Confidence levels

After each target identification a confidence level judgment 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 judgment. High values were associated with high confidence of a correct detection.

The raw data on these confidence levels 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 Table 7.3.3 and 7.3.4. For the unskilled subjects the analysis of variance shows that confidence levels are significantly affected by each of the main factors, S/N ratios, ranges and targets. Furthermore there are significant interactions between S/N ratios and targets and between ranges and targets. For the skilled subjects the levels of significance are lower and only targets are highly significant. The effect of S/N ratio reaches the 5% level but ranges and all the interactions between the main factors are non-significant. These results are in good agreement with those found in Experiment I, except for the significance of the two interaction terms found for unskilled subjects in the present experiment, but not previously.

The effects of the main factors and the significant interactions are considered in greater detail in the following sections.

TABLE 7.3.1

Confidence level scores for unskilled subjects

Range (miles)	S/N ratio (dbs)	TARGETS 3	14	17	16	15	13	1	20	10	6	5	9
1	14	6 / $\underline{5}$	7 / 7	$\underline{4}$ / 4	3 / $\underline{1}$	$\underline{6}$ / $\underline{7}$	$\underline{3}$ / $\underline{5}$	$\underline{5}$ / $\underline{4}$	5 / $\underline{4}$	4 / 6	$\underline{3}$ / $\underline{4}$	$\underline{3}$ / $\underline{4}$	4 / 7
	19	6 / 4	7 / 6	4 / 6	7 / 6	5 / $\underline{6}$	$\underline{3}$ / 5	$\underline{2}$ / $\underline{6}$	6 / $\underline{6}$	5 / 4	$\underline{5}$ / $\underline{5}$	$\underline{3}$ / $\underline{3}$	7 / 6
	24	6 / 7	7 / 7	6 / 5	5 / 4	7 / 5	$\underline{3}$ / $\underline{5}$	$\underline{3}$ / $\underline{5}$	4 / 6	6 / 7	$\underline{6}$ / $\underline{4}$	3 / $\underline{6}$	4 / 6
	30	6 / $\underline{5}$	7 / 7	7 / 7	6 / 7	$\underline{3}$ / 7	$\underline{4}$ / $\underline{4}$	$\underline{6}$ / 5	$\underline{3}$ / 7	4 / 7	$\underline{4}$ / $\underline{3}$	5 / 4	7 / 6
2	14	7 / 7	7 / 6	$\underline{3}$ / $\underline{4}$	4 / 3	$\underline{3}$ / $\underline{6}$	$\underline{5}$ / $\underline{6}$	$\underline{4}$ / 2	$\underline{5}$ / 5	3 / $\underline{4}$	$\underline{3}$ / $\underline{5}$	$\underline{5}$ / 5	7 / 6
	19	7 / 7	6 / $\underline{6}$	3 / 4	3 / 6	5 / 5	$\underline{3}$ / $\underline{6}$	$\underline{1}$ / $\underline{4}$	7 / 6	$\underline{4}$ / $\underline{4}$	$\underline{6}$ / $\underline{6}$	6 / 7	$\underline{5}$ / $\underline{5}$
	24	7 / 7	6 / 7	$\underline{3}$ / $\underline{3}$	4 / 4	$\underline{5}$ / $\underline{5}$	$\underline{4}$ / $\underline{6}$	$\underline{2}$ / 5	4 / 6	$\underline{4}$ / 6	$\underline{4}$ / $\underline{2}$	4 / $\underline{6}$	6 / 6
	30	6 / 7	6 / $\underline{6}$	$\underline{3}$ / $\underline{2}$	2 / $\underline{4}$	$\underline{4}$ / $\underline{4}$	6 / 5	3 / $\underline{4}$	3 / 6	$\underline{5}$ / 6	$\underline{2}$ / $\underline{1}$	5 / 5	6 / 7
3	14	$\underline{6}$ / $\underline{4}$	6 / 7	$\underline{5}$ / $\underline{4}$	2 / $\underline{3}$	3 / 4	$\underline{3}$ / $\underline{4}$	$\underline{6}$ / $\underline{4}$	$\underline{3}$ / $\underline{2}$	$\underline{6}$ / $\underline{4}$	4 / $\underline{3}$	$\underline{2}$ / $\underline{1}$	5 / 5
	19	$\underline{5}$ / 7	7 / 7	$\underline{4}$ / $\underline{6}$	$\underline{5}$ / $\underline{5}$	5 / $\underline{4}$	$\underline{3}$ / $\underline{6}$	$\underline{3}$ / $\underline{3}$	4 / $\underline{7}$	5 / $\underline{4}$	$\underline{3}$ / $\underline{4}$	$\underline{3}$ / $\underline{5}$	5 / $\underline{5}$
	24	6 / 6	7 / 7	4 / $\underline{5}$	$\underline{5}$ / $\underline{6}$	$\underline{3}$ / $\underline{3}$	6 / $\underline{5}$	$\underline{6}$ / $\underline{3}$	5 / 5	$\underline{4}$ / $\underline{5}$	$\underline{4}$ / $\underline{4}$	$\underline{4}$ / $\underline{6}$	5 / 5
	30	4 / 7	7 / 7	5 / $\underline{4}$	6 / 5	$\underline{5}$ / 3	$\underline{2}$ / $\underline{5}$	$\underline{4}$ / $\underline{4}$	$\underline{3}$ / 6	$\underline{3}$ / $\underline{5}$	$\underline{4}$ / 5	$\underline{6}$ / $\underline{3}$	4 / 6
4	14	6 / $\underline{4}$	3 / $\underline{3}$	$\underline{6}$ / $\underline{6}$	5 / 4	$\underline{2}$ / $\underline{4}$	$\underline{2}$ / 2	$\underline{7}$ / $\underline{6}$	4 / $\underline{4}$	$\underline{3}$ / $\underline{4}$	$\underline{5}$ / $\underline{3}$	$\underline{5}$ / $\underline{5}$	$\underline{3}$ / 4
	19	2 / $\underline{4}$	$\underline{6}$ / $\underline{6}$	$\underline{4}$ / $\underline{4}$	5 / $\underline{6}$	4 / $\underline{3}$	$\underline{2}$ / $\underline{4}$	$\underline{2}$ / $\underline{4}$	5 / $\underline{7}$	$\underline{4}$ / $\underline{4}$	$\underline{5}$ / $\underline{5}$	$\underline{3}$ / $\underline{3}$	$\underline{5}$ / 5
	24	6 / 7	$\underline{6}$ / $\underline{1}$	$\underline{5}$ / $\underline{4}$	$\underline{4}$ / 5	$\underline{4}$ / 2	5 / $\underline{5}$	4 / $\underline{5}$	3 / 6	$\underline{3}$ / 4	$\underline{3}$ / 5	4 / 3	4 / 4
	30	7 / 7	$\underline{5}$ / 7	$\underline{4}$ / 5	4 / 6	$\underline{4}$ / 2	3 / 5	$\underline{6}$ / $\underline{6}$	$\underline{5}$ / $\underline{4}$	$\underline{3}$ / $\underline{5}$	$\underline{3}$ / $\underline{3}$	$\underline{3}$ / $\underline{3}$	3 / 4

Values underlined relate to incorrect detections. High values are associated with high confidence of a correct detection.

TABLE 7.3.2

Confidence level scores for skilled subjects

Range (miles)	S/N ratio (dbs)	TARGETS											
		3	14	17	16	15	13	1	20	10	6	5	9
1	14	$\underline{7}$	4	$\underline{0}$	4	$\underline{4}$	3	$\underline{3}$	7	6	$\underline{2}$	$\underline{3}$	7
	24	7	7	3	6	7	6	$\underline{6}$	7	7	$\underline{5}$	$\underline{3}$	7
2	14	6	7	$\underline{1}$	2	$\underline{4}$	$\underline{7}$	$\underline{2}$	2	$\underline{2}$	$\underline{7}$	3	$\underline{5}$
	24	7	7	3	6	$\underline{2}$	6	2	7	3	$\underline{2}$	$\underline{2}$	7
3	14	$\underline{6}$	7	$\underline{2}$	7	$\underline{4}$	$\underline{2}$	$\underline{7}$	6	$\underline{3}$	$\underline{4}$	$\underline{2}$	$\underline{2}$
	24	$\underline{6}$	7	$\underline{2}$	$\underline{3}$	$\underline{7}$	$\underline{6}$	$\underline{2}$	$\underline{5}$	$\underline{7}$	$\underline{4}$	$\underline{7}$	4
4	14	6	7	$\underline{2}$	3	$\underline{2}$	$\underline{3}$	$\underline{3}$	$\underline{2}$	$\underline{4}$	$\underline{7}$	$\underline{2}$	7
	24	3	$\underline{5}$	$\underline{6}$	$\underline{3}$	3	$\underline{2}$	6	$\underline{6}$	$\underline{2}$	$\underline{5}$	3	5

Values underlined relate to incorrect decisions.
High values are associated with high confidence of a correct detection.

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
S/N ratios (N)	3	12.42	4.14	3.18(b)	$p < 0.025$
Ranges (R)	3	35.85	11.95	9.19(b)	$p < 0.001$
Targets (T)	11	173.80	15.80	12.15(b)	$p < 0.001$
N x R	9	15.03	1.67	1.28(b)	N.S.
N x T	33	77.88	2.36	1.82(b)	$p < 0.01$
R x T	33	140.91	4.27	3.28(b)	$p < 0.001$
N x R x T	99	141.57	1.43	1.16(a)	N.S.
Residual	192	236.24	1.23(a)		
Pooled residual (Residual + N x R x T)	291	377.81	1.30(b)		
TOTAL	383	833.70			

TABLE 7.3.4

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

Source	D.F.	S.S.	M.S.	V.R.	Significance
S/N ratios (N)	1	13.50	13.50	4.17(b)	$p < 0.05$
Ranges (R)	3	14.25	4.75	1.47(b)	N.S.
Targets (T)	11	115.25	10.48	3.23(b)	$p < 0.005$
N x R	3	9.08	3.03	- (a)	N.S.
N x T	11	19.75	1.80	- (a)	N.S.
R x T	33	111.50	3.38	- (a)	N.S.
Residual	33	118.67	3.60(a)		
Pooled residual (Residual + N x R N x T R x T)	80	259.00	3.24(b)		
TOTAL	95	402.00			

7.3.1 The effect of S/N ratio on confidence level

The mean confidence levels for unskilled and skilled subjects under each S/N ratio condition are shown in Table 7.3.5.

TABLE 7.3.5

Mean confidence levels under each condition of S/N ratio

	S/N ratio (dbs)			
	14	19	24	30
Unskilled subjects	4.40	4.81	4.83	4.78
Skilled subjects	4.13	-	4.88	-

It can be seen from this table that there is good agreement between the values relating to the unskilled subjects and the corresponding values relating to the skilled subjects. However, the range of the mean values for both groups of subjects is very small compared with the overall range of the scale (1 - 7). For the unskilled subjects the mean confidence level associated with the 14 dbs S/N ratio is significantly lower than those for the other S/N ratios. The two values for skilled subjects (relating to the 14 and 24 dbs S/N ratios) are also significantly different. Otherwise all differences between means for the S/N ratio conditions and also differences between unskilled and skilled subjects are non-significant.

A regression analysis was carried out on the data shown in Table 7.3.5 for unskilled subjects to determine the extent to which the relationship between mean confidence level and S/N ratio was linear. This analysis is shown in Table 7.3.6.

TABLE 7.3.6

Regression analysis of S/N ratio variation

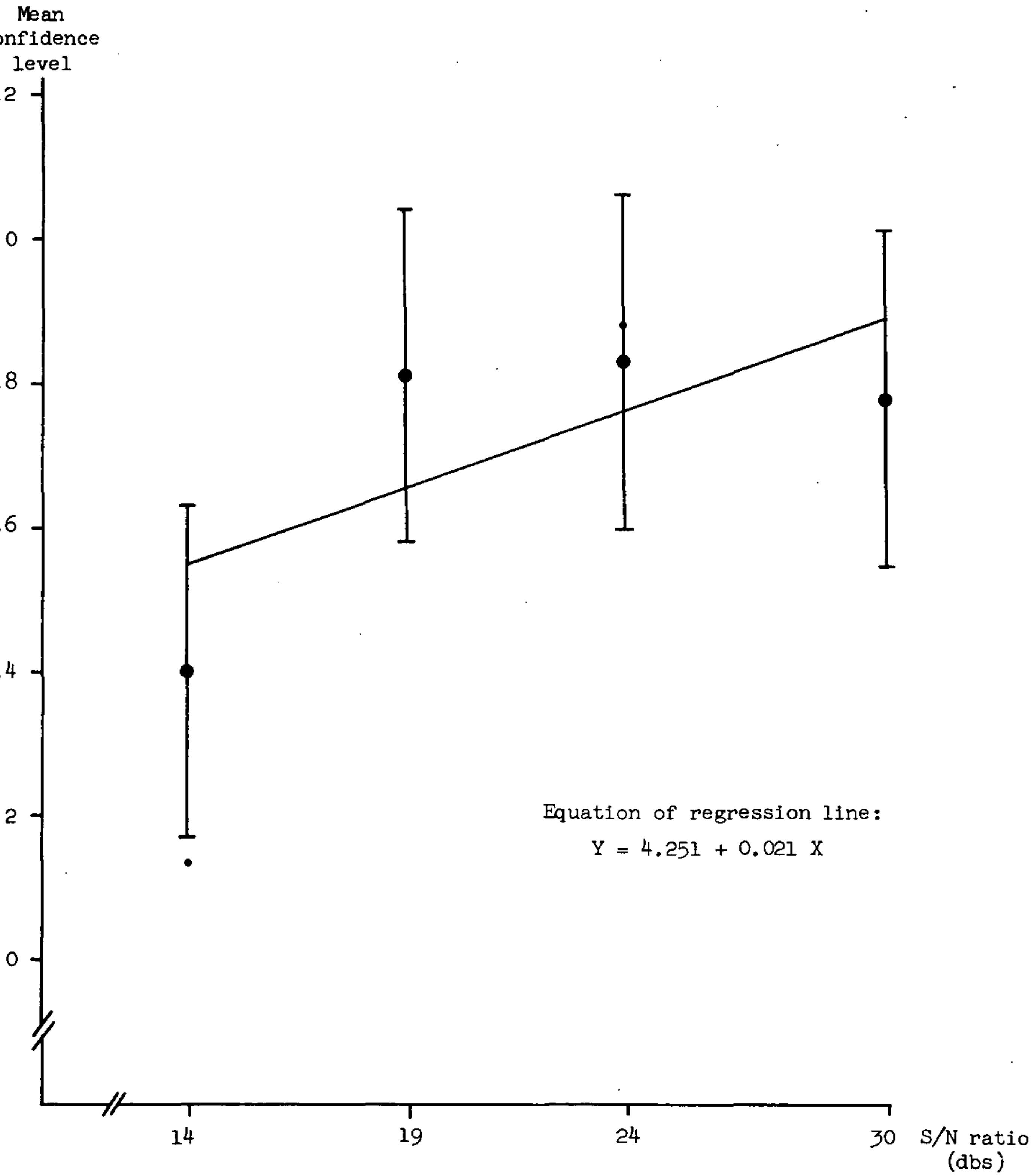
Source	D.F.	S.S.	M.S.	V.R.	Significance
S/N RATIO*	3	12.42	4.14	3.18	$p<0.025$
Linear regression	1	6.21	6.21	4.78	$p<0.05$
Deviation	2	6.21	3.11	2.39	$(p<0.10)$
RESIDUAL*	291	377.81	1.30		

* Values taken from the analysis of variance shown in Table 7.3.3

It can be seen from this analysis that the linear regression component of the S/N ratio variation is significant at the 5% level, i.e. that the relationship between confidence level and S/N ratio is basically a linear one. However, the deviation component reaches the 10% significance level, which suggests that there is a tendency for the mean values to deviate about the regression line. This can be seen in Figure 7.3.0 in which the regression line for unskilled subjects and the actual mean values for unskilled and skilled subjects are shown. A comparison of these data with those relating to detection probabilities at each S/N ratio (Section 7.1.1) indicates that both detection probabilities and mean confidence levels decrease with decreasing S/N ratio. Thus, in general, deterioration in actual performance is associated with a deterioration in the observer's subjective assessment of his performance. However, whereas the significant deterioration in detection performance occurs between the 19 and 24 dbs levels the significant fall in confidence level takes place between the 14 and 19 dbs levels. Thus, it appears that although the subjects' performance deteriorates significantly at S/N ratios of 19 dbs and lower the subjects themselves are not aware of this deterioration until the S/N ratio has fallen to 14 dbs.

FIGURE 7.3.0

The effect of signal/noise ratio on confidence level.



● Unskilled subjects.

• Skilled subjects.

NOTE The regression line is based only on the values relating to unskilled subjects.

Since the significant fall in confidence level did not take place between the 19 and 24 dbs level it was not appropriate to partition the S/N ratio variation into components relating to variation within and between the high and low levels of S/N ratio, as was done in the case of detection probabilities. However, a partition analysis was carried out to determine the extent to which the total variation due to S/N ratios was accounted for by the difference between the value at 14 dbs and the other three values. This analysis is shown in Table 7.3.7.

TABLE 7.3.7

Partition of S/N ratio variation

Source	D.F.	S.S.	M.S.	V.R.	Significance
S/N RATIO*	3	12.42	4.14	3.18	$p < 0.025$
Between 14 dbs level and the 19, 24, 30 dbs levels	1	12.29	12.29	9.45	$p < 0.005$
Within the 19, 24 and 30 dbs levels	2	0.13	0.06	-	N.S.
RESIDUAL*	291	377.81	1.30		

* Values taken from the analysis of variance shown in Table 7.3.3

It can be seen from this analysis that almost the whole of the variation due to S/N ratio was due to the low value associated with the 14 dbs S/N ratio. Thus, the significance of the overall effect due to S/N ratio is very largely due to this one value.

7.3.2 The effect of range on confidence level

The analyses of variance shown in Tables 7.3.3 and 7.3.4 indicate that range has a significant effect on confidence level for unskilled subjects but that for skilled subjects this effect fails to reach significance. The mean confidence levels at each range for both groups of subjects are shown in Table 7.3.8.

TABLE 7.3.8

Mean confidence levels at each range

	Range (miles)			
	1	2	3	4
Unskilled subjects	5.13	4.80	4.62	4.28
Skilled subjects	5.04	4.25	4.67	4.05

For unskilled subjects there were significant differences between each pair of range means except the 2 and 3 mile ranges. As would be expected mean confidence levels decreased with increasing range. For skilled subjects there was a similar but less consistent trend which was not significant. Even the largest difference i.e. that between 1 and 4 miles, failed to reach significance, but these means were based on only one quarter as many readings as those for the unskilled subjects. Differences between the means for the skilled subjects and the corresponding values for unskilled subjects (i.e. those relating only to S/N ratios of 14 and 24 dbs) were non-significant at each range.

A comparison was also made betweeen the mean confidence levels at each range under conditions of photographic presentation (data from Experiment I) and television presentation. The comparison was based on data relating to the original seven targets and ranges 1 - 3 miles only.

It was found that only at range 2 miles was there a significant difference, the mean confidence level under conditions of photographic presentation being higher than that under television conditions. The difference between the overall means for the two presentation modes was significant at the 5% level. However, the higher mean confidence level associated with photographic presentation was very largely due to the difference at the 2 mile range, which could have been a chance effect. The significance of this result should therefore be regarded with some caution although it is in the expected direction, i.e. lower confidence is associated with television presentation than with the higher quality photographic presentation.

For unskilled subjects the range variation was further analysed by calculating the values of the linear regression and deviation components as shown in Table 7.3.9.

TABLE 7.3.9

Regression analysis of range variation

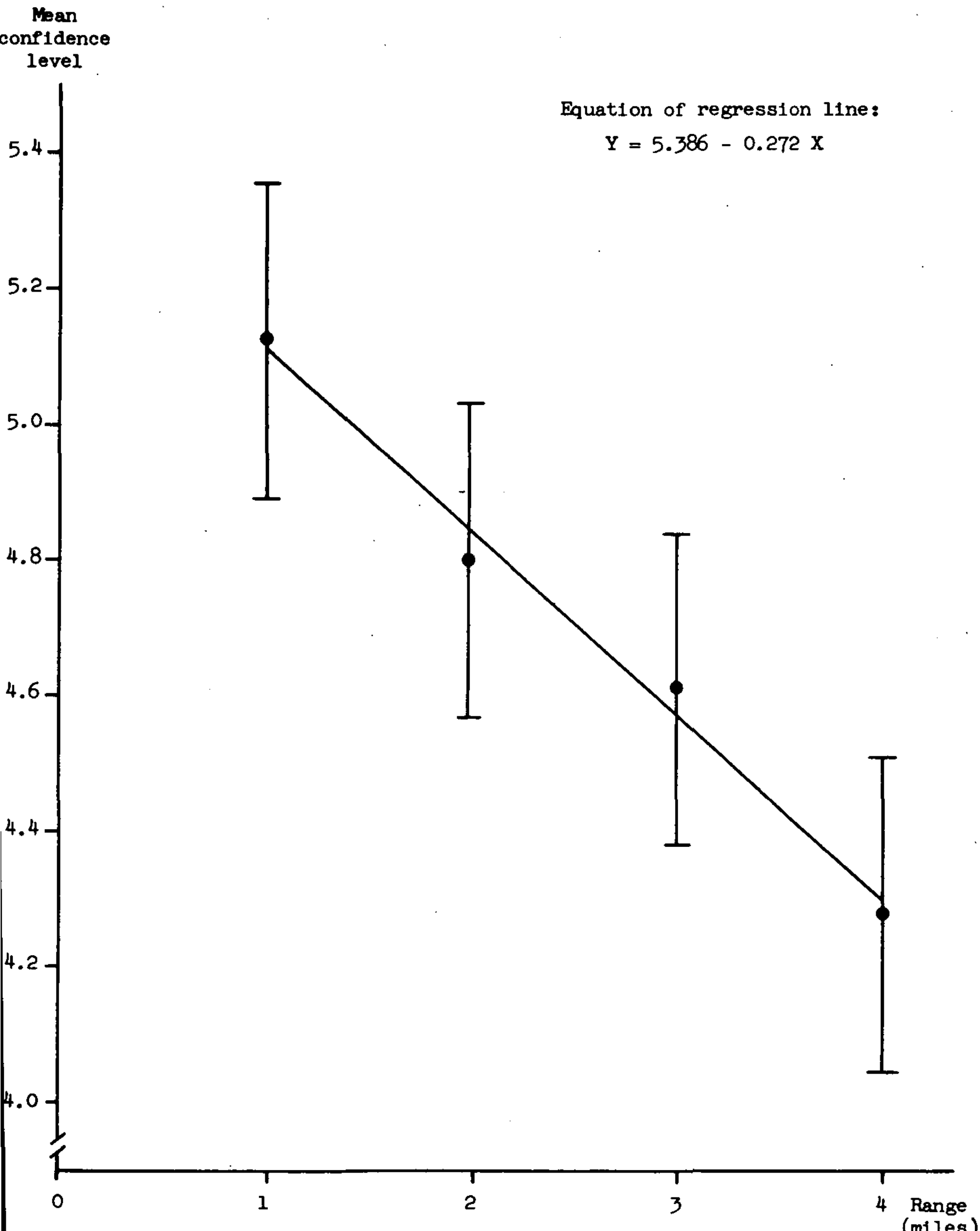
Source	D.F.	S.S.	M.S.	V.R.	Significance
RANGE*	3	35.85	11.95	9.19	$p < 0.001$
Linear regression	1	35.48	35.48	27.29	$p < 0.001$
Deviation	2	0.37	0.19	-	N.S.
RESIDUAL*	291	377.81	1.30		

*Values taken from analysis of variance shown in Table 7.3.3

It is clear from this analysis that the highly significant linear regression accounts for almost the whole of the variation due to ranges. Deviation about this linear regression is extremely small. The regression line and the actual mean confidence levels are shown in Figure 7.3.1. These relate only to unskilled subjects.

FIGURE 7.3.1

The effect of range on confidence level.



NOTE This diagram relates only to unskilled subjects.

7.3.3 The effect of target differences on confidence levels

The effect of targets on confidence levels was found to be highly significant for both unskilled and skilled subjects, as shown in the analyses of variance in Tables 7.3.3 and 7.3.4. The mean confidence levels for targets are shown in rank order in Table 7.3.10. These values relate only to unskilled subjects.

TABLE 7.3.10

Mean confidence levels for targets

Target	Mean confidence level	Ranking
14	6.16	1
3	5.88	2
9	5.22	3
20	4.88	4
16	4.53	5½
10	4.53	5½
17	4.47	7
15	4.31	8
13	4.22	9
1	4.19	10
5	4.16	111
6	3.94	12

These mean values can be regarded as the subjects' overall assessment of the likelihood of their having correctly detected the target. It can be seen that, as would be expected, high mean confidence levels tend to be associated with large targets. The rank orders of the targets, as shown in Table 7.3.10 was compared with the rank orders according to detection probabilities and search times. The correlations were both found to be highly significant, ($p < 0.001$ in each case), i.e. those targets which were associated with high confidence levels also tended to be associated with high detection probabilities and low search times. These tended to be the large targets. Conversely the small targets tended to be associated with low detection probabilities, high search times and low confidence levels. The values of Kendall's tau and the corresponding significance levels for all correlations between performance measures are shown in a summary table, Table 7.6.3.

It is interesting to note that the mean confidence level values shown in Table 7.3.10 all fall in the upper half of the confidence level scale which ranged from 1 - 7. This can be contrasted with the corresponding target detection probabilities which range from approximately 0.10 to 0.84. This suggests that, for targets with low detection probabilities, subjects were either not aware of their low success rate or else they were not making full use of the confidence level scale, i.e. they were assigning a value of, say 3, to targets about which they were very uncertain.

Differences between the target means for skilled and unskilled subjects (14 and 24 dbs data only) were, in general, very small and only reached significance in the case of Target 17, the value for unskilled subjects being greater than that for skilled subjects. The significant correlations between the rank orders according to confidence levels and those according to detection probabilities and search times were similar to those found for the unskilled subjects. Values of Kendall's tau and significance levels are shown in the summary table, Table 7.6.3.

The confidence level data for the unskilled subjects were further analysed by calculating the difference between each pair of target means. These differences, together with the associated significance levels, are shown in Table 7.3.11.

TABLE 7.3.11

Differences between mean confidence levels for the twelve targets.

TARGETS	14	3	9	20	16	10	17	15	13	1	5	6
14		0.28	0.94	1.28	1.63	1.63	1.69	1.85	1.94	1.97	2.00	2.22
3			0.66	1.00	1.35	1.35	1.41	1.57	1.66	1.69	1.72	1.94
9				0.34	0.69	0.69	0.75	0.91	1.00	1.03	1.06	1.28
20					0.35	0.35	0.41	0.57	0.66	0.69	0.72	0.94
16						0.00	0.06	0.22	0.31	0.34	0.37	0.59
10							0.06	0.22	0.31	0.34	0.37	0.59
17								0.16	0.25	0.28	0.31	0.53
15									0.09	0.12	0.15	0.37
13										0.03	0.06	0.28
1											0.03	0.25
5												0.22
6												

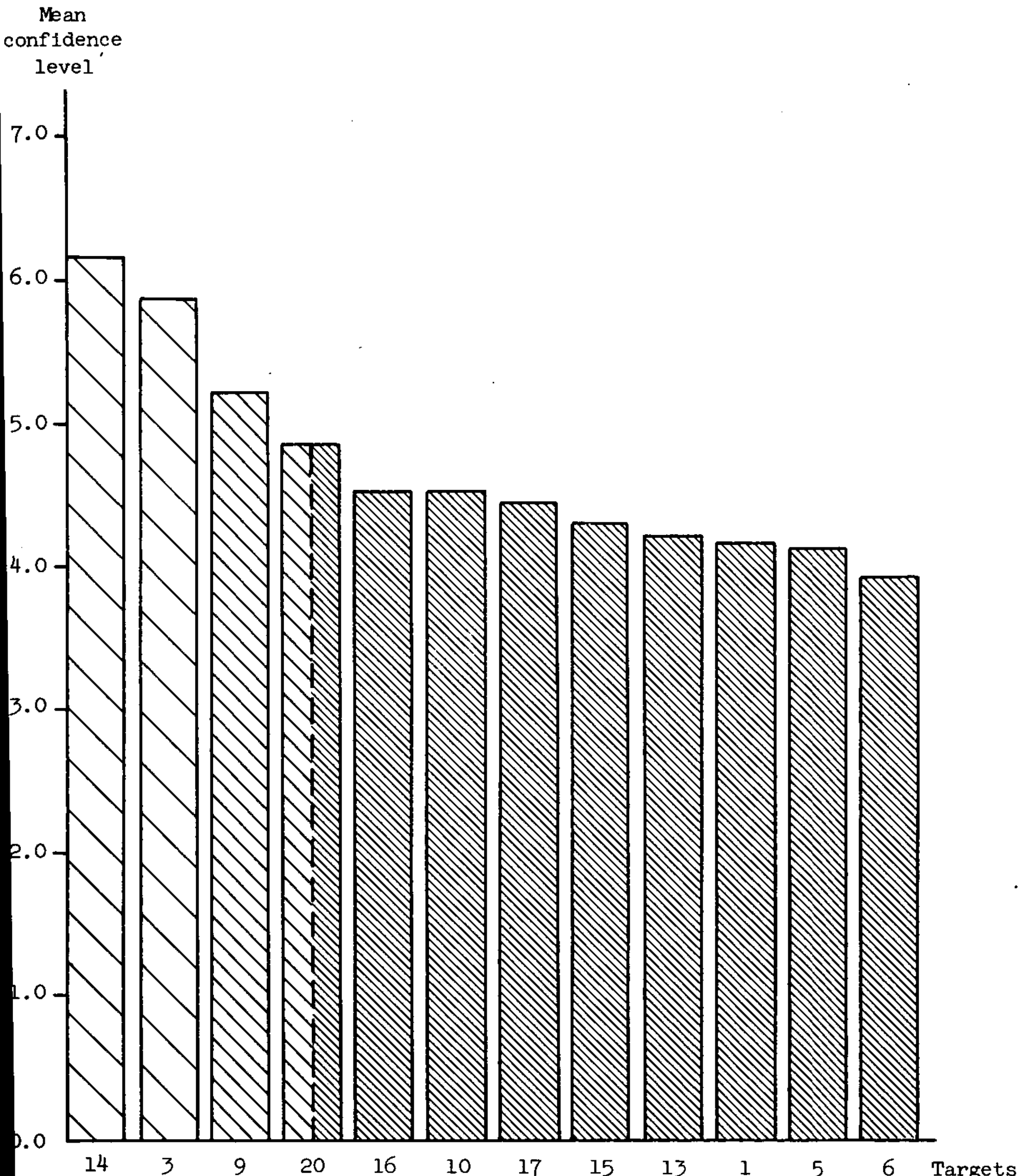
Values significant at the 1% level are indicated by double underlining, and those significant at the 5% level by single underlining.

It can be seen from Table 7.3.11 that Targets 14 and 3 are associated with significantly higher mean confidence levels than the other targets. Targets 9 and 20 are intermediate and the remaining eight targets form a group within which only two difference values are significant. The mean confidence levels are shown as a histogram in Figure 7.3.2 and the main significant differences between the targets are shown by different shadings.

For unskilled subjects the total variation due to targets was partitioned into three components representing the variation between large and small targets, i.e. that due to target size, and the variation within large targets and within small targets. This analysis is given in Table 7.3.12.

FIGURE 7.3.2

Mean confidence levels for the twelve targets.



NOTE The three different types of shading indicate the main significant differences between the mean confidence levels for the targets. A combination of shadings (Target 20) indicates that the target is not significantly different from those shaded with either of the single shadings.

TABLE 7.3.12

Partition of target variation

Source	D.F.	S.S.	M.S.	V.R.	Significance
TARGETS*	11	173.80	15.80	12.15	$p < 0.001$
Target size	1	93.02	93.02	71.56	$p < 0.001$
Targets (within small targets)	5	4.96	0.99	-	N.S.
Targets (within large targets)	5	75.82	15.16	11.67	$p < 0.001$
RESIDUAL*	291	377.81	1.30		

* Values taken from analysis of variance shown in Table 7.3.3.

This analysis shows that the variation due to target size is highly significant as is also the variation within the large target group. Variation within the small target group is however non-significant. These results are consistent with the values given in Table 7.3.10 which indicate that the range of mean confidence values is much greater for large targets than for small targets. The importance of target size is also shown by the fact that the six large targets occupy the top six places in the rank order.

7.3.4 Signal/noise ratio x range interaction

This interaction was found to be non-significant for both groups of subjects, as shown in Tables 7.3.3 and 7.3.4, i.e. the different S/N ratio conditions were affected in a similar way by the four ranges. Further analysis on the data for unskilled subjects showed that both the linear regression component and the deviation component of the variation due to the interaction were non-significant, indicating that the regression lines of confidence level on range for each of the four S/N ratios did not deviate significantly from parallel. This analysis is shown in Table 7.3.13.

TABLE 7.3.13

Regression analysis of N x R interaction

Source	D.F.	S.S.	M.S.	V.R.	Significance
N x R*	9	15.03	1.67	1.28	N.S.
Linear regression	1	0.51	0.51	-	N.S.
Deviation	8	14.52	1.82	1.40	N.S.
RESIDUAL*	291	377.81	1.30		

* Values taken from analysis of variance shown in Table 7.3.3.

Since, as was discussed in Section 7.3.1, it was inappropriate to reduce the four S/N ratios to two levels, high and low, as could be done in the case of detection probabilities, no further analyses were carried out on this interaction term.

7.3.5 Signal/noise ratio x targets interaction

The analysis of variance given in Table 7.3.3 shows that the N x T interaction is highly significant for the unskilled subjects, i.e. that individual targets were differently affected by the four S/N ratio conditions. A regression analysis indicated that the linear component of this variation was also highly significant as shown in Table 7.3.14.

TABLE 7.3.14

Regression analysis of N x T interaction

Source	D.F.	S.S.	M.S.	V.R.	Significance
N x T*	33	77.88	2.36	1.82	$p \leq 0.01$
Linear regression	1	9.86	9.86	7.58	$p \leq 0.01$
Deviation	32	68.02	2.13	1.64	$p \leq 0.025$
RESIDUAL*	291	377.81	1.30		

* Values taken from analysis of variance shown in Table 7.3.3.

This analysis shows that both the linear regression and the deviation components of the interaction are significant. Thus the regression of confidence level on S/N ratio for each target individually is non-linear and there are significant differences between these twelve regression curves, i.e. they are non-parallel.

The twelve sets of values, i.e. one for each target, were reduced to two by considering the targets in two groups, large and small, as in previous sections. Table 7.3.15 shows the effect of S/N ratio on mean confidence level for each group.

TABLE 7.3.15

Mean confidence level for large and small targets at each S/N ratio

	S/N ratio (dbs)			
	14	19	24	30
Large targets	4.65	5.44	5.31	5.40
Small targets	4.15	4.19	4.35	4.17
Differences	0.50*	1.25**	0.96**	1.23**

* Significant at 5% level, two-tail test.
** Significant at 1% level, two-tail test.

The differences between the mean confidence levels for large and small targets are significant at each S/N ratio. However, for both large and small targets the trends of increasing confidence level with increasing S/N ratio are not entirely consistent. Similar discrepancies were apparent in Section 7.3.1 in which the overall effect of S/N ratio on confidence level was analysed.

A further analysis was carried out to determine whether there was a significant interaction between S/N ratio and target size. This analysis, which involved partitioning the N x T interaction into three parts, is shown in Table 7.3.16.

TABLE 7.3.16

Partition of N x T interaction

Source	D.F.	S.S.	M.S.	V.R.	Significance
N x T*	33	77.88	2.36	1.82	$p < 0.01$
N x Target size	3	8.78	2.93	2.25	N.S.
N x T (within small targets)	15	35.35	2.36	1.81	$p < 0.05$
N x T (within large targets)	15	33.74	2.25	1.73	$p < 0.05$
RESIDUAL*	291	377.81	1.30		

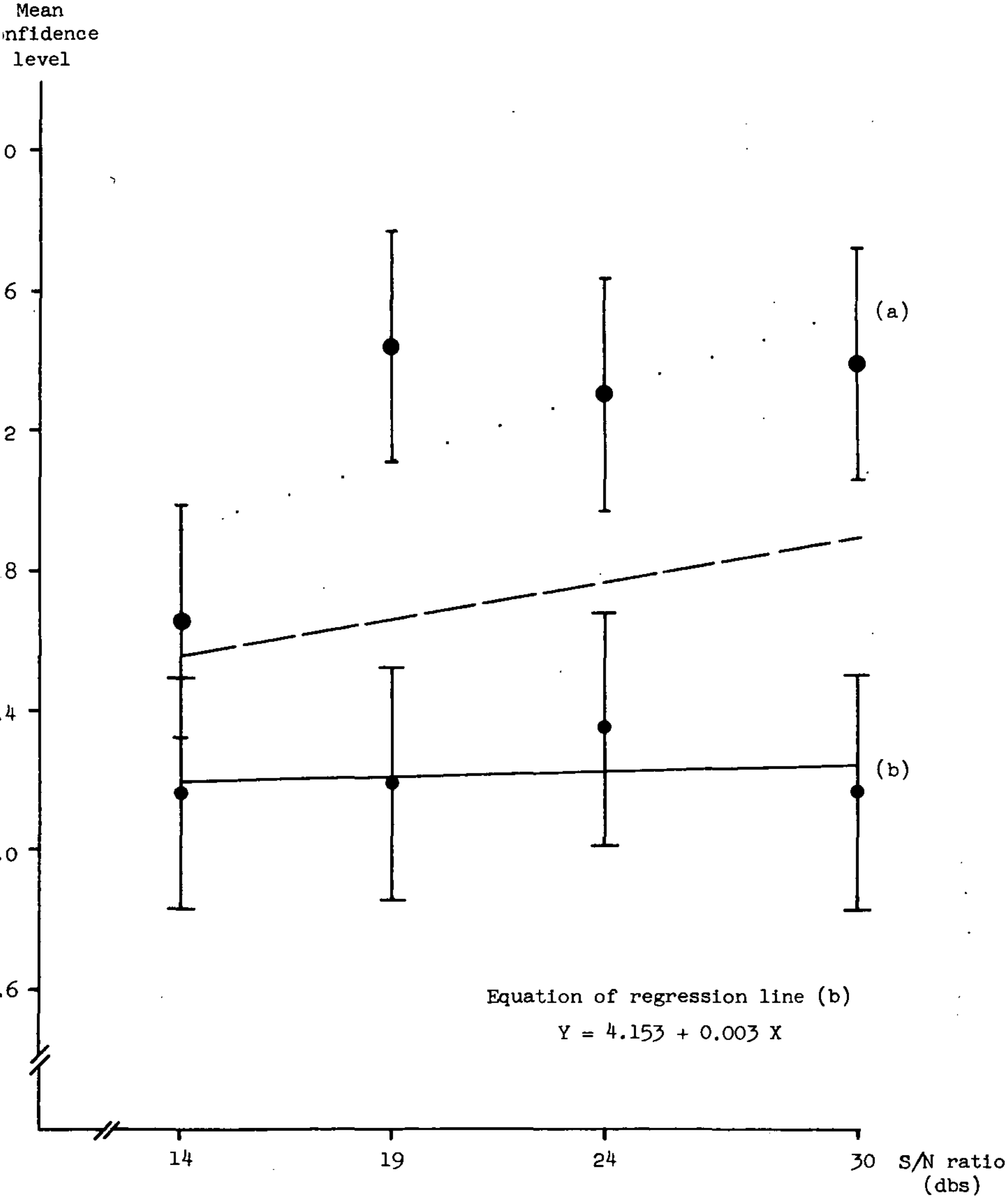
* Values taken from analysis of variance shown in Table 7.3.3.

It can be seen from this analysis that within both the large and the small target groups there is a significant N x T interaction but that the interaction between S/N ratio and target size is non-significant. An additional analysis indicated that the linear regression component of this interaction term was not significant at the 5% level although it did reach the 10% level. This suggests that there is a tendency for lines (a) and (b) in Figure 7.3.3, which represent the linear regression components of confidence level on S/N ratio for large and small targets respectively, to deviate from parallel.

Regression analyses on the confidence level data for small and large targets at each S/N ratio are shown in Table 7.3.17.

FIGURE 7.3.3

The effect of signal/noise ratio on confidence level for (a) large targets and (b) small targets.



NOTE The dotted line (a) is the best-fit straight line through the mean values for the large targets. However, since the deviation of these values about the line is significant, the data would be more properly fitted by a regression curve.
The broken line is the regression line relating to all targets.

TABLE 7.3.17

Regression analysis on the S/N ratio variation for small and large targets

Source	D.F.	S.S.	M.S.	V.R.	Significance
S/N ratio within small targets	3	1.31	0.44	-	N.S.
Linear regression	1	0.09	0.09	-	N.S.
Deviation	2	1.22	0.61	-	N.S.
S/N ratio within large targets	3	19.90	6.63	5.10	$p < 0.005$
Linear regression	1	10.36	10.36	7.97	$p < 0.01$
Deviation	2	9.54	4.77	3.67	$p < 0.05$
RESIDUAL*	291	377.81	1.30		

*Value taken from the analysis of variance shown in Table 7.3.3. The residual mean square values determined from the separate analyses of variance on the data for large and small targets were not significantly different and therefore it was appropriate to use the overall value shown.

This table shows that for small targets both the linear regression and the deviation components of the S/N ratio variation are non-significant, i.e. the regression line has a non-significant gradient and the mean values do not deviate significantly about it. It can be seen in Figure 7.3.3. that the regression line (b) which relates to small targets is almost parallel to the x-axis.

In the case of large targets the situation is slightly more complicated since both the linear regression and the deviation components of the variation are significant. Thus the data are non-linear and would be most appropriately fitted by a curve. However, for comparison purposes, the linear component has been indicated by a dotted line in Figure 7.3.3.

The gradient of this dotted line is significant and, as shown above, there is evidence that it is not parallel to the regression line for small targets although this effect is only significant at the 10% level. Thus, these data suggest that increasing S/N ratio has no effect on the confidence levels associated with small targets but has a significant, positive and apparently non-linear effect on the confidence levels associated with large targets.

If Figure 7.3.3 is compared with Figure 7.1.6 which shows the corresponding detection probability data for large and small targets it can be seen that for small targets increase in signal/noise ratio results in a significant increase in detection probability but only a marginal increase in the associated confidence levels. For large targets a similar increase in detection probability is observed and this is accompanied by a significant increase in confidence level. It should be noted, however, that whereas the increase in detection probability does not take place until the S/N ratio reaches 24 dbs, the increase in confidence level takes place at 19 dbs. Thus, this feature of the data, which was noted also in the overall analysis of the S/N ratio effect (Section 7.3.1) appears to be associated only with the large targets.

Therefore, although for individual targets detection probabilities are highly correlated with the corresponding mean confidence levels (Section 7.3.3), it appears that there are some discrepancies between the effect of signal/noise ratio as found objectively by detection probability measures and subjectively by the associated confidence levels. This is probably accounted for by the fact that target differences are relatively large whereas the variation in mean confidence levels for the signal/noise ratio conditions tested extends over only a relatively small part of the 1 - 7 confidence level scale.

7.3.6 Ranges x targets interaction

The analysis of variance on the confidence level data for unskilled subjects shown in Table 7.3.3 indicates that the interaction between ranges and targets is highly significant, i.e. different targets are differently affected by the range conditions. The linear regression and deviation components of this interaction are both highly significant as shown in Table 7.3.18.

TABLE 7.3.18

Regression analysis of R x T interaction

Source	D.F.	S.S.	M.S.	V.R.	Significance
R x T*	33	140.91	4.27	3.28	$p < 0.001$
Linear regression	1	59.14	59.14	45.49	$p < 0.001$
Deviation	32	81.77	2.56	1.97	$p < 0.005$
RESIDUAL*	291	377.81	1.30		

* Values taken from analysis of variance shown in Table 7.3.3.

This analysis shows that the regression of confidence level on range for each target individually is non-linear and that there are significant differences between these twelve regression curves, i.e. they are non-parallel. The somewhat confused situation which was revealed by this analysis was simplified by considering the targets in two groups, large and small, as was done for the detection probability data (Section 7.1.6) and the search time data (Section 7.2.4).

Table 7.3.19 shows the mean confidence levels at each range for large and small targets. The data relate only to unskilled subjects.

TABLE 7.3.19

Mean confidence levels at each range for large and small targets

	Range (miles)			
	1	2	3	4
Large targets	5.63	5.44	5.17	4.56
Small targets	4.63	4.17	4.06	4.00
Differences	1.00**	1.27**	1.11**	0.56**

The differences between the mean confidence levels for large and small targets at each range are highly significant.

The variation due to the range x target size interaction was found to be non-significant as shown in Table 7.3.20.

TABLE 7.3.20

Partition of the R x T interaction

Source	D.F.	S.S.	M.S.	V.R.	Significance
R x T*	33	140.91	4.27	3.28	$p < 0.001$
R x Target size	3	6.61	2.20	1.69	N.S.
R x T (within small targets)	15	85.39	5.69	4.38	$p < 0.001$
R x T (within large targets)	15	48.91	3.26	2.51	$p < 0.005$
RESIDUAL*	291	377.81	1.30		

* Values taken from the analysis of variance shown in Table 7.3.3.

This table also shows that within both the large and small target groups there are highly significant interactions between ranges and targets, i.e. within each group the targets are differently affected by range.

Further analysis of the R x Target size interaction showed that both the linear regression and the deviation components of this interaction were also non-significant. Thus the two regression lines shown in Figure 7.3.4 do not deviate significantly from parallel, i.e. targets of different sizes are not differently affected by increasing range. These regression lines were calculated from the two sets of mean confidence levels shown in Table 7.3.19 and analyses were also carried to determine the significance of the corresponding linear regression components. These analyses are shown in Table 7.3.21.

TABLE 7.3.21

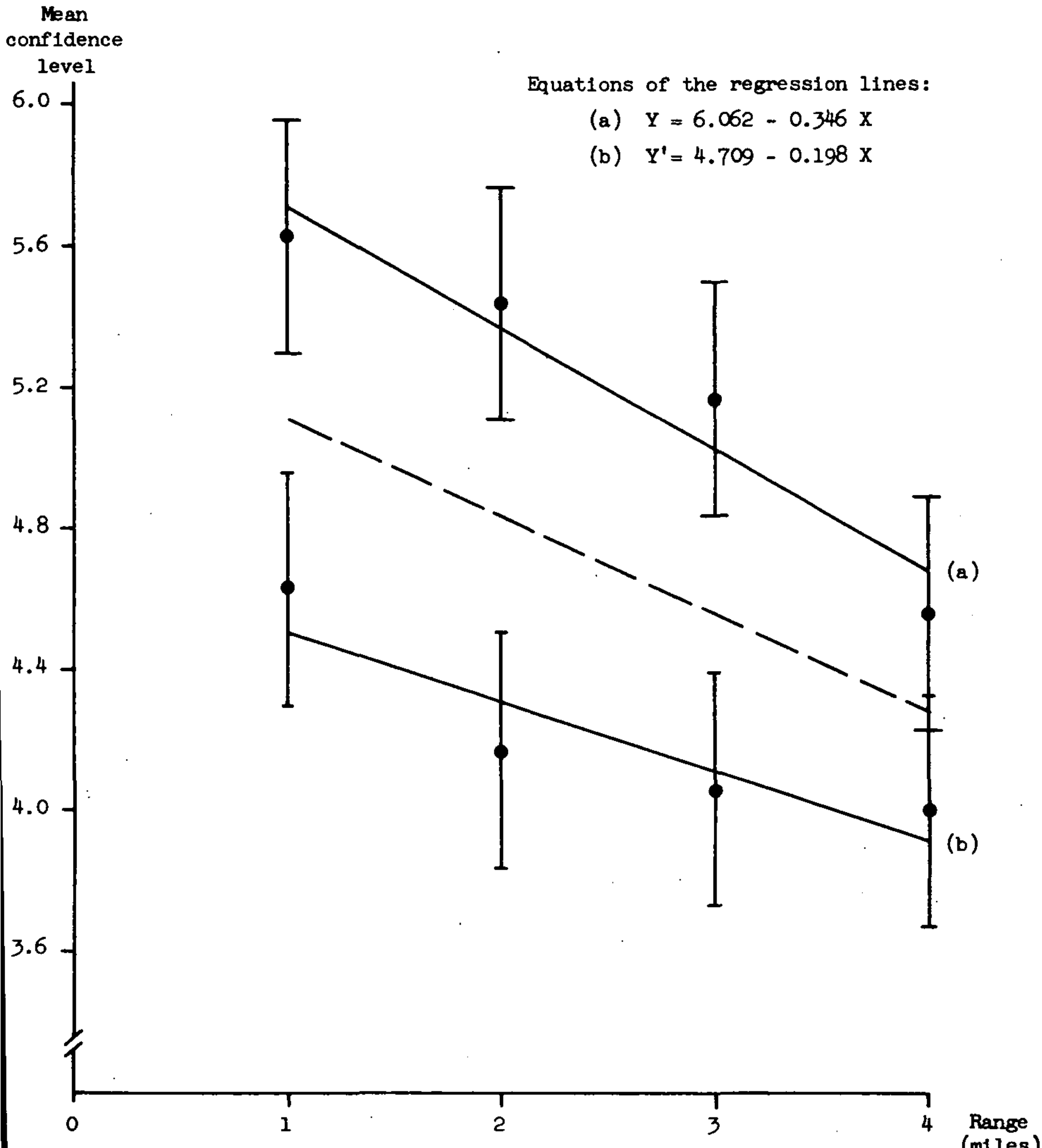
Regression analysis on the range variation for large and small targets

Source	D.F.	S.S.	M.S.	V.R.	Significance
Range (within small targets)	3	11.52	3.84	2.95	$p < 0.05$
Linear regression	1	9.60	9.60	7.38	$p < 0.01$
Deviation	2	1.92	0.96	-	N.S.
Range (within large targets)	3	30.94	10.31	7.93	$p < 0.001$
Linear regression	1	29.06	20.06	22.35	$p < 0.001$
Deviation	2	1.88	0.94	-	N.S.
RESIDUAL*	291	377.81	1.30		

* Value taken from the analysis of variance shown in Table 7.3.3. The residual mean square values found from the separate analyses on the data for small and large targets were not significantly different and therefore it was appropriate to use the overall value shown.

FIGURE 7.3.4

The effect of range on confidence level for (a) large targets and (b) small targets.



NOTE The broken line is the regression line relating to all targets.

This analysis shows that within both the large and the small targets groups range has a significant effect on confidence level. In each case the relationship is a linear one and the deviation of the mean values about the regression lines is non-significant. The regression lines are shown in Figure 7.3.4 together with the mean confidence level values at each range for large and small targets.

TABLE 7.4.1

Map-briefing times for unskilled subjects.

Range (miles)	S/N ratio (dbs)	TARGETS											
		3	14	17	16	15	13	1	20	10	6	5	9
1	14	176.4	52.8	75.0	87.8	52.6	52.6	70.8	200.8	112.6	58.4	55.2	54.2
		63.2	43.8	115.8	110.8	74.8	227.0	57.2	106.0	99.2	84.0	43.8	93.0
	19	69.8	30.2	80.8	60.4	72.2	125.2	63.6	54.4	101.0	145.8	113.2	65.2
		45.2	27.8	125.4	55.2	48.4	76.2	83.2	64.2	132.6	62.4	120.4	111.2
	24	47.4	45.8	97.6	46.2	72.8	101.2	119.2	80.6	41.8	170.6	57.4	61.2
		74.2	75.0	87.8	43.0	70.2	164.6	96.8	134.2	239.8	134.2	99.8	49.6
	30	108.0	70.0	46.0	51.0	113.8	99.8	78.8	163.4	89.4	75.8	62.4	99.8
		223.8	48.2	116.0	70.4	77.6	126.2	44.6	65.6	125.4	120.2	72.6	46.0
2	14	47.4	72.8	59.8	51.0	162.6	114.2	115.0	70.2	81.2	78.0	68.8	48.4
		48.4	130.8	53.4	199.2	75.8	103.4	136.8	56.8	66.0	120.8	134.2	60.2
	19	93.8	154.2	51.6	83.0	131.8	65.0	64.0	46.0	63.0	100.4	50.6	51.8
		60.4	80.6	67.0	105.0	187.0	114.0	155.0	41.0	108.4	66.2	95.0	54.4
	24	29.6	62.4	85.8	72.6	62.8	56.0	123.4	63.2	74.4	92.4	169.6	75.2
		35.4	95.8	63.0	204.6	86.2	40.2	87.0	78.0	71.0	114.0	64.0	74.8
	30	54.2	54.0	67.8	143.8	60.6	41.2	71.6	63.0	62.8	43.2	195.2	59.6
		39.6	72.4	97.8	75.8	121.6	65.4	166.8	48.8	51.4	175.4	100.6	141.4
3	14	56.8	56.0	52.6	67.8	93.4	66.6	58.2	89.8	66.2	65.8	47.6	123.0
		54.2	43.2	81.6	140.2	57.4	130.2	82.4	127.6	89.2	51.2	205.6	153.2
	19	49.6	64.0	176.4	63.4	110.0	147.2	154.2	95.8	40.0	85.8	77.4	70.2
		208.4	66.2	171.2	48.0	72.0	96.2	106.4	107.4	76.0	68.8	146.8	129.2
	24	119.8	107.4	118.2	49.6	56.8	194.0	48.0	48.8	48.4	49.6	87.2	35.6
		100.0	84.4	76.2	60.6	65.6	129.2	88.2	99.2	54.0	83.0	67.0	67.8
	30	66.6	50.8	76.4	45.6	76.6	63.0	63.8	96.0	151.8	50.8	117.8	150.0
		169.0	83.0	103.8	57.0	79.0	88.0	50.6	79.6	92.6	67.8	73.2	81.6
4	14	30.2	73.0	53.0	66.8	132.0	59.4	56.8	43.2	150.6	161.4	56.4	82.2
		48.0	184.6	80.2	89.6	80.4	78.4	78.8	36.2	71.8	91.6	80.2	99.0
	19	48.0	119.4	50.0	52.8	82.8	79.4	67.4	45.0	189.4	54.6	65.8	45.8
		78.8	79.4	48.4	74.8	156.6	74.4	118.6	62.8	127.0	103.8	61.8	201.0
	24	51.4	34.4	71.8	135.2	86.0	61.0	171.6	88.4	70.2	40.2	84.0	73.2
		29.6	74.0	74.8	85.8	168.8	75.8	115.0	86.8	137.0	82.4	53.8	166.6
	30	61.6	96.6	90.8	142.0	55.2	51.2	166.2	69.2	52.4	58.8	80.4	126.6
		50.2	127.4	92.2	69.4	59.6	53.2	163.6	118.4	76.8	37.0	128.0	91.0

All values given in seconds.

7.4 Map-briefing times

Subjects were allowed as much time as they wanted to study the map before viewing the television display. The time taken for this map-briefing was recorded, in seconds, on the print-out and the raw data for the two groups of subjects are shown in Table 7.4.1 and 7.4.2. While the subject was briefing himself on the map, he did not know under which conditions of range and signal/noise ratio he would subsequently be viewing the target. Thus, one would not expect these factors to have a significant effect on map times, and no effect was found for either unskilled or skilled subjects. Furthermore, there was no significant effect due to target differences, although this had been found in Experiment I. In general, therefore, the analysis of the map time data is of relatively little importance.

However, since the skilled subjects were very much more experienced in map-reading than the unskilled subjects it was of interest to compare the data for the two groups, particularly as it had previously been found that the skilled subjects required on average approximately half as much time for map-briefing as did the unskilled subjects. The mean search times required for each target by unskilled and skilled subjects are shown in Table 7.4.3, together with the corresponding rank orders.

TABLE 7.4.1

Map-briefing times for unskilled subjects.

Range (miles)	S/N ratio (dbs)	TARGETS 3	14	17	16	15	13	1	20	10	6	5	9
1	14	176.4	52.8	75.0	87.8	52.6	52.6	70.8	200.8	112.6	58.4	55.2	54.2
		63.2	43.8	115.8	110.8	74.8	227.0	57.2	106.0	99.2	84.0	43.8	93.0
	19	69.8	30.2	80.8	60.4	72.2	125.2	63.6	54.4	101.0	145.8	113.2	65.2
		45.2	27.8	125.4	55.2	48.4	76.2	83.2	64.2	132.6	62.4	120.4	111.2
	24	47.4	45.8	97.6	46.2	72.8	101.2	119.2	80.6	41.8	170.6	57.4	61.2
		74.2	75.0	87.8	43.0	70.2	164.6	96.8	134.2	239.8	134.2	99.8	49.6
	30	108.0	70.0	46.0	51.0	113.8	99.8	78.8	163.4	89.4	75.8	62.4	99.8
		223.8	48.2	116.0	70.4	77.6	126.2	44.6	65.6	125.4	120.2	72.6	46.0
2	14	47.4	72.8	59.8	51.0	162.6	114.2	115.0	70.2	81.2	78.0	68.8	48.4
		48.4	130.8	53.4	199.2	75.8	103.4	136.8	56.8	66.0	120.8	134.2	60.2
	19	93.8	154.2	51.6	83.0	131.8	65.0	64.0	46.0	63.0	100.4	50.6	51.8
		60.4	80.6	67.0	105.0	187.0	114.0	155.0	41.0	108.4	66.2	95.0	54.4
	24	29.6	62.4	85.8	72.6	62.8	56.0	123.4	63.2	74.4	92.4	169.6	75.2
		35.4	95.8	63.0	204.6	86.2	40.2	87.0	78.0	71.0	114.0	64.0	74.8
	30	54.2	54.0	67.8	143.8	60.6	41.2	71.6	63.0	62.8	43.2	195.2	59.6
		39.6	72.4	97.8	75.8	121.6	65.4	166.8	48.8	51.4	175.4	100.6	141.4
3	14	56.8	56.0	52.6	67.8	93.4	66.6	58.2	89.8	66.2	65.8	47.6	123.0
		54.2	43.2	81.6	140.2	57.4	130.2	82.4	127.6	89.2	51.2	205.6	153.2
	19	49.6	64.0	176.4	63.4	110.0	147.2	154.2	95.8	40.0	85.8	77.4	70.2
		208.4	66.2	171.2	48.0	72.0	96.2	106.4	107.4	76.0	68.8	146.8	129.2
	24	119.8	107.4	118.2	49.6	56.8	194.0	48.0	48.8	48.4	49.6	87.2	35.6
		100.0	84.4	76.2	60.6	65.6	129.2	88.2	99.2	54.0	83.0	67.0	67.8
	30	66.6	50.8	76.4	45.6	76.6	63.0	63.8	96.0	151.8	50.8	117.8	150.0
		169.0	83.0	103.8	57.0	79.0	88.0	50.6	79.6	92.6	67.8	73.2	81.6
4	14	30.2	73.0	53.0	66.8	132.0	59.4	56.8	43.2	150.6	161.4	56.4	82.2
		48.0	184.6	80.2	89.6	80.4	78.4	78.8	36.2	71.8	91.6	80.2	99.0
	19	48.0	119.4	50.0	52.8	82.8	79.4	67.4	45.0	189.4	54.6	65.8	45.8
		78.8	79.4	48.4	74.8	156.6	74.4	118.6	62.8	127.0	103.8	61.8	201.0
	24	51.4	34.4	71.8	135.2	86.0	61.0	171.6	88.4	70.2	40.2	84.0	73.2
		29.6	74.0	74.8	85.8	168.8	75.8	115.0	86.8	137.0	82.4	53.8	166.6
	30	61.6	96.6	90.8	142.0	55.2	51.2	166.2	69.2	52.4	58.8	80.4	126.6
		50.2	127.4	92.2	69.4	59.6	53.2	163.6	118.4	76.8	37.0	128.0	91.0

All values given in seconds.

TABLE 7.4.2

Map-briefing times for skilled subjects.

Range (miles)	S/N ratio (dbs)	TARGETS											
		3	14	17	16	15	13	1	20	10	6	5	9
1	14	33.0	43.0	167.2	56.0	51.4	141.4	51.4	27.8	37.4	77.2	38.0	76.2
	24	45.8	19.8	58.8	142.2	74.0	59.8	102.0	59.4	22.4	97.0	48.2	59.0
2	14	38.0	5.2	33.4	147.8	134.8	57.8	66.4	114.8	185.8	33.4	140.6	55.2
	24	111.8	66.6	33.0	39.2	49.4	179.6	72.6	49.4	63.0	49.6	50.6	49.2
3	14	34.2	160.0	52.6	39.4	51.6	78.6	196.6	48.6	50.6	96.8	49.0	45.0
	24	48.6	51.4	82.8	83.0	43.2	35.2	51.2	85.2	64.8	61.0	51.8	154.0
4	14	97.4	40.4	37.2	154.2	80.6	13.2	39.2	63.4	156.0	56.0	59.6	43.2
	24	35.4	123.8	75.8	23.0	201.0	72.8	32.6	38.2	52.0	43.8	137.8	28.6

All values are given in seconds.

TABLE 7.4.3

Map-briefing times for each target

Targets	Unskilled subjects		Skilled subjects	
	Map-briefing time	Ranking	Map-briefing time	Ranking
3	76.2	1	55.5	1
14	76.9	2	63.7	3
20	82.2	3	60.9	2
16	84.6	$4\frac{1}{2}$	85.6	11
17	84.6	$4\frac{1}{2}$	67.6	6
6	87.3	6	64.4	5
9	88.8	7	63.8	4
15	90.7	8	85.8	12
5	91.7	9	71.9	7
10	94.2	10	79.0	9
13	94.4	11	79.8	10
1	97.6	12	76.5	8
Overall mean	87.4		71.2	

Three analyses were carried out on these data:

(a) The difference between the overall means was found to be significant at the 1% level, i.e. the skilled subjects required significantly less map-briefing time than the unskilled subjects. This result is in agreement with that found in Experiment I. The overall mean value for the unskilled subjects was very close to those found previously. However, the overall mean value for the skilled subjects who took part in this experiment was significantly higher ($p < 0.01$) than that for the skilled subjects who took part in Experiment I.

(b) The mean map-briefing times for each target for unskilled subjects were compared with the corresponding values for skilled subjects. Although in almost every case the mean values were higher for the unskilled subjects than for the skilled group it was found that none of these differences reached the 5% significance level.

(c) The rank orders of the targets according to the mean briefing times as shown in Table 7.4.3 were tested by Kendall's tau to determine whether they were significantly correlated. Values of tau were also calculated for the correlation of map times with detection probability, search times and confidence levels for both groups of subjects. The results of these analyses are shown in Table 7.4.4.

TABLE 7.4.4

Correlations between the rank orders of targets according to map times with those for other performance measures

	Kendall's tau	Significance
Map times Unskilled/skilled	0.51	$p < 0.05$
Unskilled subjects		
Map times/detection probabilities	0.50	$p < 0.05$
Map times/search times	0.45	$p < 0.05$
Map times/confidence levels	0.52	$p < 0.05$
Skilled subjects		
Map times/detection probabilities	0.13	N.S.
Map times/search times	0.21	N.S.
Map times/confidence levels	0.41	N.S.

It can be seen from Table 7.4.4. that for the unskilled subjects the rank order of the map-briefing times for the twelve targets is positively correlated with the rank orders according to the other three performance measures, i.e. low map-briefing times tend to be associated with high detection probabilities, low search times and high confidence levels. This is an interesting result and one that has not been found in previous experiments. Since the correlations are significant only at the 5% level it could be due to a chance effect. If, however, it represents a genuine effect it suggests that, for those targets which were relatively easy to detect in terms of detection probability, search time and confidence level, the map-briefing task was also easier. Conversely for the more difficult targets the map-briefing task took longer. For the skilled subjects, as also shown in Table 7.4.4, the map-briefing times were not correlated with the other performance measures although they were correlated with the map-briefing times for unskilled subjects.

7.5 Relationship between detection performance and psychometric measures

During the experimental program psychometric tests giving numerical values relating to each subject's intelligence and personality were carried out. These scores were analysed to determine whether detection performance, in terms of the number of test targets correctly detected, and mean search time, were related to intelligence or personality variables.

Tables 7.5.1 and 7.5.2 show the mean and standard deviation values for the scores obtained on Heims A.H.5. test of high grade intelligence, and on the Eysenck Personality Inventory which gives numerical values relating to subjects extraversion - intraversion (E) and neuroticism (N). For comparison purposes the relevant population norms are also shown.

TABLE 7.5.1

Intelligence, E and N scores for unskilled subjects

	Subjects tested (32 students)		Population norms	
	Mean	s.d.	Mean	s.d.
A.H.5 intelligence test score	44.9*	5.7	39.1	8.3
Eysenck Personality Inventory				
E	13.3*	6.7	11.1	4.5
N	8.7	3.3	10.0	5.0

The population norms relate to students in each case.
The average age of the 32 students tested was 20.7 years.

*These values are significantly different from the corresponding population norms, ($p < 0.01$ in each case).

TABLE 7.5.2

Intelligence, E and N scores for skilled subjects

	Subjects tested (8 R.A.F. aircrew)		Population norms	
	Mean	s.d.	Mean	s.d.
A.H.5 intelligence test score	31.1*	8.6	39.9	6.7
Eysenck Personality Inventory.				
E	11.0	2.9	11.1	4.5
N	7.9	3.8	10.0	5.0

The population norms relate to R.A.F. permanent commission candidates (A.H.5 scores) and to students (E and N scores). The average age of the 8 skilled aircrew tested was 37.3 years.

*This value was significantly different from the corresponding population norm, ($p < 0.01$).

It can be seen from Table 7.5.1 that for the group of unskilled subjects the mean scores on the A.H.5 intelligence test and on the extraversion - intraversion (E) scale of the Eysenck Personality Inventory were significantly higher than the population norms. However, none of the mean values differed significantly from those found for the students who took part in Experiment I.

The skilled subjects did not differ significantly from the corresponding population norms in E or N scores but, as shown in Table 7.5.2, their mean A.H.5 score was significantly lower than the population norm. This score was also significantly lower than that of the skilled subjects who took part in Experiment I.

Comparisons of the data shown in Tables 7.5.1 and 7.5.2 indicated that differences between the unskilled and the skilled subjects were significant only for the A.H.5 scores ($p < 0.001$), the mean value for the skilled subjects being considerably lower than that for the unskilled subjects.

In order to determine whether there was any correlation between an individual's performance at the target detection task and his scores on the psychometric tests two measures of performance were calculated for each subject.

These performance measures were: (a) accuracy, i.e. the number of correct detections out of the twelve test targets and (b) mean search time, i.e. the mean of the search times recorded for twelve targets.

Subjects, skilled and unskilled considered separately, were then ranked according to these performance measures and the ranks compared by means of Kendall's rank correlation coefficient, tau, with the rankings according to the intelligence and personality variables for each subject. Finally the rankings for accuracy and search time were compared for both groups of subjects.

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

TABLE 7.5.3

Correlations between detection performance measures and psychometric measures

	Unskilled subjects		Skilled subjects	
	Accuracy	Mean time	Accuracy	Mean time
Intelligence score	tau = 0.24 p = 0.03*	tau = 0.05 p = 0.34	tau = 0.05 p = 0.44	tau = 0.37 p = 0.10
E score	tau = 0.18 p = 0.07	tau =-0.01 p = 0.46	tau =-0.18 p = 0.26	tau = 0.07 p = 0.40
N score	tau = 0.03 p = 0.40	tau =-0.05 p = 0.36	tau =-0.38 p = 0.09	tau =-0.49 p = 0.04*
	Accuracy/ mean time	tau = 0.00 p = 1.00	Accuracy/ mean time	tau = 0.36 p = 0.11

NOTE A positive correlation in this table indicates that high accuracy and low mean search time, i.e. good performance, were associated with high intelligence score, low E score and low N score at the probability values shown.

The most significant correlation in Table 7.5.3 is that between intelligence and accuracy for the unskilled subjects, i.e. high intelligence is associated with high accuracy. In the case of the skilled subjects there is a significant negative correlation between N score and mean search time, i.e. the more neurotic subjects tend to work more quickly. Both these results are in good agreement with those found in Experiment I. None of the other four values shown in Table 7.5.3 reach the 5% significance level. The absence of any correlation between accuracy and mean search time for unskilled subjects is in agreement with previous experiments, and is due to the fact that an individual's performance is averaged over the series of twelve targets, some easy and some difficult. Thus, although there is a high correlation between high detection probability and low search time for individual targets, this is not so between the accuracy and mean search time measures for individual subjects.

7.6 Summary of results

For convenient reference summary tables of the main results of this experiment are given on the following pages.

	DETECTION PROBABILITY	SEARCH TIME	CONFIDENCE LEVEL
OVERALL MEANS	0.46	11.1 seconds	4.7
SIGNAL/NOISE RATIO (N)	Significant effect ($p < 0.001$) Mean values range from 0.38 (14 dbs) to 0.55 (30 dbs). Relationship between S/N ratio and detection probability is linear. Highly significant fall in detection probability between 24 and 19 dbs. (33-37)	No significant effect. Mean values range from 10.8 secs. (14 dbs) to 11.4 secs. (30 dbs), but show no consistent trend. (81-82)	Significant effect ($p < 0.025$) Mean values range from 4.4 (14 dbs) to 4.8 (24 dbs). There is a significant linear relationship between confidence level and S/N ratio. Variation within S/N ratios is almost entirely due to the low value for the 14 dbs level. (101-104)
RANGE (R)	Significant effect ($p < 0.001$) Mean values range from 0.60 (1 mile) to 0.36 (4 miles). Relationship between range and detection probability is linear. (38-43)	Just fails to reach significance. ($0.05 < p < 0.10$) Mean values range from 10.0 secs. (1 mile) to 12.7 secs. (4 miles). Relationship between range and search time is linear. (82-85)	Significant effect ($p < 0.001$) Mean values range from 5.1 (1 mile) to 4.3 (4 miles). Relationship between range and confidence level is linear. (105-107)
TARGETS (T)	Significant effect ($p < 0.001$) Mean values range from 0.84 for Target 9 to 0.09 for Target 6. Highly significant difference between large and small targets. Mean for large targets: 0.68 Mean for small targets: 0.24 (44-49)	Significant effect ($p < 0.005$) Mean values range from 5.4 secs. for Target 14 to 15.8 secs. for Target 5. There is a highly significant difference between large and small targets. Mean for large targets: 9.0 secs. Mean for small targets: 13.2 secs. (86-90)	Significant effect ($p < 0.001$) Mean values range from 3.9 for Target 6 to 6.2 for Target 14. Highly significant difference between large and small targets. Mean for large targets: 5.2 Mean for small targets: 4.2 (108-112)
DIFFERENCES BETWEEN SKILLED AND UNSKILLED SUBJECTS.	No significant differences.	Mean search times were significantly higher for the skilled subjects. Overall mean for the skilled subjects is 15.8 secs., as compared with 11.1 secs. for the unskilled subjects.	No significant differences.

NOTE The numbers at the bottom right-hand corner of each cell are the numbers of the relevant pages of the report.

	DETECTION PROBABILITY	SEARCH TIME	CONFIDENCE LEVEL
N x R High/Low S/N ratios x R	No significant interaction Detection probability decreases linearly with range for both high and low S/N ratios in a similar manner, i.e. the two regression lines do not deviate significantly from parallel. (50-54)	No significant interaction No further analyses were carried out since the main S/N ratio effect was also not significant. (76)	No significant interaction No further analyses were carried out since in this case it was not appropriate to partition S/N ratios into high and low levels. (113)
N x T N x Target size	No significant interaction. Detection probability increases linearly with S/N ratio for both large and small targets in a similar manner; the two regression lines do not deviate significantly from parallel. Detection probabilities are significantly lower for small targets at each S/N ratio. (55-60)	No significant interaction No further analyses were carried out since the main S/N ratio effect was also not significant. (76)	Significant interaction ($p < 0.01$) i.e. the twelve targets are differently affected by S/N ratio. For large targets confidence levels increase with increasing S/N ratio in a non-linear manner. For small targets S/N ratio has no significant effect on confidence level. Large targets have significantly higher confidence levels at each S/N ratio. (114-119)
R x T R x Target size	Significant interaction ($p < 0.001$) i.e. the twelve targets are differently affected by range. Detection probability decreases linearly with range for both large and small targets, but the regression lines are significantly non-parallel and tend to converge towards longer ranges. Detection probabilities are significantly lower for small targets at each range. (61-66)	Significant interaction ($p < 0.01$) i.e. the twelve targets are differently affected by range. For large targets search times increase linearly with range. For small targets this effect does not reach significance but there is no evidence that the two regression lines deviate significantly from parallel. Search times are significantly lower for large targets at each range. (90-95)	Significant interaction ($p < 0.001$) i.e. the twelve targets are differently affected by range. Confidence levels decrease linearly with increasing range for both large and small targets in a similar way, i.e. the two regression lines do not deviate significantly from parallel. Confidence levels are significantly lower for small targets at each range. (120-124)

NOTE The numbers at the bottom right-hand corner of each cell are the numbers of the relevant pages of the report.

TABLE 7.6.3

Summary table of the Kendall rank correlation coefficient, tau, for the correlations between the rank orders of the twelve targets according to the four performance measures.

	Detection probability	Search time	Confidence level	Map-briefing time
Detection probability	tau = 0.71 $p < 0.01$	tau = 0.73 $p < 0.001$	tau = 0.77 $p < 0.001$	tau = 0.50 $p < 0.05$
Search time	tau = 0.58 $p < 0.01$	tau = 0.63 $p < 0.01$	tau = 0.80 $p < 0.001$	tau = 0.45 $p < 0.05$
Confidence level	tau = 0.54 $p < 0.01$	tau = 0.74 $p < 0.001$	tau = 0.57 $p < 0.01$	tau = 0.52 $p < 0.05$
Map-briefing time	tau = 0.13 N.S.	tau = 0.21 N.S.	tau = 0.41 N.S.	tau = 0.50 $p < 0.05$

Values on the diagonal line relate to the correlation between the rank orders of the targets for skilled and unskilled subjects on the same performance measures. Values above, and to the right, of this line relate to correlations between the different performance measures for unskilled subjects. Values below, and to the left, of the diagonal line show the corresponding values for the skilled subjects. All significance levels shown relate to two-tail tests.

Positive correlations in this table indicate a correlation between high detection probability, low search time, high confidence level and low map time. For the unskilled subjects it can be seen that all correlations between performance measures are significant, i.e. those targets which are associated with high detection probabilities also tend to be associated with low search times, high confidence levels and low map times. These can be regarded as relatively easy targets. Conversely, the more difficult targets were associated with low detection probabilities, high search times, low confidence levels and high map times. In each case the correlations involving map times are less significant than those for the other performance measures. For the skilled subjects the map time correlations fail to reach significance although the other measures are significantly correlated. The correlations between unskilled and skilled subjects for each performance measure are all significant.

8. DISCUSSION

The results of this experiment have been reported in detail in Section 7. The principal purpose of this section is to discuss the more important of these results, particularly those concerned with the effects of signal/noise ratio and target size, and to consider possible implications arising from them. This discussion is mainly concerned with the results for unskilled subjects for whom more extensive data were available. In general, the performance of the skilled subjects was very similar to that of the unskilled but where there are important differences these have been noted.

Throughout the discussion the emphasis is on the detection probability results since this was the most important of the performance measures used and these results could most appropriately be compared with those found by other workers. However, where the importance of the results justifies it the other two performance measures are also discussed.

For convenience the discussion has been divided into the following parts:

8.1 The effect of signal/noise ratio on detection performance.

8.2 The effect of range on detection performance.

8.3 Target differences.

8.4 Interaction effects.

8.5 Differences between skilled and unskilled subjects.

8.6 Relationship between psychometric measures and detection performance.

8.7 Comparison of the results with those found from dynamic experiments.

8.8 Further work.

8.1 The effect of signal/noise ratio on detection performance

The results of this experiment showed that the signal/noise ratio of the display system significantly affected detection performance, for both skilled and unskilled subjects, in terms of detection probability and confidence level but it had no effect on search time. For unskilled subjects the actual mean detection probabilities at each signal/noise ratio showed a significant decrease between the 24 and 19 dbs levels (from 0.54 to 0.39), whereas there was very little difference between the 14 and 19 dbs level or between the 24 and 30 dbs levels. However, there was no evidence that the data were non-linear within the overall 14 - 30 dbs range of signal/noise ratios investigated. The deviation about the linear regression was non-significant, and small as compared with the significant linear component. The results for skilled subjects, who were exposed only to signal/noise ratios of 14 and 24 dbs, were in good agreement with corresponding values for unskilled subjects.

These data suggest that, under the conditions investigated in this experiment, the critical region for signal/noise ratios is between 24 and 19 dbs. It was not possible to determine the exact nature of the relationship between detection probability and signal/noise ratio within this region since no data were available relating to intermediate values. It must be concluded that, in the absence of further information relating to this critical region, the signal/noise ratio of a television display system used for target acquisition tasks of this type should not be allowed to fall below the 24 dbs level. However, the extent to which the results of this static simulation experiment can be applied to dynamic situations requires further consideration, particularly in relation to the detection of small targets. The application of the data obtained in this experiment to operational conditions is discussed in detail in a later section (Section 8.7). The remainder of the present section is concerned with a more general discussion of the observed effect of signal/noise ratio on performance, in relation to the complex nature of the task involved.

The task of an airborne observer required to locate and recognise a given target by means of a television viewing system can be regarded as consisting of two main parts. The first of these is overall geographic orientation during which the observer has to recognise conspicuous features in the terrain and use these to determine his position in relation to the target. He should then be able to locate the probable target area. The second part is the detection and recognition of the target itself. The difficulty of this is likely to depend largely on the apparent size and conspicuity of the target, as it appears on the television monitor. The relative importance of these two parts of the overall task depends very much on the particular situation investigated, especially the type of targets and terrain, the altitude and speed of the aircraft, and field of view of the camera. This discussion is concerned only with the conditions studied in the present experiment in which the type of target varied considerably, particularly in ground size, the largest being an airfield and the smallest a minor road/river bridge. Range varied from 1 to 4 miles. Other relevant factors, including the type of terrain, remained effectively constant.

To discuss possible explanations for the effect of signal/noise ratio on detection performance it is necessary to consider the possible effect of visual noise on the two separate parts of the target acquisition task. Geographic orientation is likely to depend very much on large or particularly conspicuous features in the foreground of the terrain, as displayed on the television monitor. These are the features of greatest value to the observer in the initial orientation task. The extent to which geographic orientation becomes more difficult under conditions of decreasing signal/noise ratio therefore depends largely on whether those features become more difficult to recognise as visual noise increases.

It appears reasonable to assume that the features of importance in geographic orientation are of a size and conspicuity similar to those of the large target group studied in this experiment. (The basis on which the classification of targets was made has been described in Section 7.1.3 and is discussed in Section 8.3.2). The results of this experiment show that the recognition of these large targets at ranges of 1 - 2 miles is not significantly affected by decreasing the signal/noise ratio from a high level (24 - 30 dbs) to a low level (14 - 19 dbs). This can be seen in Figure 7.1.8 (page 70). The important conclusion that can be drawn from this is that the initial geographic orientation part of the overall target acquisition task is likely to be relatively little affected by decreasing the signal/noise ratio of the display system.

On the other hand decreasing the signal/noise ratio is likely to have a detrimental effect on the second part of the task, target recognition. If the apparent size and conspicuity of the target is such that many of the important cues to recognition are totally or partially obliterated by the superimposed visual noise then recognition of the targets will become more difficult as the amount of noise increases. In particular, work carried out by Crook and Coules (1959) suggests that if the target contours are seriously degraded by visual noise then recognition performance will deteriorate. The overall effect is likely to be more marked for targets which occupy a relatively small proportion of the display. Targets which occupy a relatively large proportion of the display are much less likely to be affected by visual noise, within the limited range of signal/noise ratios studied in the present experiment. For these targets many of the critical features on which recognition depends are sufficiently large and conspicuous for the effect of noise to be comparatively slight. Overall recognition of the target is therefore likely to be little affected by the presence of noise.

The ground size of the targets studied in the present experiment, and the ranges from which they were viewed, gave rise to some apparent target sizes which could be regarded as very large. However, the majority of the target size and range combinations gave rise to relatively small apparent sizes. The effect of visual noise on recognition could therefore be expected to depend both on target size and range, which together largely determined the apparent size of the target as displayed on the television monitor.

In general, it is reasonable to conclude that overall geographic orientation is unlikely to be seriously affected by decreasing the signal/noise ratio, but that the actual recognition of some of the targets, under conditions resulting in small apparent sizes, will be adversely affected.

The fact that signal/noise ratio was not found to have a significant effect on search time is also in accordance with expectation since the geographic orientation part of the task is liable to take up most of the search time. When the observer has decided on the probable target area, the time taken to recognise the target, if in the expected location, should be relatively short. If he cannot recognise the target in the position he expects he would be likely to attempt further orientation. Thus, if orientation is not affected by signal/noise ratio, then search time is unlikely to be significantly affected. Furthermore, it would also be expected that there would be no interaction between signal/noise ratio and either range or targets in the search time data. This was in accordance with the results found.

The effect of signal/noise ratio on detection probability, which was discussed earlier and is illustrated in Figure 7.1.1 (page 41), can be interpreted in relation to the above discussion. The significant performance deterioration associated with a reduction of the signal/noise ratio from 24 to 19 dbs suggests that the increased degradation of the display between these values is critical in relation to the size and conspicuity of essential cues to the recognition of some of the targets. Since very little additional deterioration in performance is observed when the signal/noise ratio is further decreased to 14 dbs it appears that the degradation of important cues associated with this level of noise is effectively no more detrimental than that at 19 dbs. Thus, cues essential to the recognition of some targets appear to undergo critical degradation between the 24 and 19 dbs level, whereas **for** other targets the essential cues are unaffected by the entire 30 - 14 dbs signal/noise ratios investigated. As discussed above, the targets for which detection performance is most likely to be affected by the levels of noise studied are those presented under conditions in which their apparent size is relatively small.

Although this experiment was concerned with a relatively limited range of signal/noise ratios the results obtained can be related to the overall effect on detection performance of a much wider range of signal/noise ratio conditions. At extremely low signal/noise ratios the degrading effect of the visual noise would be so great that virtually no useful information could be obtained from the display. Under such conditions geographic orientation and target recognition would be impossible and performance would be either zero or at an extremely low level representing random guessing. As the signal/noise ratio is increased there would be no effect on detection performance until at least some of the major features of the terrain could be identified. At this level performance would start to improve and continue to do so as signal/noise ratio is further increased and more features become recognisable. Performance would show further improvement until the signal/noise ratio reached a value at which the degradation caused by visual noise was no longer the factor limiting performance. At this point detection performance would level out and no further improvement would take place. The overall relationship between detection performance and signal/noise ratio can therefore be regarded as a curve, asymptotic to zero (or random level) performance at low signal/noise ratios and asymptotic to maximum performance at some relatively high value of signal/noise ratio, depending on the conditions studied. The exact nature of the relationship between these points can only be determined by an extensive study of the complete range of signal/noise ratio values.

However, it is of importance to attempt to relate the limited range of signal/noise ratios studied in the present experiment to this overall curve. There is some evidence to suggest that the 30 dbs level investigated is approaching the upper asymptotic value for the types of targets and conditions studied. This evidence comes from a comparison of the results obtained in Experiment I with those obtained in the present experiment. Unfortunately, the two sets of data are not directly comparable since the detailed analysis of Experiment I involved only three range conditions (1 - 3 miles) and seven targets. To compare the results of the two experiments it was necessary to extract the appropriate data from those obtained in the present experiment.

It should also be noted that the viewing distance used in the present experiment (21") was greater than that used in Experiment I (13"). However, this was not a serious discrepancy since the second experiment in this series had shown that there was no deterioration in performance due to increasing viewing distance from 13" to 21". The amount of data obtained at the 21" viewing distance was inadequate for comparison with that obtained in the present experiment and therefore the more extensive data from Experiment I were used for this purpose.

The results of these comparisons indicated that the overall detection probability under conditions of photographic presentation was 0.63 as compared with 0.57 found in the present experiment for the same targets and range conditions at the 30 dbs signal/noise ratio. This difference was not significant which suggests that little improvement would occur if the signal/noise ratio was increased above 30 dbs. There was also no significant difference between detection probabilities associated with photographic presentation and with the 24 dbs signal/noise ratio condition. However, both the lower signal/noise ratios resulted in lower detection probabilities, significant at each range, than photographic presentation. Averaged over all signal/noise ratios, as shown in the results section in Figure 7.1.3 (page 43) this difference was also significant at each range. Furthermore, there was no apparent interaction between range and presentation mode.

For the type of targets studied it is reasonable to conclude that the high levels of signal/noise ratio are towards the upper end of the overall curve relating detection probability to signal/noise ratio. On the other hand, it is not possible to determine the position of the 14 dbs level, the lowest studied, in relation to the lower end of the overall curve. Since the mean detection probability was approximately 0.36 at this value it is clear that the signal/noise ratio could be further decreased before performance reaches the lower asymptote. It is not possible to predict at what signal/noise ratio this would occur for target groups, such as the present one, in which target size varies considerably.

More precise information can be obtained by considering the effects of signal/noise ratio on targets of large and small apparent sizes separately. Although the basic form of the overall curve would be the same for both kinds of targets, with asymptotes at either end, the relative positions of the curves along the signal/noise ratio axis would be different. Large targets would become asymptotic to zero performance, and to maximum performance, at lower signal/noise ratios than for small targets. Furthermore, the curve for large targets would level out at a higher value of maximum detection probability than that for small targets. It is possible that the results obtained in the present experiment arose from the combined effects of these two different curves in the particular region of signal/noise ratios investigated.

The effect of signal/noise ratio on large and small targets is shown in Figure 7.1.6 (page 58), but this classification of targets is not based on apparent size. The results are therefore difficult to interpret in relation to the hypothetical curves discussed above. For small targets, which could all be regarded as small in apparent size at all ranges, detection probabilities are relatively low but it is not possible to predict where the 14 - 30 dbs region investigated would fall in relation to the appropriate hypothetical curve, or at what maximum value performance would level out. Unfortunately, not enough data relating to small targets were available from Experiment I to allow appropriate comparisons to be made between the 30 dbs signal/noise ratio, television presentation and photographic presentation for these targets. These comparisons would have given some indication of the maximum performance level that could be expected for small targets under optimum conditions of signal/noise ratio. As can be seen in Figure 7.1.6 the increase in detection probability with increasing signal/noise ratio for small targets is much more closely linear than that for large targets. However, the very limited data available from Experiment I suggested that increase in signal/noise ratio would not result in a significant improvement in detection performance, although slightly higher values could be expected.

The large targets studied in this experiment could not be regarded as large in apparent size at all ranges, but at short ranges they were very little affected by the 14 - 30 dbs signal/noise ratios investigated. This suggests that this region was towards the upper end of the hypothetical curve for large targets.

8.2 The effect of range on detection performance

The results of this experiment showed that for unskilled subjects range significantly affected the three main performance measures, although for search time the effect was only of borderline significance. Performance deteriorated consistently as range increased; mean detection probability and confidence level were lower and search time was higher. In each case the relationship was linear. For the skilled subjects only detection probability was significantly affected by range. For search time and confidence level the overall trends were similar to those for unskilled subjects, although non-significant.

The significant effect of range on performance for unskilled subjects was also found in previous experiments and would be expected from the nature of the task involved. As in the case of signal/noise ratio, the effect of range on the two main parts of the target acquisition task, geographic orientation and target recognition, can be considered separately. It seems reasonable to suppose, particularly under the conditions of the present experiment, that the overall geographic orientation task depends largely on the recognition of conspicuous features at relatively short ranges, 1 - 2 miles. The correct interpretation of ground structure beyond these features is complicated by the perspective effects inherent in oblique terrain views. In particular, the effects of masking and clutter are accentuated. Thus, correct geographic orientation and location of the target area become more difficult and the chance of error greater as the range of the target increases.

Target recognition depends, once the correct target area has been located, mainly on the apparent size and conspicuity of the target which determine whether critical cues to recognition are available. As range increases the apparent size of the target decreases (provided that the camera field of view is constant) and contrast is reduced by atmospheric attenuation. The difficulty of the target recognition task therefore increases rapidly with increasing range, and for small targets may become impossible at ranges of more than 3 miles. The effect of range on targets of different sizes is considered in detail in Section 8.4.3 and here it need only be noted that both geographic orientation and target recognition tend to become more difficult as range increases. This is in good agreement with the results found in the present experiment, although the linear nature of the relationship would not necessarily have been predicted. This linearity is likely to be a feature of the particular range values studied (1 - 4 miles), and it may not be maintained at longer ranges.

The deterioration in performance brought about by increasing range results from a change in scene content, the overall effect of which is to make target acquisition more difficult. This can be contrasted with the effect of decreasing the signal/noise ratio of the display system which also results in a deterioration in performance. In this case the actual content of the scene displayed is not changed but the quality of the display is degraded by the visual noise. As discussed in Section 8.1 the deterioration due to decreasing the signal/noise ratio seems to be brought about by the increased difficulty of target recognition, whereas the deterioration due to increasing range appears to be associated with both geographic orientation and target recognition, but more extensive research would be required to investigate these possibilities further.

8.3 Target differences

8.3.1 Differences between individual targets

Analysis of the data obtained in this experiment showed that for unskilled subjects target differences were the largest source of variation in each of the three main performance measures. This had also been found in previous experiments and there was no evidence to suggest that the inclusion of five new targets in the test sequence significantly altered the overall characteristics of the target group. This suggests that the targets studied in this series of experiments can be regarded as a representative sample of ground features of different sizes in Southern England.

The significant correlations between the rank orders of the targets according to detection probability, search time and confidence level were also not affected by the addition of the five new targets. Furthermore, there were significant correlations between the rank orders on each measure for skilled and unskilled subjects. These results were also found in Experiment I and need not be discussed here.

One result found in the present experiment, but not previously, was that for unskilled subjects map-briefing times were significantly correlated with other performance measures. Shorter map-briefing times were associated with higher detection probabilities, lower search times and higher confidence levels. This suggests that these subjects tended to find the map-briefing task easier for those targets which subsequently proved easier to detect.

8.3.2 Classification of the targets.

It had been clear from previous experiments that a large amount, although not all, of the variation between targets was due to the large differences in target size. The increased number of test targets included in this study made it possible to divide the targets into two groups and carry out separate analyses on each group. This division was made basically according to the ground size of the targets. Six of them, such as bridges and buildings, could clearly be regarded as small and difficult to detect and three, a pond, an airfield and a village were obviously large. The remaining three targets, although relatively small, were situated very close to large conspicuous terrain features, as detailed in Appendix III. These targets were more difficult to classify since recognition of the adjacent feature led almost inevitably to correct recognition of the target itself, in spite of its small size. Thus, detection performance associated with these targets would tend to be more characteristic of large targets than of small targets. These three targets were therefore included in the large target group since not enough data were available to allow separate analysis of more than two groups. In terms of detection probability the results showed that there were no significant differences between five of the six targets which formed the large target group. The remaining target (Target 10), although sixth in the rank order, had a detection probability more characteristic of those associated with small targets. This can be seen in Figure 7.1.4 (page 46). It appeared that in this case the adjacent terrain feature was less conspicuous than would have been expected from the map information.

Having divided the targets into these two groups it was possible in the case of each performance measure, to partition the total variation into three components relating to the variation due to differences between the groups and due to differences within each group. As shown in the Results section the difference between the large and small groups was by far the largest source of target variation in each performance measure. Furthermore, for both detection probabilities and search times the variation within each of the two groups was not significantly different. Thus, this classification led to two relatively homogenous target groups instead of one in which there was a very high degree of variation. It was therefore possible to make more precise analyses of the data.

This method of classifying targets, although apparently justified in this case, is not altogether satisfactory since it depends in some instances on a subjective judgment of the importance of terrain features other than the target itself. An objective method of classifying targets on the basis of apparent size is described by Rusis and Snyder (1965) who carried out a dynamic simulation study of the effect of the T.V. camera field of view on the detection of targets of different sizes. They determined, for each of 15 targets, the percentage of the film frame (52° x 40° camera field of view) covered by the target at a range of 1000 ft. and an altitude of 500 ft. These percentages were then rank ordered and the targets on one half of the resulting continuum were defined as small (mean area covered = 0.5%) and those on the other half as large (mean area covered = 14%). No indication is given as to the extent of the variation within each of these groups.

This method of classification has the advantage of depending only on physical measurements, and apparent size is likely to be a better guide than ground size as to whether a target will be readily detected. Kause (1965) studied the effect of television picture degradation on target detection in a static simulation experiment involving both high-altitude and low-altitude imagery. In this experiment target size was stated in terms of ground size and visual angle subtended. There was considerable variation in the ground size of the nine targets studied. They ranged from 27 ft. to 392 ft., but seven of them were less than 110 ft. Although better performance was associated with the two largest targets, calculation of Kendall's tau for the correlation between the rank orders of the seven relatively small targets on the basis of ground size and percentage of correct recognitions, indicated that there was no significant correlation between target size and detection probability.

This absence of correlation can be explained by the fact that within a relatively homogenous group of targets the slight differences in size do not give rise to consistent differences in performance and thus there is no correlation between ground size and detection rate. Although size is a convenient basis of classification it cannot be used to reliably predict detectability unless the size differences are very large. Particularly in the case of small targets, detection is likely to be greatly influenced by other factors, including the presence of conspicuous 'lead-in' features. This is also shown by the results of the present experiment in which it was found that the detection probabilities for small targets situated close to large, conspicuous features were similar to those for large targets.

8.3.3 Differences between large and small targets

As discussed in the previous section the classification of the twelve targets into six large targets and six small targets, resulted in two relatively homogeneous groups. The differences between these groups, in terms of the three performance measures used, were highly significant and the variation within the groups, although significant, was very much less. For convenience the overall means of the three performance measures for unskilled subjects are summarised in Table 8.3.1.

TABLE 8.3.1

Mean values for the performance measures for large and small targets

	Detection probability	Search time	Confidence level
Large targets	0.68	9.0 seconds	5.2
Small targets	0.24	13.2 seconds	4.2

It can be seen that the mean detection probability for small targets is only slightly more than one third that for large targets. In contrast to this substantial fall in detection probability the mean confidence level for small targets is approximately 80% of that for large targets. Since the confidence level scale ranged from 7 (completely certain) to 1 (very uncertain) the mean value associated with large targets accurately reflects the actual performance level in terms of detection probability. The very optimistic value for the confidence level associated with small targets may be due to the fact that subjects were only using the upper half of the scale, or it may represent a genuine over-estimation of their performance. Very similar values were found for the skilled subjects.

The low value of the overall detection probability for small targets relative to that for large targets can be ascribed mainly to the difficulty of recognising targets which occupy only a very small proportion of the display. In the present experiment the apparent size of the targets, in terms of the proportion of the display occupied, depended largely on the ground size of the targets and on range. The classification of targets into large and small groups on the basis of ground size and the presence of conspicuous terrain features has been discussed in the previous section.

Since the camera field of view and the display size remained constant, apparent size and range were inevitably confounded. The large targets, viewed from ranges of 1 or 2 miles, occupied on average approximately 15% of the display. (In the case of targets situated immediately adjacent to large terrain features, this value relates to the size of the large feature and not the target itself). Under the conditions studied in the present experiment these targets viewed at short ranges were extremely conspicuous and could be regarded as large in apparent size. When the same targets were viewed at ranges of 3 or 4 miles the proportion of the display occupied by the targets decreased to an average value of approximately 1%. This value was comparable to the average for small targets viewed from 1 to 2 miles. At longer ranges the small targets occupied considerably less than 1% of the display.

The difference between the value of 15% (corresponding to large apparent size) for large targets viewed at short ranges and the values of 1% or less (corresponding to small apparent size) for all other target size and range combinations appeared to be critical in this experiment, very high detection probabilities and confidence levels being associated with large apparent sizes. Thus there was an important difference between the large and the small target groups in terms of the effect of range on apparent size. Whereas the small targets under all range conditions were effectively small in apparent size, the large targets were either large or small in apparent size depending on the range from which they were viewed.

This difference complicated the interpretation of effects which appeared to depend on apparent size.

It should be emphasised that this experiment was not intended to investigate effects due to apparent size. The classification of targets was basically according to ground size and was intended to allow more precise analysis of the data in relation to practical situations. Consideration of apparent sizes in the present experiment is only relevant to the interpretation of the results observed. A more extensive experiment in which the apparent sizes of the targets are carefully controlled in a quantitative manner would be required for the detailed investigation of the effect of visual noise on targets of different sizes.

8.4 Interaction effects

This section is concerned with the interactions between the main factors studied, signal/noise ratios, ranges and targets. Possible explanations can be suggested on the basis of similar assumptions to those made previously, for the results obtained from the analyses of these interactions. The three interactions are considered in the same order as the corresponding results sections: signal/noise ratio x range, signal/noise ratio x targets and range x targets.

8.4.1 The interaction between signal/noise ratio and range

The interaction between the four levels of signal/noise ratio and the four levels of range studied was found to be non-significant for each performance measure. Only in the case of the detection probability data was further analysis worthwhile. For this performance measure the effect of range on performance under conditions of high signal/noise ratio (30 and 24 dbs) and low signal/noise ratio (19 and 14 dbs) was analysed separately.

As would be expected, under both conditions detection probability decreased linearly with range. Furthermore, performance was lower and, in general, significantly so, at each range under conditions of low signal/noise ratio. This would also be expected since, as already discussed, low signal/noise ratios increase the difficulty of recognising targets of small apparent size. It might therefore be expected that the effect of low signal/noise ratios would be accentuated as range increased and apparent size decreased. Although there was some evidence of this, as shown by the fact that the regression lines of detection probability on range for the two signal/noise ratio conditions tended to diverge slightly towards longer ranges, the effect was not significant. A possible explanation is as follows. In this analysis all twelve targets were considered together. If all these targets were large in ground size, their apparent size on the television monitor would tend to be large at short ranges, 1 and 2 miles, but at long ranges, 3 and 4 miles, their apparent size would tend to be small. Thus one would expect that the detrimental effect on performance of decreasing the signal/noise ratio from high to low would be relatively slight at short ranges but significant at long ranges. The two regression lines would therefore diverge significantly towards the long ranges. On the other hand, if the ground sizes of all the targets were small, their apparent size on the television monitor would be small at all ranges. Thus the effect of decreasing the signal/noise ratio would be approximately the same at all ranges, and the two regression lines would be parallel. However, the twelve targets studied in this experiment comprised six large targets and six small targets. The differential effect of range on the detection of the twelve targets under high and low signal/noise ratio conditions would therefore be intermediate between that for large targets (significant effect) and that for small targets (non-significant effect). This was in agreement with the result found, a slight but non-significant tendency for the two regression lines to diverge towards longer ranges. Although this is only a qualitative explanation, some evidence for it can be seen in Figure 7.1.8 (page 70). This figure shows the regression lines of detection probability on range for high and low signal/noise ratio conditions, each further divided into large targets and small targets. It can be seen that for small targets the regression lines are almost exactly parallel, indicating that small targets are similarly affected by range under conditions of high and low signal/noise ratios. For large targets the corresponding regression lines tend to diverge towards longer ranges, indicating that the difference between high and low signal/noise ratios is greater at longer ranges. This is confirmed by the fact that at ranges 3 and 4 miles the differences between high and low signal/noise ratio values are significant whereas at ranges 1 and 2 miles they are not.

8.4.2 Signal/noise ratio x targets interaction

The results showed that for both unskilled and skilled subjects the interactions between the twelve targets and the four levels of signal/noise ratio were, in general, non-significant for each performance measure. The only exception to this was the significant interaction found in the confidence level data for unskilled subjects. In addition, for the detection probability data, the linear regression component of the interaction was highly significant. Thus there was evidence that performance associated with different targets was differently affected by decreasing the signal/noise ratio, as would be expected from the variation in apparent sizes.

For both the detection probability data and the confidence level data, the effect of signal/noise ratio was analysed separately for large and for small targets. This analysis was not carried out for search time data since signal/noise ratio had been found to have no overall effect on this performance measure.

Analysis of the detection probability data showed that for both large and small targets detection performance decreased linearly with decreasing signal/ noise ratio. At each of the four levels of signal/ noise ratio detection probability was significantly lower for the small targets as shown in Figure 7.1.6, page 58. Both these results would be expected from the detrimental affect of decreasing signal/noise ratio on the detection of targets of small apparent size. As discussed previously, all the targets in the small target group could be regarded as having small apparent size at all ranges. For these targets the relationship between signal/noise ratio and detection probability was closely linear. On the other hand, for the large target group the detection probability values at each signal/noise ratio represented an average effect on targets of both large apparent size (those presented at short ranges), and small apparent size (those presented at long ranges), since in this analysis the data were averaged over all ranges. Thus there was greater variability in these data. The regression line showed that performance deteriorated more slowly towards the lower signal/noise ratios than for the small target group. However, the extent to which the regression lines diverged was slight and the effect was not significant. This is due to the fact that, as previously explained, the large target group included targets of small apparent size (those presented at long ranges) and those reduced the overall interaction effect. This possible explanation for the results of the analysis of the interaction between signal/noise ratio and target size exactly parallels that for the interaction between range and high and low signal/noise ratios. Both explanations depend on the fact that range affects apparent size differently for small targets and for large targets, in terms of the significance of the signal/noise ratio effect. In the analysis of the interaction between high and low signal/noise ratios and range no distinction was made between targets of different sizes. Similarly, in the analysis of the interaction between signal/noise ratio and target size no distinction was made between different ranges. Thus the interaction between signal/noise ratio and the apparent size of the target was not apparent in either analysis.

The results found in the analysis of the effect of signal/noise ratio on confidence levels associated with large and small targets showed similar trends to those found for the detection probability data. Two differences should be mentioned. Firstly, there was evidence of non-linearity in the effect of signal/noise ratio on confidence levels for large targets, the value at 19 dbs signal/noise ratio being unexpectedly high. This corresponded to a detection probability value slightly lower than would have been expected which suggests that the subjects were not aware of the deterioration in their performance at this signal/noise ratio level. The second difference, the fact that for small targets there was no significant effect of signal/noise ratio on confidence level, also suggests that subjects were not accurate in assessing their own performance relative to the signal/noise ratio conditions tested.

8.4.3 The interaction between ranges and targets

The interaction between the ranges and targets was significant for each performance measure. Further analyses were carried out to determine the effect of range on large targets and small targets separately. In each case it was found that performance deteriorated with increasing range and that the levels of performance associated with small targets were significantly less favourable at each range than those for large targets. These results are in accordance with expectation. Although, for each performance measure, the two regression lines relating to large and small targets converged slightly towards longer ranges (see Figure 7.1.7, page 65, Figure 7.2.3, page 93 and Figure 7.3.4, page 123) this effect was only significant for the detection probability data.

The significance of this interaction would be predicted from the effect of range on apparent size for targets of different ground sizes. As discussed previously, large targets viewed from short ranges were large in apparent size, and were relatively easily recognised under the conditions investigated. At longer ranges the apparent sizes were small and a much higher degree of overall geographic orientation was necessary. Thus performance tended to deteriorate markedly with range. For small targets the effect of range on detection probability was less marked since even at short ranges these targets were not very conspicuous and to locate them some reference to surrounding terrain features was necessary. The two regression lines of detection probability on range were therefore non-parallel and tended to diverge at short ranges.

The various combinations of range and target size studied in this experiment resulted in considerable differences in the nature of the acquisition task, in terms of the relative importance of geographic orientation and target recognition. For large targets at the 1 mile range the task was extremely easy and almost no overall geographic orientation was necessary for correct recognition of the target. Conversely, for small targets at the four miles range actual recognition of the target was virtually impossible but the correct target area could be located by reference to more conspicuous terrain features. Between these two extremes, other combinations of target size and range resulted in situations in which, in varying degrees, both general geographic orientation and actual recognition of the target were important.

For small targets at the 4 mile range, location of the target area ($\pm$ 500 ft. from the target position) was regarded as a correct response. These limits made the task comparable to that of locating a large target at the 4 mile range. It therefore is possible to compare performance at this range for acquisition tasks in which only geographic orientation is involved (locating target areas for small targets), with those in which both orientation and recognition is possible, (actual recognition of large targets). The importance of actually being able to recognise the target, after locating the probable target area, is shown by the much higher probability for a correct response for the detection of large targets at 4 miles than for the detection of target areas, comparable in apparent size, for small targets. The difference in detection probabilities for large and small targets at this range is considerable, as can be seen in Figure 7.1.7, but other factors may also contribute to this.

A different situation occurs at the 1 mile range, at which, for large targets the task involves only recognition, whereas for small targets some degree of geographic orientation with reference to features in the foreground is also required. At this range the difference in detection probabilities for large and small targets is even greater than at range 4 miles, this being due to the particularly high values found for large targets when no overall orientation is necessary.

8.5 Differences between skilled and unskilled subjects.

The results of this experiment showed that there were no significant differences between skilled and unskilled subjects in overall mean detection probability and confidence level. These results are in agreement with those found in Experiment I and, in the case of the detection probability data are also in agreement with results found by Erickson (1966). He studied the visual search performance of 12 high school students and compared it with that of pilots. The experimental task was the recognition of a target against a plain background containing non-target objects, in the presence of visual noise. He found that the absolute performance of the students was effectively the same as that of the pilots. Erickson concludes that, if the task does not depend on specialised pilot experience, students can be used to give preliminary estimates of the visual search performance that could be expected from pilots.

Whilst the task in the present experiment is clearly much more closely related to the pilots' experience, it appears that, provided adequate training is given, unskilled subjects can achieve detection probabilities very similar to those of the skilled subjects. However, the static nature of this simulation technique made the experimental task somewhat unrealistic in terms of the operational experience of the pilots and possibly dynamic experiments would reveal differences between skilled and unskilled subjects. This is to some extent confirmed by a dynamic simulation experiment carried out by Gilmour (1964) in which the performance of skilled and unskilled subjects was compared. It was found that on first exposure to the series of targets the skilled subjects showed a higher probability of correct acquisition but there was no difference between the two groups in the range at which acquisition occurred.

The present experiment showed that the mean search times for the skilled subjects were significantly higher, and the mean map-briefing times significantly lower, than the corresponding values for unskilled subjects. On the basis of the results obtained in Experiment I it would have been expected that both search times and map times would have been lower for skilled subjects than for unskilled subjects. This apparent anomaly can be explained by differences between the two groups of skilled subjects. In Experiment I the skilled subjects were experienced at high-speed, low-level navigation carried out both by direct view and by means of television. In the present experiment the skilled subjects were not experienced at low-level flying or television navigation. Thus, although they were skilled at map-reading, and this is reflected by the fact that their map-briefing times were significantly less than those for unskilled subjects, the simulated television navigation task was new to them. It could therefore be expected that the mean search times would not be shorter than those for unskilled subjects. However, this does not explain why they were, in fact, significantly longer.

Two tentative suggestions can be put forward to account for this. Firstly, the skilled subjects were considerably older (average age 37 years as compared with 20 years for the unskilled subjects) and secondly, they were considerably less intelligent, as measured by Heim's test of intelligence, than the unskilled subjects. Taken together these two factors might account for the unexpectedly long search times required by the skilled subjects who took part in the present experiment, since older and less intelligent subjects might be expected to take longer to carry out a task new to them. This did not occur in Experiment I since, although the skilled subjects were again older than the unskilled subjects, they were experienced at television navigation and were of an average intelligence level comparable to and, in fact marginally above, that of the unskilled subjects.

In view of the lower average intelligence level of the skilled subjects who took part in the present experiment and their lack of television navigation experience it might be expected that they would have achieved a lower overall detection probability than the unskilled subjects. However, the results suggest that the comparable level of detection probability was achieved at the expense of the longer search times.

The overall conclusions that can be drawn from these comparisons of skilled and unskilled subject performance in Experiment I and the present experiment are that:

(a) The overall performance of skilled subjects in terms of detection probability is closely similar to that of the unskilled subjects. However, mean search times may be longer or shorter than those for unskilled subjects depending on the age, background experience and intelligence of the skilled subjects. If these are favourable, as in Experiment I, search times are likely to be shorter than corresponding values for unskilled subjects, If these factors are unfavourable, i.e. higher average age, lower intelligence and no experience of television navigation, as in the present experiment, search times tend to be longer for those found for unskilled subjects.

(b) Map-briefing times were consistently and significantly shorter for the skilled subjects than the unskilled subjects. These values were exceptionally short for the skilled subjects who took part in Experiment I.

(c) The overall performance of different groups of unskilled subjects in terms of the performance measures made is very consistent, provided that the subjects are of high intelligence and that the groups are equally matched in this respect. It is also important that they are adequately trained for the task and that the experimental procedure is standardised.

8.6 Relationship between psychometric measures and detection performance.

In general, detection performance did not correlate well with any of the individual scores obtained from psychometric tests. The main exception to this was the significant correlation for unskilled subjects between intelligence scores and accuracy scores, i.e. the proportion of correct detections made by each individual subject. As found in Experiment I, the more intelligent subjects tended to achieve a higher proportion of correct detections. This correlation was not significant for the skilled subjects. It is of interest to have confirmed the significance of the correlation between intelligence and detection performance for unskilled subjects since this clearly has implications in the selection of students to take part in this type of experiment.

The correlation between high scores on the neuroticism scale and low mean search times was significant for the skilled subjects but not for the unskilled subjects. This result was found for both groups of subjects in Experiment I and suggests that the more neurotic subjects, who would have found the situation more stressful, tended to work more quickly.

8.7 Comparison of the results with those found from dynamic experiments.

The performance measures used in the present experiment do not correspond directly with those obtained in dynamic experiments. In particular, the measurement of search time was unrealistic under static simulation conditions and it is difficult to relate these times to dynamic conditions. Furthermore, the measurement of a subjective judgment, confidence level, is apparently not used by other workers in this field of research and no comparisons can be made.

The detection probability results can be compared with those found by other workers but even in this case the overall means do not correspond directly. In dynamic experiments it is usual to measure the range at which recognition occurs and whether or not it was correct. Under such conditions, subjects, unless instructed otherwise, will tend to wait until the target is close enough for the chance of correct recognition to be high. In the present static experiment subjects were exposed to each target at one range only and had to attempt recognition at that range. Thus, if the range was relatively large the chance of correctly locating the target area was proportionately low. The small targets were normally undetectable at long range and location of the target area, ± 500 ft. from the target at a range of 4 miles, was counted as a correct response.

The detection probabilities averaged over all range conditions in the present experiment do not therefore adequately represent the proportion of targets that would be detected in a dynamic situation. Reports of dynamic simulation experiments suggest that the mean recognition ranges for small targets are 1 mile or less and for large targets are rarely more than 1 - 2 miles, depending on the method of simulation, altitude, field of view and other factors, (Gilmour, 1964, Rusis and Snyder, 1965). In relating the results of the present experiment to dynamic conditions it is therefore more appropriate to use the detection probabilities for the 1 mile range than the overall values. Even the 1 mile range values may be low as compared with dynamic data since in the present experiment subjects exposed to a target under the 1 mile condition had not previously seen any longer range view of that target. They had therefore no prior indications as to the probable target area which an aircraft navigator would normally have been able to acquire at longer ranges. This is likely to be more important for small targets than for large ones which are very conspicuous at the 1 mile range.

Dynamic experiments carried out by Gilmour (1964) and by Rusis and Snyder (1965) did not include visual noise as a factor for investigation, although the latter experiment did involve television presentation. Kause (1965) studied the effect of visual noise by a static simulation technique. Not only did the simulation methods differ in these three experiments, but also altitude, field of view and briefing material. It is therefore not possible to make detailed comparisons of the results of these experiments and the present one. However it is of interest to investigate in general terms the implications of the various results obtained, particularly in relation to the effect of target size on detection performance, under conditions of visual noise.

Kause concludes from the results of his experiment that in the airborne situation large military targets would be detected with a success rate of 90-100% over a wide variety of conditions including moderately severe picture degradation. This prediction is in accordance with the results reported by Gilmour and by Rusis and Snyder for large, conspicuous targets. The results of the present experiment indicate that for large targets detection probability is 87% at 1 mile range. The gradient of the regression line of detection probability on range for large targets (see Figure 7.1.7, page 65) predicts that at zero range the corresponding detection probability would be very close to 100%.

These values suggest that in a dynamic situation the chance of a correct detection before the target disappears out of the field of view will be 87 - 100% depending possibly on the extent of the dead-space in front of the aircraft. As shown in Figure 7.1.8 (page 70) the values are not very much affected by whether the signal/noise ratio is high or low. These results are therefore, as far as can be determined, in good agreement with those of other workers. Further evidence is provided by data obtained in dynamic simulation experiments carried out at the Royal Aircraft Establishment, Farnborough. The detection of a number of large targets was studied under conditions of signal/noise ratio varying from 12 dbs upwards. It was found that signal/noise ratio had no significant effect and detection rates were approximately 90%, again in good agreement with those discussed above. It is therefore reasonable to conclude that the detection of large targets, or the location of target areas, is not likely to give rise to serious difficulty under typical operational conditions.

The situation is considerably more complex for small targets and detection probabilities appear to vary widely according to the conditions investigated. Again, detailed comparisons between the results of the present experiment and those of other workers are not meaningful since the experimental conditions, particularly altitude and field of view, varied so widely. It is obvious, however, that the detection probabilities found in the present experiment are substantially lower than those reported by Kause (1965) and by Rusis and Snyder (1965) for small targets, although the ground size of the targets involved were comparable to those of the small targets used in the present experiment.

The relevant values obtained in the present experiment, relating to the 1 mile range, were 46% under conditions of high signal/noise ratio and only 20% under conditions of low signal/noise ratio. If the relative difference between these values is maintained under dynamic conditions and it is reasonable to suppose that this will be so, then it is clearly important that in operational situations the signal/noise ratio should not be allowed to fall below the high level (24 - 30 dbs) studied in this experiment. Preferably the value should be as close as possible to 30 dbs, particularly as the effect of decreasing signal/noise ratio on the detection of small targets may be accentuated under dynamic conditions.

There are a number of reasons why the mean detection probabilities found for small targets are low compared with those of other workers. In particular, for a comparable field of view, the detection probabilities reported by Rusis and Snyder (1965) for small targets relate to mean recognition ranges of approximately 0.50 miles, at an altitude of 500 ft., whereas in the present experiment no range values of less than 1 mile were studied. The type of briefing material used is also likely to be an important factor. In the static experiment carried out by Kause a high quality briefing photograph was provided, and subjects also had a preliminary high-altitude view in which to locate the target area. In the present experiment the only briefing provided was a 1 inch = 1 mile map. Thus, it would be expected that in both these experiments detection probabilities would be higher than those obtained in the present experiment, as was found.

It was possible that the actual detection probabilities for small targets at 1 mile range, obtained in the present experiment are also low as compared with those that might be obtained in flight trials under similar level of visual noise, particularly if more effective briefing material were available. However, for very small targets whose position cannot be directly related to information given on a map or other form of briefing material the situation is different and these detection probabilities, although low, are likely to be higher than those that would be found under operational conditions.

The results of the present experiment, considered together with those obtained by other workers under dynamic conditions, can thus be used to predict in general terms the effect of visual noise on dynamic detection performance. These conclusions can be summarised as follows:

(i) There is good agreement that large, conspicuous targets will be detected with a success rate of 90-100% under a wide range of operational conditions including moderately severe visual noise.

(ii) For small ground targets success rates are likely to be considerably lower than for large targets, although not as low as those found in the present static experiment, and they are likely to be significantly affected by conditions of visual noise. To minimise this effect signal/noise ratio should preferably not fall below 30 dbs and certainly not below 24 dbs. The type of briefing information used is also likely to be important.

(iii) For very small targets whose exact position cannot be determined from the available briefing information success rates cannot be predicted but they are liable to be extremely low in the presence of visual noise and, in some cases, the task may be impossible.

8.8 Further work

The results of the present experiments, and those obtained by other workers, indicate a number of areas in which further research into the effect of visual noise on target detection performance would be of value. Some of these are clearly related to practical situations, but others are of a more fundamental nature.

From a practical point of view further research should be closely associated with the operational requirements of the system. The present experiment showed that the signal/noise ratios studied allowed observers to achieve acceptable levels of performance for large targets. However, if the system is intended for use in the recognition of small targets, then the achievement of acceptable performance is more doubtful, even if the signal/noise ratio is maintained in the upper levels studied, 24 - 30 dbs. One important area of further investigation is therefore the acquisition of all types of small targets, in the presence of visual noise, under dynamic conditions.

One subject of this investigation could be to determine whether, under dynamic conditions, any improvement in the recognition of these targets would result from increasing the signal/noise ratio above 30 dbs. On the whole, the results of this experiment suggest that such an improvement, if it occurred at all, would not be large enough to justify the additional cost and complexity involved, except in very critical situations.

Since it appears that, above this upper level, performance is limited by factors other than visual noise, then further work should be directed towards the improvement of performance by different means. If the critical factor affecting performance under conditions of noise is the apparent size of the target on the display, then it is possible that decreasing the field of view and thus magnifying the target would result in an improvement in recognition performance. However, this tends to lead to increased difficulty in geographic orientation which is particularly important in the acquisition of small targets. This problem could be overcome by the use of a variable focal length lens but such systems tend to reduce resolution. It is therefore difficult to assess the overall effect of magnifying the target but, if a wide field of view were also available for orientation purposes, this facility might have a favourable effect on performance under conditions of noise.

Another factor which might prove of importance in improving acquisition performance under conditions of visual noise is the type of briefing information given. It is common practice to use a high quality target photograph, when this is available, for briefing purposes both in operational situations and in some of the simulation experiments described in this report. The advisability of presenting photographic briefing material under noise-free conditions as an aid to performance under conditions of visual noise can be questioned, since it is vital that briefing information should not be misleading. It is possible that high quality briefing material gives rise to false expectation, even if the subject is aware that the quality of the display he is subsequently to be presented with may be degraded. This is likely to be detrimental to performance.

There is some evidence for this from an experiment carried out by Baker, Morris and Steedman (1960). They studied the speed and accuracy of form recognition as a function of, among other factors, the amount of distortion between the reference form which acted as briefing material, and the target form which was embedded in a complex display. The results showed that both search time and errors increased as the degradation of the target form relative to the reference form increased. The display degradation studied was a decrease in resolution, but it is certainly possible that a similar effect would be found if the degradation was caused by visual noise.

A further result found by Baker et al was that the absolute resolution of the forms appeared to be of little significance so long as the resolution of the reference form was the same as that of the target form. Although this result may not apply in the case of degradation due to visual noise, it would be worth investigating the possibility in the context of the situation involved in the televisual detection of ground targets during high-speed, low-level flight. Such an experiment would clearly have important implications for acquisition tasks in which a target photograph was the main form of briefing information.

Although the present experiment was intended to provide information of basically practical, rather than fundamental value, the detailed analysis of the data allows interpretation of the results in terms of a number of possible explanations. The validity of the suggestions put forward to account for the observed effects could be assessed by means of more fundamental studies. In particular, the following investigations would confirm or refute the explanations put forward:

(a) A study of the effect of noise on the recognition of targets of different apparent sizes under conditions in which apparent size was not confounded with range. Rigorously controlled conditions could possibly most easily be obtained by the use of simulation techniques, particularly high fidelity terrain simulation.

(b) An investigation into the effect of visual noise on (i) geographic orientation and (ii) target recognition carried out as separate tasks rather than combined in the overall acquisition task.

(i) The ability of a subject to relate map information to a terrain display, on which visual noise was superimposed, could be studied.

(ii) Target recognition in the presence of noise could be studied by investigating changes in 'available range', as described by Gilmour (1964), as visual noise increases.

(c) An experimental investigation of the possibility that, if moderate noise has little or no effect on geographic orientation, this could be partly due to the fact that the electronic noise on the display may tend to reduce the effects of 'terrain noise'. Thus, unwanted features in the display, which yield no useful information would appear to be masked, but the major features of the terrain, recognition of which is vital to correct orientation, would be relatively little affected. Some form of artificial display simulating conspicuous 'lead-in' features and various levels of terrain noise could be used in this type of study.

(d) A study of the effect of a much wider range of signal/noise ratios on targets of known sizes so that hypothetical curves discussed in Section 8.1 could be investigated.

These suggested investigations would involve a very extensive research program but the results would be of value, not only in relation to the effects of visual noise, but also in elucidating the fundamental nature of the target acquisition task.

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APPENDICES

APPENDIX I

Since this report contains a number of references to the first experiment carried out in this series, the summary and a table of the main results found in Experiment I 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 I

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

The design of this experiment was based on a 12 x 16 (targets x conditions) matrix. The 16 conditions tested resulted from the combination of four S/N ratio values and four range conditions. Sixteen unskilled subjects were assigned to the matrix so that each subject saw each target once and once only and each S/N ratio and each range three times. This matrix was replicated twice using a total of 32 subjects.

The eight skilled subjects were exposed to only two S/N ratios and the experimental design was therefore based on a 12 x 8 (targets x conditions) matrix. The experimental schedules for unskilled and skilled subjects are shown on the following pages.

UNSKILLED SUBJECTS.

Range	S/N ratio	TARGETS 3	14	17	16	15	13	1	20	10	6	5	9
1	14	1	5	9	13	16	12	8	4	11	3	15	7
	19	2	6	10	14	15	11	7	3	9	1	13	5
	24	3	7	11	15	14	10	6	2	12	4	16	8
	30	4	8	12	16	13	9	5	1	10	2	14	6
2	14	16	4	8	12	1	13	9	5	6	10	2	14
	19	13	1	5	9	4	16	12	8	7	11	3	15
	24	14	2	6	10	3	15	11	7	5	9	1	13
	30	15	3	7	11	2	14	10	6	8	12	4	16
3	14	11	15	3	7	6	2	14	10	16	8	12	4
	19	12	16	4	8	5	1	13	9	14	6	10	2
	24	9	13	1	5	8	4	16	12	15	7	11	3
	30	10	14	2	6	7	3	15	11	13	5	9	1
4	14	6	10	14	2	11	7	3	15	1	13	5	9
	19	7	11	15	3	10	6	2	14	4	16	8	12
	24	8	12	16	4	9	5	1	13	2	14	6	10
	30	5	9	13	1	12	8	4	16	3	15	7	11

The numbers shown in this matrix relate to 16 unskilled subjects who were exposed to the combinations of target-range-S/N ratio conditions as indicated. The order of presentation was randomised in each case. This matrix was replicated twice. For the second replication, using a further 16 subjects, the orders of presentation were re-randomised.

SKILLED SUBJECTS

Range	S/N ratio	TARGETS 3	14	17	16	15	13	1	20	10	6	5	9
1	14	1	8	7	6	5	4	3	2	1	8	5	4
	24	2	1	8	7	6	5	4	3	2	7	6	3
2	14	3	2	1	8	7	6	5	4	3	2	7	6
	24	4	3	2	1	8	7	6	5	4	1	8	5
3	14	5	4	3	2	1	8	7	6	5	4	1	8
	24	6	5	4	3	2	1	8	7	6	3	2	7
4	14	7	6	5	4	3	2	1	8	7	6	3	2
	24	8	7	6	5	4	3	2	1	8	5	4	1

The numbers shown in this matrix relate to the 8 skilled subjects who were exposed to the target-range-S/N ratios as indicated. The order of presentation was randomised in each case.

APPENDIX III

In the detailed statistical analysis of this experiment the twelve targets were divided into two groups of six. The first group consisted of small targets, e.g. bridges, buildings, etc. The second group of targets consisted of targets which were either large, e.g. an airfield, or situated immediately adjacent to a large conspicuous feature, e.g. a station immediately adjacent to a large pond. Since recognition of the conspicuous feature greatly facilitated detection of the adjacent target, it was appropriate to include these three targets in the large target group. Details of the targets in each group are shown on the following pages.

CLASSIFICATION OF TARGETS INTO TWO GROUPS

SMALL TARGETS		
Number	Name	Description
1	Aldershot Garrison Church	A church situated in a dense built-up area, interspersed with woodland.
5	Wellington Monument	A white obelisk situated in woodland.
6	Road/river bridge near Sheffield	A bridge partially masked by a surrounding patch of woodland.
13	Cross-roads at Bordon Camp	Cross-roads in a built-up area.
15	Cross-roads at Hindhead	Cross-roads in built-up area surrounded by woodland.
17	Charterhouse School	School buildings surrounded by fields on the edge of a built-up area.
LARGE TARGETS		
9	Odiham airfield	An airfield situated in open country.
14	Frensham Pond	A large conspicuous pond
16	Chiddingfold Village	A village in an open area surrounded by dense woods.
3*	Fleet Station	A small station on a long straight stretch of railway and adjacent to a large pond.
10*	Rail/road bridge East of Chawton	A bridge close to two large patches of woodland and a large country house.
20*	Major road-over-road crossing	A flyover at the junction of four major roads, close to a large conspicuous wood.

*The asterisk indicates targets which are close to large conspicuous features.

APPENDIX IV

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, who wrote the following report.

Logit analysis of detection probability data

The method is basically a linear logit model being fitted to the 192 observations, each providing a number of successes out of 2. No account is taken of subjects. The independent variables are:

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 " " 20, " 0

x_9 = 1 " " 10, " 0

x_{10} = 1 " " 6, " 0

x_{11} = 1 " " 1, " 0

x_{12} = 1 " " 5, " P

(x_2 to x_{12} thus represent comparisons of each target with target 9. Note that targets are used in a different order from that on the data sheets, due to a confusion in punching instructions).

x_{13} = -3 for 1 mile
-1 for 2 miles
1 for 3 miles
3 for 4 miles

x_{13} represents linear range effect

x_{14} = 1 for 1 mile
-1 for 2 miles
-1 for 3 miles
1 for 4 miles

x_{14} represents quadratic range effect

x_{15} = -3 for S/N ratio 14(dbs)
-1 for S/N ratio 19 "
1 for S/N ratio 24 "
3 for S/N ratio 30 "

x_{15} represents linear noise effect

$$x_{16} = \begin{cases} 1 & \text{for S/N ratio 14(dbs)} \\ -1 & \text{for S/N ratio 19 "} \\ -1 & \text{for S/N ratio 24 "} \\ 1 & \text{for S/N ratio 30 "} \end{cases}$$

x_{16} represents quadratic noise effect

$x_{17} = x_{13} \times x_{15}$ (Linear range X linear S/N ratio interaction)

$x_{18} = x_{13} \times x_{16}$ (Linear range X quadratic S/N ratio)

$x_{19} = x_{14} \times x_{15}$ (Quadratic range X linear S/N ratio)

$x_{20} = x_{14} \times x_{16}$ (Quadratic range X quadratic S/N ratio)

The regression coefficients, with standard errors, are as follows. Numbers in brackets are numbers of successes out of 32.

Target	Coefficient	Successes
	$b_1 = 0.93 \pm 0.25$	
3	$b_2 = -0.22 \pm 0.34$	(25)
14	$b_3 = -0.31 \pm 0.33$	(24)
17	$b_4 = -1.29 \pm 0.32$*	(11)
16	$b_5 = -0.40 \pm 0.33$	(23)
15	$b_6 = -1.21 \pm 0.32$*	(12)
13	$b_7 = -1.64 \pm 0.34$*	(7)
20	$b_8 = -0.64 \pm 0.32$(*)	(20)
10	$b_9 = -1.21 \pm 0.32$*	(12)
6	$b_{10} = -2.18 \pm 0.41$*	(3)
1	$b_{11} = -1.86 \pm 0.36$*	(4)
5	$b_{12} = -1.37 \pm 0.33$*	(10)
9		(27)

$b_{13} = -0.118 \pm 0.029$*

$b_{14} = 0.066 \pm 0.063$

$b_{15} = 0.103 \pm 0.029$*

$b_{16} = -0.010 \pm 0.062$

$b_{17} = 0.002 \pm 0.013$

$b_{18} = 0.027 \pm 0.028$

$b_{19} = 0.022 \pm 0.028$

$b_{20} = -0.085 \pm 0.063$

Asterisks denote coefficients more than twice their standard errors. However, the standard errors ought to be increased by about 11% for reasons explained below, and this affects the status of b_8. Differences between pairs of b's for different targets have about the same precision as individual b's (since the latter also represent a contrast between two targets). It is rather difficult to group the targets clearly into clusters since even the largest gap between the ranked responses (that between targets

15 and 20) is not significant. There are, of course, very highly significant differences between the group of targets with the lowest success rate and that with the highest rate.

The coefficients b_{13} and b_{15}, representing the linear effects of range and S/N ratio, are highly significant. The quadratic components are not, nor are the interactions. The numbers of successes out of 96 at the four levels of each of these factors are as follows:

Range		S/N ratio	
1	58	14 dbs	36
2	48	19 "	37
3	37	24 "	52
4	35	30 "	53

The χ^2 index based on a comparison of observed and expected frequencies (out of 2) after fitting all the variables gives 213.1 on 192-20 = 172 d.f. ($.01 < P < .02$). This suggests some lack of goodness of fit of the model, although the validity of the χ^2-test is somewhat doubtful owing to the small number (2) of observations in a cell. The fit would probably be improved by introducing a cubic effect of S/N ratio (which over the observed range of conditions would probably produce a curve suggesting upper and lower asymptotes). The contributions to χ^2 are particularly large (> 10) from the following cells:

Target	Conditions	Success out of 2 Obs.	Exp.
6	Range 3 miles S/N ratio 14 dbs	1	0.08
9	Range 2 miles S/N ratio 19 dbs	0	1.69

Subjects may account for some of the residual variation. If the lack of fit is due to general heterogeneity rather than inadequacy of the model, the standard errors ought to be increased in the ratio of $\sqrt{(213.1/172)} = 1.11$, i.e. by about 11%.

PART V

VISUAL AND TELEVISUAL DETECTION STUDIES

Mintech contract PD/170/04/AT

PART V

THE EFFECT OF LIMITED SEARCH TIME ON TARGET DETECTION PERFORMANCE

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MARCH 1969

SUMMARY

This report describes the fifth in a series of experiments intended to investigate performance at a statically simulated target detection task. The main aim of this experiment was to obtain detection performance data under paced conditions in which search time, i.e. the time the subject was allowed to view the photographic display, was limited to (a) 10 seconds, and (b) 5 seconds. 21 unskilled subjects were assigned to each of these conditions, in a replicated Latin Square experimental design. In a subsidiary experiment a limited amount of data were obtained relating to search times of 1 second and 2.5 seconds, seven subjects being assigned to each of these conditions.

The data obtained under these paced conditions were compared with those obtained previously under unpaced conditions, in which subjects were allowed to decide for themselves when to respond. The recorded search times ranged from 1.2 - 55.6 seconds.

The main results obtained from the analysis of these data were:

(i) Overall detection probability decreased consistantly as search time was reduced. The highest value was that obtained under unpaced conditions. Further analysis showed that this decrease was more marked for the small targets than for the large targets.

(ii) The overall detection probabilities achieved in each of the paced search times were higher than the cumulated probabilities achieved in the corresponding times under unpaced conditions. Further analysis indicated that there was a definite relationship between paced and unpaced performance.

(iii) Both detection probability and mean confidence level were linearly related to range (1-4 miles) but in each case there was no significant interaction between range and search time.

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Finally the author wishes to thank the many students who acted as subjects in these experiments.

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INDEX

1. INTRODUCTION 1

2. PURPOSE OF THE EXPERIMENT 14

3. EXPERIMENTAL DESIGN 15

4. DISPLAY AND RECORDING EQUIPMENT 17

4.1 Main experiment 17
4.2 Subsidiary experiment 18

5. EXPERIMENTAL MATERIALS 18

6. EXPERIMENTAL PROCEDURE 19

6.1 Main experiment 19
6.2 Subsidiary experiment 20

7. EXPERIMENTAL RESULTS 21

7.1 Detection probability 22
7.2 Confidence level 52
7.3 Map-briefing time 69
7.4 Psychometric measures 70

8. DISCUSSION 72

9. REFERENCES 86

APPENDICES

Appendix I 87
Appendix II 88

ILLUSTRATIONS

FIGURE 7.1.1 The effect of search time on detection probability under paced and unpaced conditions 26

FIGURE 7.1.2 The effect of range on detection probability under the 5 second paced condition 35

FIGURE 7.1.3 The effect of range on detection probability under the 10 second paced condition 36

FIGURE 7.1.4 The effect of range on detection probability under the unpaced condition 37

FIGURE 7.1.5 Regression lines showing the effect of range on detection for the paced and unpaced conditions 39

FIGURE 7.1.6 The effect of search time on detection probability for large and small targets under paced and unpaced conditions 43

FIGURE 7.1.7 The effect of search time on detection probability for large and small targets at long and short ranges . 49

FIGURE 7.2.1 The effect of search time on mean confidence level under paced and unpaced conditions 59

FIGURE 7.2.2 The effect of range on mean confidence level under the 5 second paced condition 62

FIGURE 7.2.3 The effect of range on mean confidence level under the 10 second paced condition 63

FIGURE 7.2.4 The effect of range on mean confidence level under the unpaced condition 64

FIGURE 7.2.5 Regression lines showing the effect of range on mean confidence level under paced and unpaced conditions. . 65

1. INTRODUCTION

The experiment described in this report is the fifth in a series of studies intended to investigate performance at an air-to-ground televisual target detection task. The television display was simulated statically, by means of a series of oblique aerial photographs, showing the target and surrounding terrain. Four photographs, taken at different ranges, were available for each target. In the previous experiments in this series the subjects had been instructed to carry out the detection task as quickly as possible, but no fixed limit had been imposed on the length of time they searched the display. Under these unpaced conditions a wide range of search times had been recorded, the longest being 56 seconds. Whilst these experiments were of value in indicating the conditions under which longer search times were required, two important questions arose:

(a) To what extent would overall detection performance deteriorate if search were limited to certain specific times?

(b) To what extent would the detection probabilities achieved in those limited search times be different from those obtained in the same times under unpaced conditions?

The present experiment was intended to provide data relating to detection performance under the conditions of limited search time, referred to as paced conditions, for comparison with the data obtained previously under unpaced conditions (Parkes, 1967).

Studies of parameters affecting performance at high-speed, low-level target recognition are more usually carried out by means of dynamic simulation techniques and, in this case, the appropriate performance measure is recognition range, rather than search time. Nonetheless, numerous laboratory experiments intended to investigate problems of visual search in both abstract and realistic displays have been carried out using static imagery. Search time is clearly an important factor in experiments of this type, and it can be treated as either a dependent or an independent variable. In the first case the subject responds when he has completed the search task. The search times are recorded and used as a performance measure to compare different experimental conditions. Subjects may be motivated to work quickly by appropriate monetary rewards, or alternatively an upper time limit, longer than the task would be expected to require, can be fixed after which the trial is abandoned if no response has been made.

If search time is treated as an independent variable two or more different levels are chosen such that the task cannot usually be completed in the time allowed. The effect on performance of these changes in the time available for search, and interactions between search time and other experimental conditions, can then be studied. These two techniques are sometimes combined by fixing two or more exposure times and recording the search times actually required under each exposure time condition. A study of the literature on visual search indicates that the first technique, treating search time as a dependent variable, is most commonly employed. The following two examples are typical of the many reported experiments in which search time, usually in conjunction with a measure of accuracy, is used as a measure of performance to compare different experimental conditions.

Baker, Morris and Steedman (1960) studied the speed and accuracy of the recognition of complex forms displayed against a background of confusable forms. The two main variables investigated were the number of forms in the background, and the difference in resolution between the reference form, presented for briefing purposes, and the actual display. It was found that both search time and errors increased as a function of the number of confusable forms, and the difference in resolution between the reference form and the display. The results also indicated that median search time varied according to the position of the target in the display. Targets positioned midway between the centre and the periphery were found most quickly, those in the centre of the display took slightly longer, and those at the periphery considerably longer. In addition, the results showed that targets in the lower half of the display, and particularly in the lower right-hand quadrant, took longer to find than those in the upper half.

An experiment using more realistic imagery was carried out by Johnston (1968) who used search time and recognition probability as performance measures in a study of the effects of horizontal resolution and shades of grey on target recognition. A static display showing the target at various different slant ranges, together with the surrounding terrain, was presented to subjects by means of a closed-circuit TV used in conjunction with a terrain model. Under these conditions the results showed reliable differences in target recognition time and probability as a function of resolution and slant range. Under conditions in which the subjects were also allowed an external cockpit view of the terrain model the number of shades of grey, and several of the interactions between factors, also had significant effects on target recognition time. It was also found that both performance measures were highly correlated with a measure of the complexity of the terrain scene displayed.

The second technique, treating search time as an independent variable and studying the effect of different fixed times, has also been used for both abstract and realistic visual search experiments. For example, Boynton (1960) studied the effect of four exposure times ranging from 3 to 24 seconds on the recognition of rectilinear shapes against a background of curvilinear 'struniforms'. The number of background forms and the contrast levels were the two other variables studied. The motivation of the subjects was maintained at a high level by an elaborate system of monetary rewards. Under these conditions it was found that exposure time had little effect on the percentage of targets correctly recognised when the number of background objects was small but the effect became much more marked as the number of background forms was increased. Further experiments indicated that N, the number of background objects, and t, the search time appeared to be interchangeable. For example, it was found that if a performance level of p was obtained when $N = 64$ and $t = 3$, approximately the same value of p was obtained when $N = 128$ and $t = 6$. This indicates a high level of motivation and search efficiency on the part of the subjects. In considering how these results might apply to real-life visual reconnaissance situations Boynton points out that much field work would be necessary to determine what types of terrain complexity would correspond to various values of N, and what would be the effect of oblique as opposed to vertical viewing.

Another experiment in which exposure times were systematically varied is reported by Simon (1965). In this experiment radar imagery was presented to observers either in a series of discrete, static steps or it was moved continuously at such a speed that the time taken for the target to move across the field of view was the same as the exposure time for the static display. The variables investigated were display size and ground coverage (2 levels each), target characteristics (4 types) and exposure times (10, 20 or 40 seconds). This experiment was of a rather different nature in that the task could be completed in these exposure times and the time taken to find the target from the time it first appeared was recorded and analysed. The results indicated that although more targets were found with the longer exposure times, the larger display and the smaller ground coverage, there were no significant differences between the number of targets acquired from the static and moving displays. It was also found that the median time taken to locate a target from the time it first appeared on the display was significantly longer for the static displays than for the moving displays. These recognition times were also more variable for the static displays.

This difference in acquisition time favouring the moving display increased as the observation time increased, or as the targets became more difficult to find because of varying display and image factors. These results are discussed in terms of possible differences in search patterns for the moving and static displays.

The effect of limiting the time available for search on visual search patterns has been studied by Richman, Enoch and Fry (1958). This experiment compared the performance of two groups of subjects searching for a Landolt C against a background of simulated vertical photography under different search time conditions. The first group were allowed 20 seconds to search each of the six displays, this condition being effectively unpaced since in almost every case the target was found in considerably less than this time. A reduction in search time due to learning was found in the successive trials. The second group were allowed 20 seconds to view the first two displays but in the four subsequent ones search time was progressively reduced to 12, 9, 6 and 3 seconds. Before each trial the subjects were told the length of the search time allowed.

Comparison of the results obtained from the two groups indicated that under the paced conditions there was a tendency for the targets to be found more quickly than in the corresponding trial under the unpaced conditions. Analysis of the eye-movement recordings showed that as the search time allowed was reduced from 12 to 6 seconds the mean fixation time decreased from 0.287 to 0.187 seconds, but rose again to 0.257 seconds for the 3 second search time. Richman et al suggest that this increase could be due to the fact that under the 3 second condition the subjects were still in the initial 'orientation' phase of search. The results also showed that as fixation time decreased, mean interfixation distance also decreased, apparently to compensate for the reduced information content per fixation.

The effect of limited time on visual search is also considered by Williams (1966) in a mathematical model for predicting the level of search performance as a function of spatial and temporal variables. In this model the probability of locating the target is shown to depend on two factors, target conspicuity (C), which is defined as the rate at which the observer can scan the field with a single-scan acquisition probability of 0.632, and the information input rate (R) which is the rate at which the field is presented to the observer. The equation for predicting the probability (P) of acquiring a target in a total time of T seconds can then be written:

$$P\ (T) = 1 - e^{-C/R}$$

If the total time available for the task were reduced, it is likely that the subject would attempt to maintain his former performance by working harder to compensate for the increase in R, the rate of information input. Up to a point it would be expected that this increase in R would produce a slight increase in C, but if R reached a very high level the observer would no longer be able to bring about a corresponding increase in his working level. To predict accurately the effects of a change in total available time requires a knowledge of the precise relationship between C and R, although as a first approximation it can be assumed that C will remain constant over a broad middle range of values of R.

Use of this model depends on being able to determine the values of t_{ss}, the single-scan time and p_{ss}, the single-scan acquisition probability. Determination of these values is feasible for, say, a regular matrix containing a known number of elements, but not for the oblique terrain scenes used in the present experiment. For displays of this type the detection task depends not only on visual search but also on a knowledge ,obtained from a map or other briefing material, of the relationship between the different elements in the display. The observer's search pattern may therefore be influenced by information obtained from recognition of the conspicuous features in the display, and the area in which detailed search is necessary greatly reduced. Under these conditions the assumption that the observer fixates points systematically to scan the total field more or less uniformly is unlikely to be valid since the observer will tend to concentrate on those parts of the display that provide the most useful information. For this reason it is not possible to determine meaningful values for t_{ss} and p_{ss}, and therefore the search model is not appropriate for detection tasks of the type studied in the present experiment.

The present experiment is concerned not only with the effect on detection performance of limiting the time available for search but also with a comparison of performance under paced and unpaced conditions. The research that has been carried out in this area appears to be mainly of an industrial nature. For instance, Dudley (1968) reports a number of experiments in which paced and unpaced performance were compared for various manual tasks. These are of little relevance to the present work, although the general finding that under paced conditions the quality of performance deteriorates not only at very fast paces but also for very slow speeds of working is of some interest. The latter effect is probably due to the greater opportunity for distraction at slow working speeds.

Visual search is an important element of many industrial inspection tasks but few of these have been investigated under both paced and unpaced conditions. In one experiment of this type Kirk and Sinclair (1969) studied the inspection of a bakery product under conditions of 'search' (a 10 x 10 array of items was presented) or 'no search' (items presented individually) and under paced and unpaced conditions. It was found that under unpaced conditions faults were detected with an approximately 90% success rate for both the 'search' and 'no search' conditions. The paced condition was studied only in association with the 'search' condition and it was found that performance deteriorated as the time allowed per item was reduced. The relationship was approximately linear.

Although it is not specifically a comparison of paced and unpaced performance, an experiment carried out by Erickson (1964) is of some relevance. This experiment was intended to compare search performance in static and dynamic fields. The static search task, detecting a Landolt 'C' against a background containing varying numbers of solid rings, was carried out under unpaced conditions and the relevant search times were recorded. Under dynamic conditions a similar display was driven in a vertical direction past a 24" square aperture at three different speeds (5, 7 and 10 deg/sec.). Since each target was only in the field of view for a limited time, this dynamic search condition can be regarded as paced. The detection probabilities achieved under the dynamic condition at each speed were compared with the cumulated probabilities achieved in the corresponding times under the static condition. For instance, under the static condition 81% of the targets were found in 2.9 seconds or less. Under dynamic conditions when the target was in the field of view for 2.9 seconds (5 deg/sec. speed), 78% of the targets were found. These two probability values are very close, as were those for the 7 deg/sec. speed. When the target was in the field of view for only 1.4 seconds (10 deg/sec. speed), the percentage of targets detected (0.52) was higher than the value achieved (0.40) in the corresponding time under static conditions. Erickson concludes that the time available for search may well be the predominant variable in limiting the search performance in displays of this nature, up to velocities of 7 deg/sec., and that target movement in the 0 - 10 deg/sec. range does not necessarily have a detrimental effect on search performance.

Since the target detection task studied in the present experiment involved some degree of information-processing in addition to visual search, the effect of pacing on performance of a mental task is also worth noting. Gosney (1959) studied a simple mental task in which the subject was required to sum a sequence of twelve digits which appeared one at a time through an aperture, The exposure time was varied from 1.29 to 0.69 seconds per digit and the results showed that a corresponding linear decrease in the proportion of the 12-digit sequences correctly summed occurred.

In planning the present experiment a number of considerations had to be taken into account, including the necessity of obtaining results comparable with those obtained previously under unpaced conditions. In an airborne situation the time available for a target acquisition task depends primarily on the speed of the aircraft or missile, the parameters of the viewing system, and the potential range of the target, i.e. the range at which it first becomes detectable. For instance, an aircraft travelling at 600 mph, approaching a target with a potential range of 4 miles, would take 18 seconds to cover the three mile distance that would bring the aircraft from a distance of 4 miles to the target to a distance to 1 mile. At this 1 mile range the target, under the viewing conditions studied, would be almost at the bottom of the television display and would subsequently disappear from view. If the target had a potential range of only 2 miles the corresponding time would be only 6 seconds. For an aircraft travelling either faster or slower the times would be proportionately decreased or increased.

These values give some idea of the length of time available for a real-time target acquisition task under under operational conditions but it is difficult to relate them in a meaningful way to the static situation under consideration. Since four photographs were available for each target, representing ranges of 4, 3, 2 and 1 mile respectively, it would be possible to allow the subject to view each of the four photographs in sequence, starting with the 4 mile range, for the length of time that it would take the aircraft to travel 1 mile. Thus, again assuming a speed of 600 mph, each photograph would be displayed for 6 seconds and the sequence of four photographs would simulate the approach from $4\frac{1}{2}$ miles to $\frac{1}{2}$ mile to the target. In this way it would be possible to carry out a static experiment in which the paced times allowed for search bore some relation to an actual dynamic situation.

Although this experiment would have been of some interest, it would not have provided data comparable with those obtained under unpaced conditions in the first experiment of this series. In this, and other experiments, the subjects had been exposed to only one view of each target. Thus a subject seeing the target at, say, the 2 mile range would not also see it at longer or shorter ranges. This situation is clearly not directly comparable to a dynamic situation in which the observer would have a continuous view of the target as the aircraft approached.

Since it was not possible to directly relate the time available for target detection under dynamic conditions to the paced times in this static experiment, the values were chosen largely with reference to the range of times recorded under unpaced conditions. Under these conditions search times ranged from 1.2 seconds to 55.6 seconds, the mean being about 12 seconds. The distribution was asymmetric and a relatively high proportion of the values occurred towards the shorter search times. These shorter search times were the ones of particular interest and it was decided that the two paced intervals to be studied in the main part of this experiment should be 10 seconds and 5 seconds. These corresponded with the times in which 50% and 30%, respectively, of the responses had been made under unpaced conditions. In addition, two shorter paced times, 2.5 seconds and 1 second, were studied in a subsidiary experiment to provide further information about the effects of very short search times on detection performance. No paced times greater than 10 seconds were studied, partly because they were of little practical importance and partly because the effect of pacing would be relatively small for these longer times, as such an effect decreases as the paced time approaches the time in which all responses were completed under unpaced conditions.

The extent to which performance level deteriorates under paced conditions is likely to depend on the experience level of the subjects.

Both experienced pilots and students had taken part in Experiment I and the results had shown that, although there were no differences in the overall detection probabilities achieved by the two groups, the search times for the skilled subjects were substantially shorter than those for the unskilled subjects. It would clearly have been desirable to have used skilled subjects in the present experiment but unfortunately this was not possible. Unskilled subjects were used throughout this experiment and although these subjects were given a considerable amount of training, the detection probabilities achieved under paced conditions in the present experiment are unlikely to be as high as they would have been if skilled subjects had been used.

Under paced conditions, although the maximum search times were fixed as described above, two alternative experimental procedures were possible:

(i) The subjects could be allowed to respond before the maximum time if they wished, and the actual search times taken under each condition recorded. In this way a range of search times up to and including the maximum would be obtained, and thus a cumulative probability curve could be plotted for each paced condition.

(ii) The subjects could be told to respond only after the maximum search time allowed had elapsed. In this way a single detection probability value representing the cumulated probability of detection up to and including the maximum time would be obtained for each paced condition.

It is unlikely that these alternative procedures would have given rise to significant differences in the overall detection probabilities achieved but for the longer paced times the first approach would have provided more detailed information. For the 1 second search time it is very unlikely that a significant proportion of the responses would have been made in less than the maximum time and, since in this case a tachistoscopic presentation technique was used, it would not have been possible to measure these shorter times. In the experiment described in this report the second approach was adopted and subjects responded only at the end of the allotted search time. Thus, only an overall detection probability value was obtained for each condition.

A further question of experimental procedure arose in relation to the types of response that the subjects would be asked to make. If only a limited time were available in which to locate the target it was likely that on some occasions a subject might have little or no idea of the target position. A decision had to be made as to whether 'don't know' responses would be allowed or whether the subject would be required to indicate what he thought to be the most likely target position in each photograph, regardless of how undertain he was. In order to optimise detection performance, in terms of the number of correct detections made, the latter alternative was chosen. In disallowing 'don't know' responses the possibility that a subject might correctly detect a target but fail to report it through uncertainty was eliminated. Under unpaced conditions the subjects had been allowed to make 'don't know' responses but they were discouraged from doing so, and such responses occurred for less than 2% of the presentations. In the analysis of these data these responses had been counted as incorrect. Both these decisions as to experimental procedure are considered further in the Discussion (Section 8).

Since this study is concerned primarily with the effect of limited search time, the overall effects of the other two main factors tested, ranges and targets, are not considered in detail except where there is a significant interaction with search time. A detailed analysis of these effects was carried out for the data obtained under unpaced conditions in Experiment I and, since this report includes a further analysis of these data, a summary of the main results found previously is given in Appendix I.

1.1 A note on terminology

In experiments concerned with the ability of the human operator to find real targets against a terrain background the terminology normally used is as follows: a target is detected when a signal which could be the target is noticed in the field of view; it is recognised as one of a certain class of objects; it is finally identified as a particular object within that class. If the exact position of the target is known in relation to the surrounding terrain, as would be the case with a ground feature, such as a bridge, which could be exactly located on a map, then identification may be virtually simultaneous with recognition.

The nature of the task studied in the present series of static experiments did not lend itself to this terminology as the observer was asked to locate the target in photographs taken obliquely from different ground ranges (1 - 4 miles). At short ranges most of the targets could be recognised and identified from the information shown on the map. For the large targets this was also possible at the longer ranges, but at these longer ranges the small targets were not recognisable and in some cases not detectable. However, it was still possible for the exact position of these targets to be located by reference to the conspicuous features in the field of view whose position, relative to that of the target, was known from the map. This geographic orientation process could enable a subject to correctly designate a target position, without necessarily having detecting the target itself. Such a situation is different from a dynamic situation in which location of the target area, and detection, recognition and identification of the actual target would become possible at successive stages along the approach route.

Under the static conditions of this study, when a subject correctly indicated the position of the target in the photograph it was not always known whether he had identified, recognised or detected the target or simply deduced its position. The use of the term 'correct detection' to cover all instances in which the target position was accurately designated, and in- 'incorrect detection' to cover all other responses is perhaps misleading in that a more specific meaning is normally ascribed to the term 'detection'. In spite of this it was decided to retain this nomenclature in relation to the task studied in this series of experiments rather than cause confusion by a change of terminology.

2. PURPOSE OF THE EXPERIMENT

This experiment was intended to compare target detection performance under paced and unpaced conditions. In previous experiments subjects had been instructed to carry out the detection task as rapidly as they could and to respond when they were ready to designate the target in the photographic display. Under these unpaced conditions a wide range of search times had been recorded. The purpose of the present experiment was to determine the effect on detection performance of limiting the time the subjects were allowed to view the display to certain specific search times. In the main part of the experiment the paced search times for which detection performance data were obtained were 5 seconds and 10 seconds, 21 unskilled subjects being assigned to each of these conditions. In a subsidiary experiment a small amount of data, on detection probabilities only, was obtained relating to search times of 1 second and 2.5 seconds.

The main reasons for studying detection performance under paced conditions were to determine:

(a) To what extent, if any, the proportion of targets correctly detected decreased with a reduction in the time allowed for searching the display.

(b) Whether, under paced conditions, the proportion of targets correctly detected in the specific search time was the same as the proportion correctly detected up to and including this time under unpaced conditions.

(c) Whether search time interacted with other factors such as target differences and range.

It was hoped that this investigation would give some indication of the relationship between unpaced and paced performance.

3. EXPERIMENTAL DESIGN

The essential requirement of the statistical design of this experiment was that it should allow the data obtained under paced conditions to be directly compared with those obtained in Experiment I under unpaced conditions. This necessitated the adoption of a Latin Square design similar to that used previously, based on seven targets and seven conditions. These seven conditions arose from two conditions of navigational uncertainty (± 1 mile and ± 2 miles), the first being associated with three ranges (1, 2 and 3 miles) and the second with four ranges (1, 2, 3 and 4 miles). Seven subjects were assigned to this matrix in such a way that each subject saw each target once and once only, and each condition once and once only. The basic experimental design is shown in Appendix II. The appropriate target/condition combinations were presented to each subject in random order. In the main experiment the matrix was replicated three times under each of the two paced conditions, 5 seconds and 10 seconds, using two separate groups of 21 subjects. For the subsidiary experiment the basic Latin Square design was the same but there was only one replication, seven subjects being assigned to each of the short search time conditions (1 second and 2.5 seconds).

The experimental material available was not sufficient to allow these subject groups to be balanced in terms of detection performance on the basis of a pre-test, but care was taken to ensure that the groups were balanced in terms of the distribution of scores on Heim's intelligence test for the subjects in each group, since the results of Experiment I suggested that these scores were correlated with performance.

Although this experimental design had several disadvantages, the small amount of experimental material available and the necessity of obtaining results comparable to those from Experiment I precluded any substantial changes. The most serious disadvantage of the design was that the two conditions of navigational uncertainty were associated with a different number of range conditions. Therefore the experiment could not be balanced in terms of the range factor since only half as many readings were obtained for the 4 mile range as for ranges 1 - 3 miles. This meant that the range 4 miles data had to be excluded from the analysis of variance, and in subsequent analyses the lower number of readings for this range had to be taken into account. Since no differences between the uncertainty conditions had been shown in Experiment I, the possibility of excluding the $\pm$ 1 mile uncertainty to allow a more complete analysis of the range factor was considered, but the idea was rejected since, had this been done, the two sets of data would not have been directly comparable.

4. DISPLAY AND RECORDING EQUIPMENT

4.1. Main experiment

The display and recording equipment used in these experiments has been described in Part I of this series of reports. Only one change was made to this equipment for the purposes of the present experiment. This was the inclusion of an additional timing device which enabled an auditory signal to be presented after the subject had viewed the photographic display for the specified time. In the main part of this experiment the time intervals used under these paced conditions were 5 seconds and 10 seconds.

The interval timer was incorporated into the circuit in such a way as to leave intact the mechanism for printing out the time interval between the operation of the 'start' and 'stop' buttons, which had previously been used to measure search time. In the present experiment the 'start' button activated the interval timer, in addition to illuminating the display and starting the Decatron timer, as previously. Immediately after the auditory signal which indicated the end of the specified search period the subject was required to point out the target position. As soon as the experimenter had checked this response he operated the 'stop' button. The time printed out therefore represented the specified search time plus the time taken to point out the target. In this way it was possible to ensure that this response time was kept to a realistic minimum, approximately 1 second, and that the subject did not delay pointing out the target, thus increasing the effective search time.

In all other respects the equipment for displaying the maps and photographs and for recording map-briefing time and the confidence level scores was exactly the same as that used previously.

4.2 Subsidiary experiment

A subsidiary experiment was carried out to obtain data relating to very short search time conditions. The equipment described in Section 4.1 was used to measure detection performance when the search time was reduced to 2.5 seconds by the appropriate adjustment of the interval time.

To obtain data relating to a search time of 1 second a tachistoscopic presentation technique was used. A laboratory tachistoscope was set up so that the photographs could be displayed under appropriate conditions of illumination and viewing distance, and it was adjusted to allow an exposure time of exactly one second. Before and after the exposure of the photograph a fixation field of the same illumination level appeared. The procedure adopted in this experiment is described in Section 6.

5. EXPERIMENTAL MATERIALS

The maps and photographs used in this experiment were those used in Experiment I. For convenience a brief description is given here. The photographic material consisted of a series of 8" x 8" aerial photographs taken from an altitude of 2000 ft. with a camera field of view of $50^{\circ} \times 50^{\circ}$. For display purposes these photographs were masked so that only a central portion 4.8" x 3.6" was shown representing a camera field of 30° (horizontally) x $22\frac{1}{2}^{\circ}$(vertically). In each case the horizon appeared $\frac{1}{4}$" below the top of the displayed portion, the depression angle of the camera being 10°. For each of the 18 targets there were four photographs taken at ranges of 4, 3, 2 and 1 mile respectively along an approach route. The maps were $6\frac{1}{4}$"x $6\frac{1}{4}$" sections of the 1" = 1 mile Ordnance Survey map, Sheet 169. Each map showed the target position and surrounding terrain and the limits of the aircraft's possible position were marked along the approach route.

6. EXPERIMENTAL PROCEDURE

6.1 Main experiment

The training and test procedures adopted in the main experiment were basically similar to those used in Experiment I. The only difference was that under the paced conditions the subjects were told during the initial training procedure the length of time they would be allowed to search the photographic display and all further practice took place under the appropriate condition.

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 and practice at the detection task took a further $\frac{3}{4}$ hour. The subject was then shown how to operate the display and recording apparatus and a series of targets was presented for further practice. After each presentation the subject was told whether or not he had correctly located the target and if not, he was given a further opportunity to do so.

Finally, a series of eleven targets was presented during which the subject was given no knowledge of results. The last seven of these constituted the test run. For each presentation under paced conditions three measures of performance were obtained, (a) whether or not the target was correctly detected, (b) confidence level and (c) map-briefing time. In addition, a continuous check was made to ensure that the time spend by the subject in pointing out the target after the specified search period was kept to a minimum.

6.2 Subsidiary experiment

Two subsidiary experiments were carried out to determine the overall probabilities of correct detection when the search time was reduced to 2.5 seconds and to 1 second. In the first of these the procedure followed was exactly the same as that described in Section 6.1, except that all training and practice related to the 2.5 second search time.

The procedure adopted in the case of 1 second search time was modified since in such a limited search time it was not likely that subjects would be able to make use of the detailed information shown on the maps. It was thought that in the time available subjects would only be able to make a rapid decision as to whether the target was clearly and conspicuously present, or whether it was not. For this reason subjects were not shown the maps but were simply given a verbal description of the target before each presentation. This verbal description was as brief as possible (e.g. 'a large pond' 'a major cross-roads in the centre of a built-up area') and gave only information which would have been obtainable from the map. To avoid confusion care was taken to ensure that the description given uniquely described the target. No detailed training was given to these subjects but they were shown the usual series of practice targets before the test-run.

Since, in a large proportion of the presentations, the target could not be detected in the 1 second search time and the subjects would not be able to assess its most likely position, they were simply told to respond either 'yes' or 'no' according to whether they could or could not detect the required target. A 'yes' response was checked by asking the subject to indicate the target in the photograph after it had been removed from the tachistoscope. In general 'yes' responses only occurred for very obvious targets. The only information recorded in this experiment was whether or not the target was correctly detected.

7. EXPERIMENTAL RESULTS

The data obtained in this experiment, in which search times were limited to (a) 5 seconds and (b) 10 seconds, were analysed together with the data obtained in Experiment I, in which search times were not limited although the subjects were required to respond as quickly as possible. The results therefore relate to two paced search conditions, designated T_5 and T_{10}, and one unpaced condition, designated T_u. Throughout this analysis the differences in detection performance due to differences in these search conditions are emphasised. Other aspects of the data, e.g. differences between individual targets, correlations between performance measures etc., are similar to those found in previous experiments and are not analysed in detail.

Under the two paced conditions used in this experiment search time was an independent variable, rather than a performance measure as in previous experiments. In the data from Experiment I, the unpaced search times varied over a wide range and it was not thought to be realistic to take a mean value as representative of the search time for this condition when relating the data to those obtained under paced conditions. The detection probability and confidence level measures from Experiment I have therefore been plotted cumulatively against search time for comparison purposes.

In the following sections the effects of the main factors tested, and, in particular, the effect of limited search time, are considered in relation to the three performance measures recorded, detection probability, confidence level and map-briefing time.

7.1 Detection probability

The raw data on detection probabilities for the 5 second and 10 second paced conditions, obtained in the present experiment, are shown in Table 7.1.1. The data previously obtained in Experiment I, which relate to the unpaced condition, are also shown. The analysis of variance carried out on the complete set of data is shown in Table 7.1.2. This table shows that the overall effect of search time is significant at the 1% level. In addition, the effects of ranges and target differences are highly significant overall. These results, together with the significance of the interaction between ranges and targets, are in good agreement with those found previously. The effects of navigational uncertainty and all interactions involving this factor are non-significant, as had also been found previously, and they are not further considered in this section. In the analysis shown in Table 7.1.2. the data relating to the range 4 miles condition have been excluded since only half as many values were available for this range as for the other ranges. However, in order to extract as much information as possible from the results, in the analyses that follow, except where otherwise stated, the data from range 4 miles have been included and due allowance made for the lower number of readings.

No logit analysis has been carried out on the detection probability data obtained in this experiment since in three previous experiments it had been shown that, in spite of the quantal nature of the data, there were no substantial differences between the results of the Logit analysis and those obtained from conventional analysis of variance techniques.

In the remainder of this section the effect of the main factors on detection probability is considered in greater detail, with particular reference to the effect of search time.

TABLE 7.1.1

Detection probability data for the three search time conditions.

Search time: 5 seconds (T_5)

Target	Uncertainty 1									Uncertainty 2											
	Range (miles) 1			2			3			Range (miles) 1			2			3			4		
3	1	1	0	1	1	1	1	1	1	1	0	1	1	1	1	0	0	1	0	0	0
14	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	1	1	1	0	0	0	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0
16	1	1	1	1	1	1	0	0	1	0	1	1	1	0	1	0	1	0	1	0	1
15	0	0	1	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0
13	0	0	0	1	0	1	0	0	0	1	0	1	0	0	1	0	0	0	0	0	1
1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Search time: 10 seconds (T_{10})

Target	Uncertainty 1									Uncertainty 2											
	Range (miles) 1			2			3			Range (miles) 1			2			3			4		
3	1	1	1	1	1	1	0	1	1	1	0	1	1	0	1	1	0	1	0	0	1
14	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	0	1	0	1
17	1	1	1	0	1	0	1	1	0	1	1	1	0	1	0	0	1	0	0	0	0
16	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
15	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0
13	0	1	0	1	1	1	0	0	0	0	1	0	1	1	1	0	1	0	0	0	0
1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

Search time: unlimited (T_u)

Target	Uncertainty 1									Uncertainty 2											
	Range (miles) 1			2			3			Range (miles) 1			2			3			4		
3	1	0	1	1	1	1	0	0	0	1	1	1	1	1	0	1	1	0	0	1	1
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
17	1	1	1	1	1	0	1	1	1	1	1	1	0	0	1	0	0	0	0	0	0
16	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0
15	1	1	0	1	0	0	0	0	0	1	0	0	0	1	0	1	0	0	1	1	0
13	1	1	0	1	0	0	1	0	1	1	0	1	1	0	0	1	0	0	0	0	0
1	0	0	0	1	0	0	0	0	0	1	1	0	1	0	0	0	1	0	1	0	0

1 = correct response   0 = incorrect response

TABLE 7.1.2

Analysis of variance on the detection probability data shown in Table 7.1.1

Source	D.F.	S.S.	M.S.	V.R.	Significance
Search times (S)	2	1.47	0.73	4.70(c)	$p < 0.01$
Ranges (R)	2	3.37	1.69	10.80(c)	$p < 0.001$
Uncertainties (U)	1	0.13	0.13	–	N.S.
Targets (T)	6	27.46	4.58	29.32(c)	$p < 0.001$
S x R	4	0.36	0.09	-	N.S.
S x U	2	0.04	0.02	-	N.S.
S x T	12	1.68	0.14	-	N.S.
R x U	2	0.26	0.13	-	N.S.
R x T	12	5.89	0.49	3.14(c)	$p < 0.001$
U x T	6	0.89	0.15	-	N.S.
S x R x U	4	0.26	0.06	-	N.S.
S x R x T	24	5.16	0.21	1.38(b)	N.S.
S x U x T	12	1.78	0.15	-	N.S.
R x U x T	12	1.44	0.12	-	N.S.
S x R x U x T	24	3.70	0.15	- (a)	N.S.
Residual (a)	252	39.33	0.16(a)		
Pooled residual (b) (Residual (a) + SRUT)	276	43.03	0.16(b)		
Pooled residual (c) (Pooled residual (b) + SRU, SRT, SUT, RUT)	328	51.68	0.16(c)		
TOTAL	377	93.22			

In this analysis the data relating to the 4 mile range condition have been excluded as only half as many readings were available for this range as for ranges 1 - 3 miles.

7.1.1 The effect of search time on detection probability

The mean detection probabilities for each of the search time conditions, 5 seconds (T_5), 10 seconds (T_{10}) and unlimited (T_u) are shown in Table 7.1.3.

TABLE 7.1.3

The effect of search time on detection probability

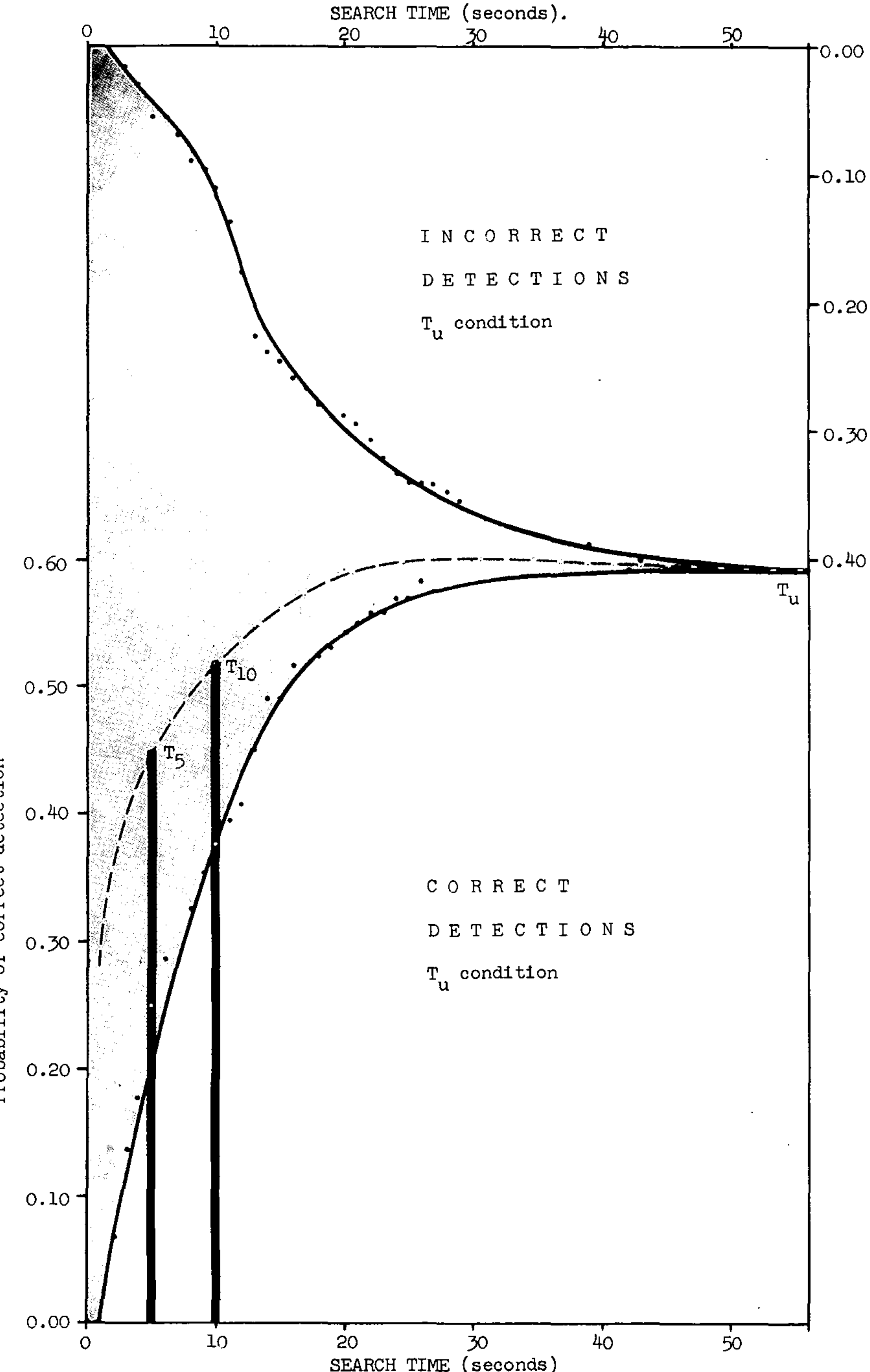
Search time condition	T_5	T_{10}	T_u
Detection probability	0.45	0.52	0.59

As shown in the analysis of variance in Table 7.1.2. the effect of search time on detection probability is significant. It can be seen in Table 7.1.3. that, as would be expected, detection probability increases with increasing search time. The difference in detection probability between the T_5 condition and the T_u condition is significant at the 1% level. The other differences, i.e. those between the T_5 and T_{10} conditions and the T_{10} and T_u conditions, just fail to reach the 5% level on a one-tail t-test, ($0.05 < p < 0.10$).

Under the unpaced condition, T_u, the search times ranged from 1.2 seconds to 55.6 seconds but the distribution was asymmetric with a high proportion of values towards the lower end. It was therefore not appropriate to take the mean search time (12 seconds) as representative of these values in comparing the detection probability data with those obtained under the two paced conditions, T_5 and T_{10}. In Figure 7.1.1 therefore the cumulated detection probability data relating to the unpaced condition have been plotted against time for both correct and incorrect detections, giving rise to three separate regions, one corresponding to decisions made correctly, one corresponding to decisions made

FIGURE 7.1.1

The effect of search time on detection probability under paced and unpaced conditions



incorrectly, and the third area, which is shaded, representing those presentations for which at any given time no response had yet been made. Superimposed on these cumulative curves are histograms which show the detection probabilities achieved under the paced conditions, T_5 and T_{10}. At the end of the paced search times the subjects were required to make a response. Therefore, under these conditions, a correct or an incorrect response was recorded for each presentation and there was no region corresponding to 'no response' outcomes.

It can be seen in Figure 7.1.1 that for both paced conditions higher detection probabilities were achieved in the time allowed than had been obtained in the same times under the unpaced condition. The relevant values are tabulated in Table 7.1.4. In each case the difference between the paced and unpaced values is highly significant. This table also shows the percentage improvement under paced conditions which is almost twice as great for the T_5 condition as for the T_{10} condition. This difference reflects the fact that under unpaced conditions the proportion of targets correctly detected in 5 seconds or less is so low that there is much greater scope for improvement.

TABLE 7.1.4

Detection probabilities under paced and unpaced conditions.

Maximum search time	Condition Paced	Condition Unpaced	% improvement in detection
5 seconds	0.45	0.25	80.0
10 seconds	0.52	0.37	40.5
Unlimited	-	0.59	-

These results also indicate that subjects are capable of responding more quickly than they choose to do under unpaced conditions without loss of accuracy. For instance, as can be seen in Figure 7.1.1, the proportion of correct detections, 0.45, achieved under the T_5 paced condition was only obtained after 13 seconds under unpaced conditions. It is also of interest to note that the unskilled subjects working under paced conditions performed considerably better than the skilled subjects had under unpaced conditions. The data for these latter subjects are not shown in Figure 7.1.1 as unfortunately no data were available relating to the performance of skilled aircrew under paced conditions. The final level of performance achieved under unpaced conditions is higher than that achieved under the paced conditions although the difference between the T_{10} and T_u conditions is relatively slight and it appears that under the unpaced conditions performance is reaching an asymptote.

It can be seen in Figure 7.1.1 that, under unpaced conditions, at any given time a certain proportion of targets had been correctly detected, a certain proportion had been incorrectly detected and no decision had been made about the remainder. Decisions made under the T_5 and T_{10} paced conditions can be regarded as being made up of a certain proportion of decisions which were also made within 5 seconds or 10 seconds respectively under unpaced conditions and a certain proportion of 'forced' decisions, i.e. decisions which the subject would not have chosen to make at or before the relevant time under unpaced conditions. It is therefore pertinent to determine what proportion of these forced decisions were made correctly under each of the two paced conditions. This can be determined by calculating the difference between the numbers of detections made correctly under paced conditions, and the number made up to the corresponding time under unpaced conditions, and expressing this difference as a proportion of the total number of decisions which had not been made before the relevant time under unpaced conditions. This value, designated I, can be calculated from the expression:

$$I_t = \frac{P_{cpt} - P_{cut}}{1 - (P_{cut} - P_{iut})}$$

where: I_t = the value of I for a particular search time, t.

P_{cpt} = the probability of correct detection in a <u>paced</u> search time of t.

P_{cut} and P_{iut} = the probabilities of correct and incorrect detections respectively, in time t seconds or less, under <u>unpaced</u> conditions

Calculations showed that the value of I_5 was 0.284 and the value of I_{10} was 0.286. The close agreement between those two values suggested the possibility that this measure might be constant over the entire time scale under consideration. If this were so it would be possible, for the target and range conditions tested in this experiment, to predict from a knowledge of the unpaced search times and corresponding detection probabilities, the detection probabilities that would be achieved under any particular paced condition. These values are shown by the dotted line in Figure 7.1.1. for which the value of I was taken as 0.285. Any point on this line represents the detection probability that would be achieved in a particular time under paced conditions. For instance, for a condition of 15 seconds paced search time the predicted detection probability would be 0.56. It is also possible to predict that, for the targets and conditions studied, the overall detection probability achieved under the T_u condition (0.59) would be obtained in a paced time of 20 seconds. It can be seen that the predictive curve is, by the nature of its calculation, asymptotic to the same overall detection level as was obtained under the unpaced conditions. This is reasonable since there is no evidence to suggest that performance would be any better if all displays were presented for the maximum time 55.6 seconds, rather than allowing subjects to choose for themselves when to respond within that time limit.

It is clearly only possible to predict detection probabilities under paced conditions in this way if the value of I remains effectively constant within the range of times under consideration. Two subsidiary experiments, described in the following section, were carried out to determine detection probabilities for paced search times of 1 second and 2.5 seconds respectively, and hence to obtain further estimates of I. These very short search times were chosen since it is in this region of the time scale that large differences in detection probability would be expected to occur.

7.1.2. The effect of very short search times on detection probability

In view of the results described in the previous section it was of interest to determine the overall detection probabilities that could be achieved in very short search times (1 second, 2.5 seconds) under paced conditions. These conditions are referred to as T_1 and $T_{2.5}$ respectively. Only seven subjects were used for each of these subsidiary experiments and therefore only one value per cell was obtained, as compared with three values per cell in the main experiment. The results cannot therefore be regarded as having the same reliability. For this reason no detailed analyses were carried out on these subsidiary data. They were used only to obtain an estimate of overall detection probability under these conditions.

Under the T_u conditions no detections were made in less than 1.2 seconds. Therefore in a paced search time of one second all the decisions can be regarded as 'forced', i.e. the subjects would not have chosen to make them at this time under unpaced conditions. The overall probability of correct detection under the T_1 paced condition will therefore be equal to I_1, as defined in Section 7.1.1., if it can be assumed that the relationship remains valid for times of less than 1.2 seconds. This appears to be a reasonable assumption since, although no detections were made in less than this time under unpaced conditions, the proportion of correct detections made under paced conditions in a given time is consistently higher than that under unpaced conditions. Therefore one would expect that some correct detections would be made in a paced time of one second.

This experiment was carried out using a tachistoscopic presentation technique which allowed the target photographs to be displayed for exactly one second, as described in Section 4.2. The normal display and timing apparatus was used to determine the overall detection probability under the $T_{2.5}$ condition, and hence to obtain a value for $I_{2.5}$. The raw data obtained in these experiments is shown in Table 7.1.5.

TABLE 7.1.5

Detection probability data for short search time conditions

Target	T_1							$T_{2.5}$						
	Uncertainty 1			Uncertainty 2				Uncertainty 1			Uncertainty 2			
	Range (miles)			Range (miles)				Range (miles)			Range (miles)			
	1	2	3	1	2	3	4	1	2	3	1	2	3	4
3	0	1	0	0	0	0	0	1	0	0	1	0	1	0
14	1	1	1	1	1	1	0	1	1	1	1	1	1	0
17	1	0	0	1	0	0	0	1	1	0	1	1	1	0
16	1	0	0	1	1	0	0	1	1	1	1	1	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	1	0	1	0	0	0	1	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The overall detection probability obtained under these two conditions are shown in Table 7.1.6 together with the values obtained under the unpaced condition T_u in the corresponding times.

TABLE 7.1.6

Comparison of detection probabilities under paced and unpaced conditions

Maximum search time	Condition: Paced	Condition: Unpaced
1 second	0.29	-
2.5 seconds	0.41	0.12

The detection probability value obtained for the $T_{2.5}$ condition (0.41) is linearly related to those obtained for the T_{10} and T_5 conditions, (0.52 and 0.45 respectively) but the value for the T_1 condition is lower than would be expected from this linear relationship.

As shown in Table 7.1.6, higher detection probabilities were obtained under the T_1 and $T_{2.5}$ conditions than had been achieved in the corresponding times under the T_u unpaced condition. The value of I_1, 0.286, agrees very closely with the values of I_5 and I_{10} determined for the T_5 and T_{10} conditions respectively. Indeed, this agreement is much closer than would be expected in view of the limited amount of data available for the T_1 condition.

The calculated value of $I_{2.5}$ is 0.33 which is rather higher than the other values. This high value reflects the fact that the detection probability achieved under the $T_{2.5}$ condition (0.41) is higher than the value predicted (0.37) if it is assumed that I has a constant value of 0.285. However, this discrepancy of 0.04 between the predicted and the experimental value is less than the standard error of the experimental mean which is 0.06. Thus there is clearly no significant difference between the two values.

Inspection of the data shows that the high overall detection probability obtained for the $T_{2.5}$ condition appears to be due to an unexpectedly high value for Target 17 (0.72). In spite of this discrepancy the results suggest that, under the conditions of this experiment, the value of I remains effectively constant within the range of search times considered. This possibility is further considered in relation to large and small targets in Sections 7.1.4 and 7.1.5.

7.1.3 The effect of range on detection probability.

The analysis of variance given in Table 7.1.2 shows that the overall effect of range on detection probability is significant, as had been found in previous experiments. Furthermore, the analysis of variance shows that there is no significant interaction between range and search time, i.e. that the three ranges are not differently affected by the search time conditions. Table 7.1.7 shows the detection probabilities at each range for each condition.

TABLE 7.1.7

Detection probabilities at each range for each search time condition.

Search time condition	Range (miles)			
	1	2	3	4
T_5	0.59	0.52	0.31	0.29
T_{10}	0.62	0.64	0.45	0.24
T_u	0.74	0.62	0.52	0.38
Mean	0.65	0.59	0.43	0.30

The difference between any pair of values in the main part of this table must reach 0.17 to be significant at the 5% level (two-tail test) or, in the case of differences involving values from the 4 mile range condition, 0.21. Inspection of Table 7.1.7 shows that, within any one range, differences between detection probability values for the three search time conditions fail to reach significance. Within any one time condition, differences between detection probabilities for 1 and 3 miles, 1 and 4 miles, and 2 and 4 miles ranges are significant but those involving only single mile differences are not. This result is in good agreement with those found previously.

In Table 7.1.7 values are also shown for range detection probability means averaged over the three conditions T_5, T_{10} and T_u. As would be expected from previous experiments, these values show a consistent, and almost linear trend of decreasing detection probability with increasing range but they are otherwise of relatively little interest. Of much greater importance is the effect of range on detection probability for each of the search time conditions individually. The data shown in Table 7.1.7 are plotted in Figures 7.1.2 - 7.1.4, together with the regression lines of detection probability on range for each of the three conditions. It can be seen that the relationship between range and detection probability is closely linear for both the T_5 and the T_u conditions but that in the T_{10} condition there is some deviation of the observed values around the regression line. However, as shown in Table 7.1.8, which gives the analysis of the range variation for each condition, this deviation is non-significant.

TABLE 7.1.8

Regression analysis of range variation for each search time condition.

Search time	Source	D.F.	S.S.	M.S.	V.R.	Significance
T_5	Range	3	2.51	0.84	5.37	$p < 0.005$
	Linear regression	1	2.28	2.28	14.61	$p < 0.001$
	Deviation	2	0.23	0.12	-	N.S.
T_{10}	Range	3	2.90	0.97	6.20	$p < 0.005$
	Linear regression	1	2.31	2.31	14.83	$p < 0.001$
	Deviation	2	0.59	0.28	1.79	N.S.
T_u	Range	3	2.06	0.69	4.31	$p < 0.01$
	Linear regression	1	2.04	2.04	12.75	$p < 0.001$
	Deviation	2	0.02	0.01	-	N.S.
	RESIDUAL*	252		0.16		

NOTE The residual variation against which the mean square values have been tested was taken from the analysis of variance shown in Table 7.1.2. It can be regarded only as an estimate of the residual variation in the three separate sets of data from which the values shown in the above table were derived. The use of the residual value shown can be justified for two reasons: (a) Evidence from previous experiments shows that the residual variation remains almost constant in different sets of data and is not affected by the inclusion of the 4 mile range condition. (b) The separate analyses of variance on the T_5, T_{10} and T_u (ranges 1 - 3 miles) data gave residual variation values which did not differ significantly and it was therefore appropriate to use a pooled value.

FIGURE 7.1.2

The effect of range on detection probability under the 5 second paced condition (T_5)

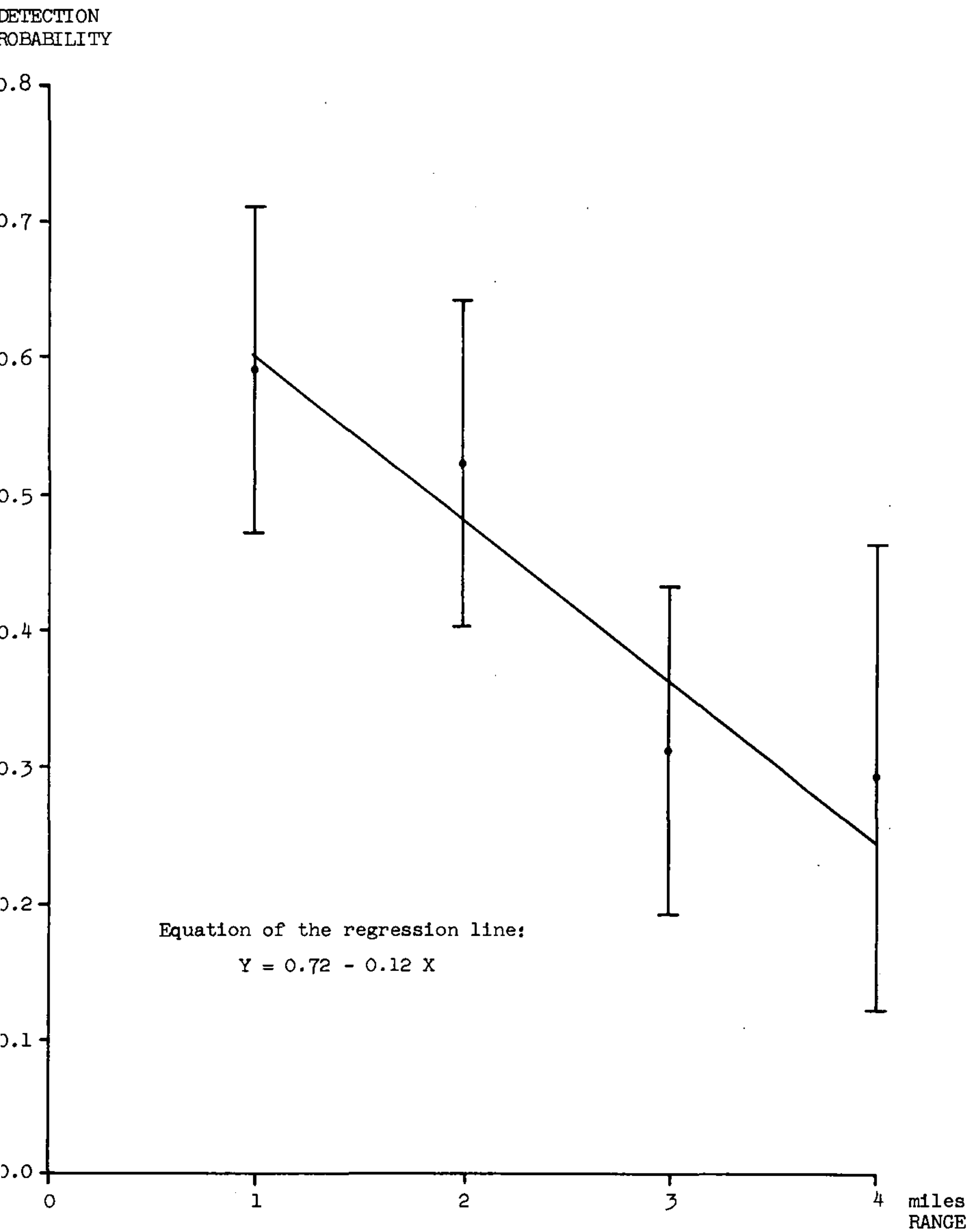


FIGURE 7.1.3

The effect of range on detection probability under the 10 second paced condition (T_{10})

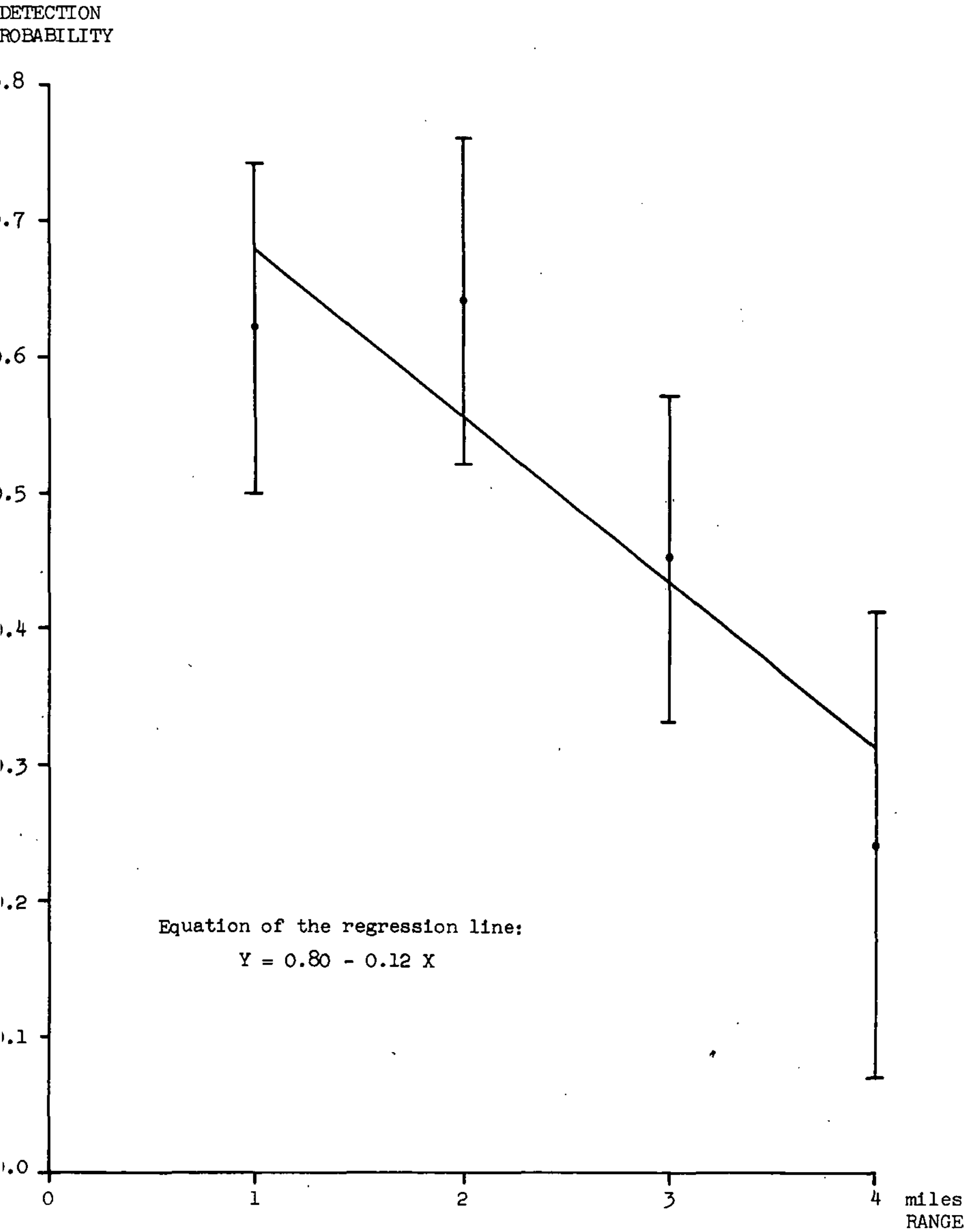
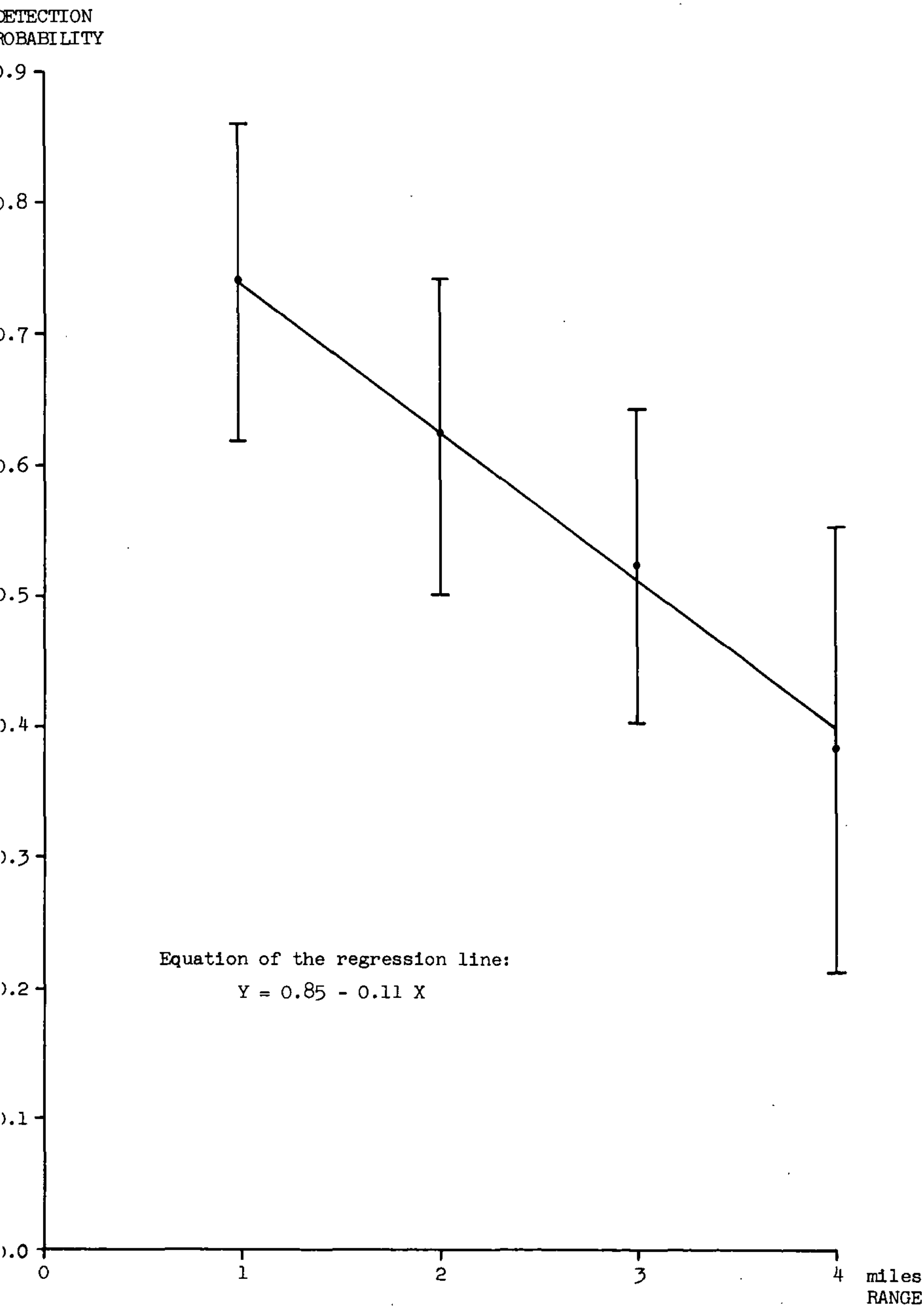


FIGURE 7.1.4

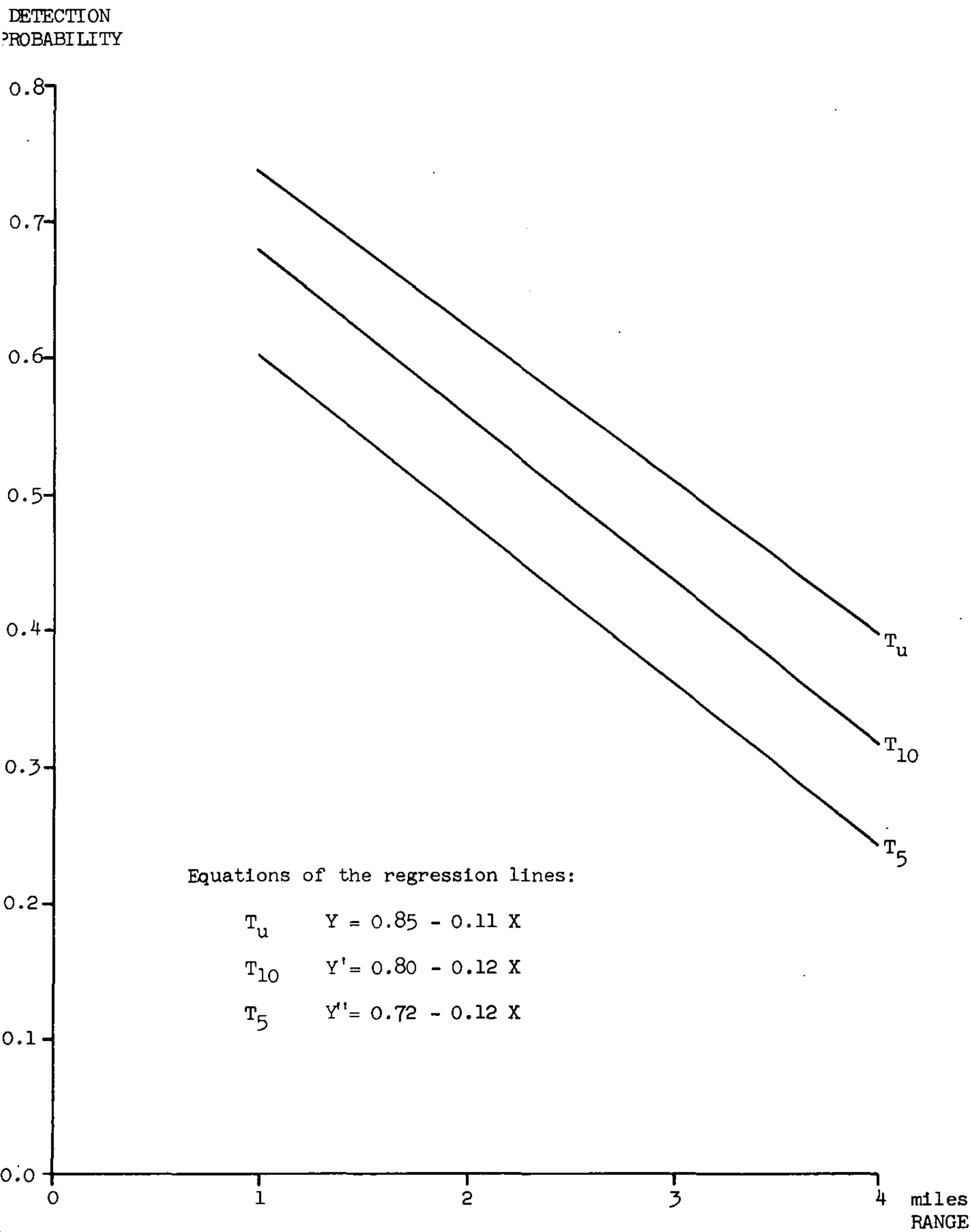
The effect of range on detection probability under the unpaced condition (T_u)



In Figure 7.1.5 the three regression lines are plotted together for comparison purposes. It can be seen that these lines are almost exactly parallel indicating that there is no interaction between the linear range effect and search time. This is consistent with the results of the analysis of variance given in Table 7.1.2. which shows that there is also no overall interaction between the range and search time conditions. Thus, although it might have been expected that the detection of targets at long ranges would be more seriously affected by the short search times there is no evidence of this from these results. As indicated earlier the difference in detection probability between the three time conditions does not reach significance for each range value on the number of readings available but Figure 7.1.5 shows clearly that there is a consistent trend of lower detection probability with reduced search time.

FIGURE 7.1.5

Regression lines showing the effect of range on detection probability for the paced and unpaced conditions.



7.1.4 The effect of target differences on detection probability

The analysis of variance given in Table 7.1.2 shows that target differences have a highly significant effect on detection probability. The interaction between search time and targets is non-significant, indicating that individual targets are not affected differently by the different search time conditions. This was confirmed by calculation of W, the coefficient of concordance, for the rank orders of the targets under each condition. The actual detection probabilities and their ranks under each condition are shown in Table 7.1.9. As in the case of ranges, the mean values averaged over all three conditions are of little interest and are therefore not shown in this table.

TABLE 7.1.9

Detection probabilities for targets under each search time condition

Target	T_5		T_{10}		T_u	
	Detection probability	Rank	Detection probability	Rank	Detection probability	Rank
14	0.95	1	0.81	2	0.90	$1\frac{1}{2}$
3	0.67	$2\frac{1}{2}$	0.71	3	0.67	3
16	0.67	$2\frac{1}{2}$	0.86	1	0.90	$1\frac{1}{2}$
17	0.33	4	0.52	4	0.57	4
13	0.29	5	0.43	5	0.43	5
15	0.19	6	0.24	6	0.38	6
1	0.05	7	0.10	7	0.29	7

Each detection probability value in this table is based on 21 readings.

The coefficient of concordance, W, for the correlation between these ranks was 0.98, a highly significant value as would be expected from the close correspondence between the 3 rank orders. Differences between the detection probability values given in Table 7.1.9 must reach 0.20 to be significant at the 5% level. For the corresponding differences between the T_u and T_{10} conditions no value reaches the 5% level although that for Target 1 (0.19) is very close to it. For the differences between the T_u and the T_5 conditions only one value, that for Target 16 reaches the 5% level but for three other targets (Numbers 17, 15 and 1) the values reach the 10% level. In spite of these low significance levels it can be seen in Table 7.1.9 that, apart from Targets 14 and 3, there is consistent trend of lower detection probability with reduced search time for each of the targets. Although the interaction between search time and targets is non-significant it can be seen that the targets most affected by the reduced search time tend to be the more difficult ones.

The seven targets used in this experiment could be divided into a group of large targets (Numbers 3, 14, 16) and a group of small targets (Numbers 17, 15, 13 and 1) as described in Part IV of this series of reports. Within each time condition there is a significant difference in detection probability between these two target groups, the mean values being shown in Table 7.1.10.

TABLE 7.1.10

Detection probabilities for large and small targets.

	Search time condition T_5	T_{10}	T_u
Large targets (3)	0.76	0.79	0.82
Small targets (4)	0.21	0.31	0.42

Within the large target group the effect of reduced search time is non-significant but within the small target group the effect is more marked and reaches the 5% level (one-tail test).

Thus, in spite of the fact that when all targets are considered individually the interaction between targets and search times is non-significant, it is clear that detection of the group of small targets is more seriously affected by reduction of search time than the detection of the group of large targets.

As indicated in Section 7.1.1, it is not appropriate to take the overall mean search time as representative of search time under the T_u condition, and the same applies to search times for the large and small target groups. The cumulative distribution curves for the probability of correct, and of incorrect detection under the T_u condition are therefore plotted separately for the large and small targets in Figure 7.1.6. As in Figure 7.1.1 the shaded area bounded by the two curves in each diagram represents the proportion of targets for which, at any specified time, no decision had been made. Histograms representing the proportion of correct detections achieved under the T_5, and the T_{10} conditions are superimposed.

The diagrams in Figure 7.1.6 show that, in general, under the T_u condition the large targets are detected not only more accurately but also in less time than the small targets. For both types of targets higher proportions of correct detections are made under the paced conditions than are made in the same time under the unpaced condition. The relevant values are shown in Table 7.1.11.

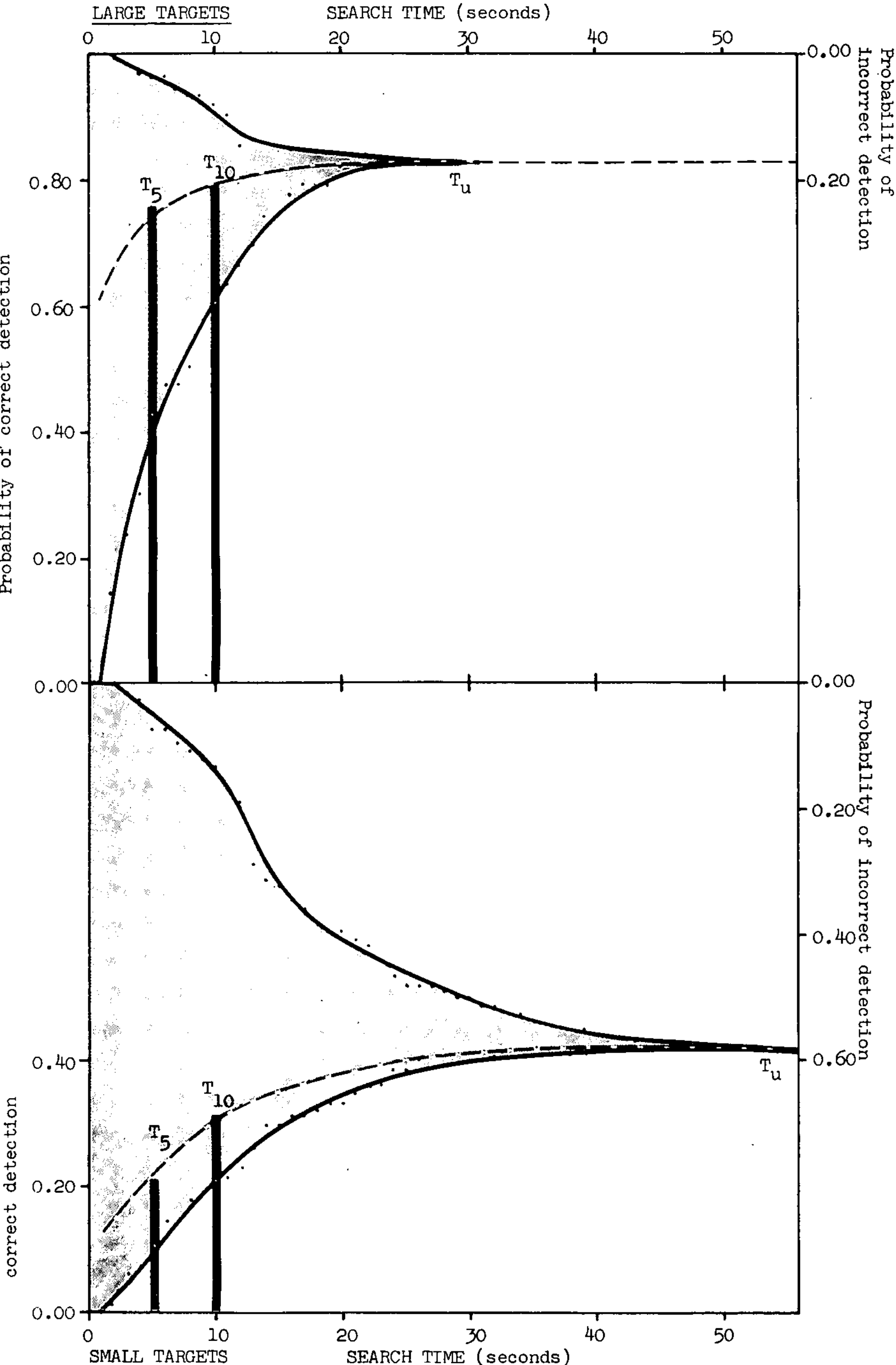
TABLE 7.1.11

Comparison of paced and unpaced conditions for large and small targets.

Maximum search time	LARGE TARGETS		SMALL TARGETS	
	Paced	Unpaced	Paced	Unpaced
5 seconds	0.76	0.43	0.21	0.11
10 seconds	0.79	0.60	0.32	0.21
Unlimited	-	0.82	-	0.42

FIGURE 7.1.6

The effect of search time on detection probability for large and small targets under paced and unpaced conditions.



As shown in Figure 7.1.6 the proportion of large targets correctly detected under the T_5 paced condition was only achieved after 15 seconds of unpaced search time. For small targets it required 10 seconds unpaced time to achieve the same detection probability as under the T_5 paced condition. For both types of targets detection probabilities achieved under the T_{10} condition were only obtained after 18 seconds unpaced search time.

It would not be expected that the values of I, as calculated from the expression given on Page28 would be the same for large and small targets since, as has been shown, the two groups of targets have very different characteristics. In particular, it would be expected that the I value, which can be regarded as a measure of the subjects' ability to correctly detect targets in less time than they would choose to under unpaced conditions, would be lower for the small targets than for the large targets, since the more difficult the targets are to detect, the less likely is it that such 'forced' decisions will be made correctly.

It would be expected, however, that for each group of targets the two values of I corresponding to the 5 second and 10 second search times would be approximately equal. Calculations showed that for large targets the value of I_5 was 0.61 and the value I_{10} was 0.59. For small targets the corresponding values were 0.12 and 0.16. The agreement between each of these pairs of values is fairly close, particularly in view of the fact that, in the case of small targets the values are relatively small, which makes them proportionately more sensitive to random variation. On the basis of these values it is possible to predict the proportions of correct detections for large and small targets separately which would be achieved in any specified paced time. These are indicated in Figure 7.1.6 by the dotted lines. It can be seen that for large targets performance is close to its asymptotic value after 10 seconds under paced conditions, whereas for small targets it appears that the asymptotic value would only be achieved after 20 seconds paced time.

Detection probability values for large and small targets under the $T_{2.5}$ and T_1 paced conditions were derived from the raw data given in Table 7.1.5. As found for the T_5 and T_{10} conditions, there was a marked difference between the values for large and small targets and, in each case, the trend of decrease in detection probability with reduction in search time was apparent. However, owing to the limited amount of data obtained in this subsidiary experiment, the 95% confidence limits of these mean values were relatively large (approximately ±0.18) and, apart from the significance of the differences in detection probabilities between large and small targets, no definite conclusions can be drawn from them. The main purpose of calculating these means was to determine the corresponding values of $I_{2.5}$ and I_1. Table 7.1.12 shows the four I values for each group of targets.

TABLE 7.1.12

Values of I for large and small targets

	Large targets	Small targets
I_{10}	0.59	0.16
I_5	0.61	0.12
$I_{2.5}$	0.60	0.16
I_1	0.48	0.14

The agreement within each set of four I values is reasonably close but it must be emphasised that the values for $I_{2.5}$ and I_1 are based on very limited amounts of data. The only marked discrepancy occurs in the I_1 value for large targets, which is lower than would be expected. This value is not significantly different from the other three values but one possible reason for the discrepancy is considered in the discussion, Section 8.

7.1.5. The interaction between ranges and targets

The analysis of variance given in Table 7.1.2 shows that there is a significant interaction between ranges and targets. This result, which has also been found in previous experiments, indicates that individual targets are differently affected by the range conditions tested. Since the effect of limited search time on detection probability was the main concern of this experiment, this overall ranges by targets interaction is of less interest than the triple interaction between ranges, targets and search times. As shown in Table 7.1.2. this triple interaction, which relates to the individual target, range and search time conditions is non-significant. It was therefore of interest to determine whether by grouping targets into large and small, as in Section 7.1.4, and ranges into long and short, it would be possible to show that some of these target and range conditions were more adversely affected by limited search times than others. The mean detection probabilities for large and small target groups at long and short ranges were calculated and are shown in Table 7.1.13.

TABLE 7.1.13

Mean detection probabilities for large and small targets at long and short ranges

	Large targets(3)			Small targets(4)			All targets		
	T_5	T_{10}	T_u	T_5	T_{10}	T_u	T_5	T_{10}	T_u
Short ranges (1 and 2 miles)	0.86	0.89	0.92	0.33	0.44	0.50	0.56	0.63	0.68
Long ranges (3 and 4 miles)	0.63	0.67	0.70	0.06	0.17	0.31	0.30	0.38	0.48
All ranges	0.76	0.79	0.82	0.21	0.32	0.42	0.45	0.52	0.59

It can be seen that, as would be expected, detection probabilities are highest for large targets at short ranges and lowest for small targets at long ranges. Within each targets/ranges block there is a decrease of detection probability with reduction of search time. Table 7.1.14 shows the difference in detection probability between the T_{10} and the T_u conditions, and between the T_5 and T_u conditions for each block, and the levels of significance reached by these differences.

TABLE 7.1.14.

Decreases in detection probability due to reduction in search time for large and small targets at long and short ranges.

	Large targets(3)		Small targets(4)		All targets (7)	
	T_u-T_{10}	T_u-T_5	T_u-T_{10}	T_u-T_5	T_u-T_{10}	T_u-T_5
Short ranges	0.03 N.S	0.05 N.S.	0.06 N.S.	0.17 $p<0.05$	0.50 N.S.	0.12 $p<0.05$
Long ranges	0.04 N.S.	0.07 N.S.	0.14 ($p<0.10$)	0.25 $p<0.01$	0.10 ($p<0.10$)	0.18 $p<0.01$
All ranges	0.03 N.S.	0.06 N.S.	0.10 ($p<0.10$)	0.21 $p<0.01$	0.07 ($p<0.10$)	0.14 ($p<0.10$)

Although not all the difference values given in Table 7.1.14 reach the 5% level of significance they do show a high degree of consistency. In each case there is a greater difference in detection probability between the T_u and the T_5 conditions than between the T_u and T_{10} conditions. It can also be seen that the decrease in detection probability under each of the paced conditions is always greater for small targets than for large ones, and greater for long ranges than for short ones. Thus the greatest decrease in detection probability, 0.25, occurs between the T_u and T_5 condition for small targets at long ranges, and the smallest decrease, 0.03, occurs between the T_u and T_{10}

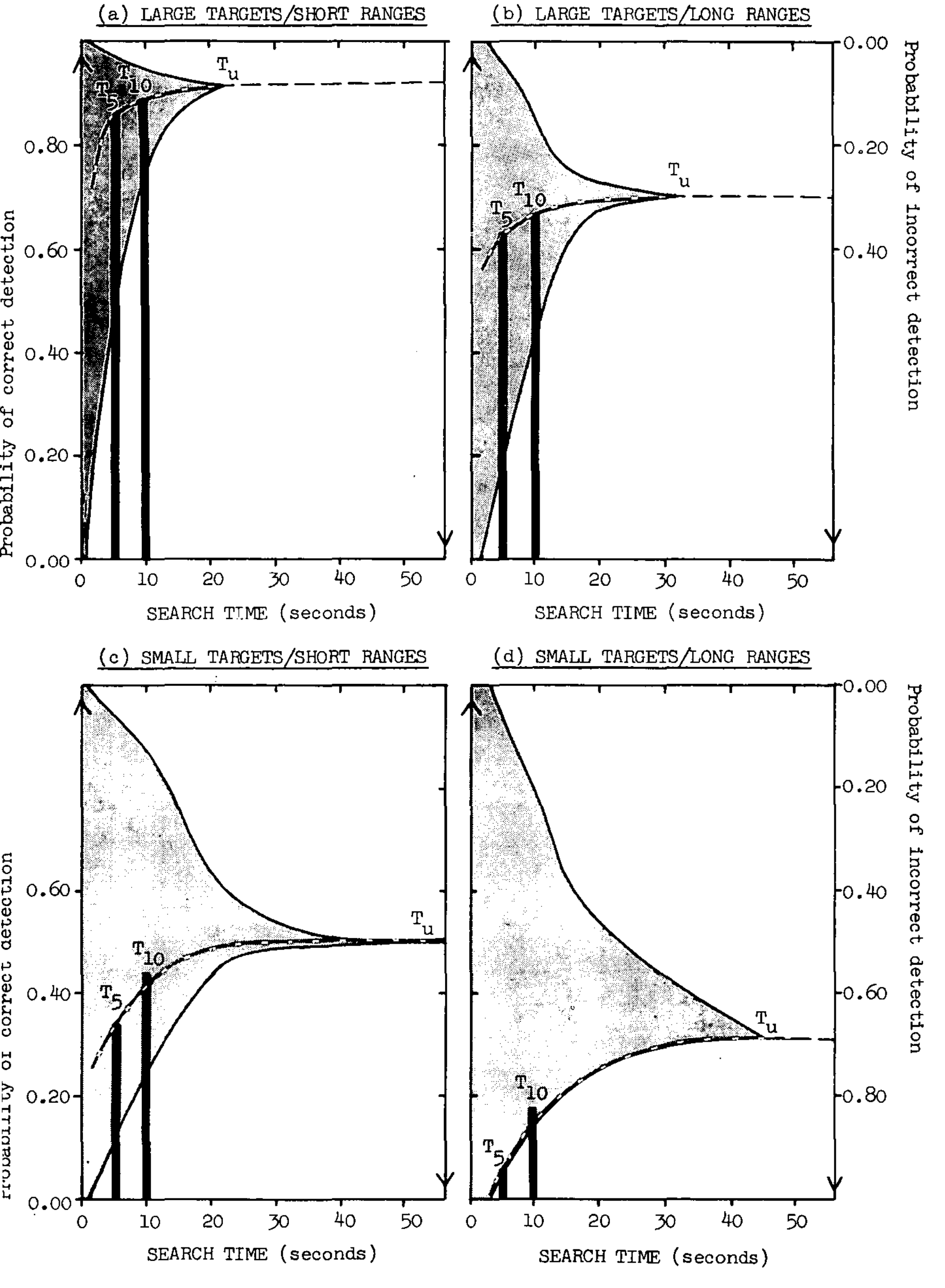
conditions for large targets at short ranges. Other combinations of targets, ranges and search time conditions result in intermediate decreases in detection probability as shown in Table 7.1.14. None of the values associated with large targets are significant but for small targets the effect is more marked and most of the values are significant.

The data given in Table 7.1.13 are shown diagrammatically in Figure 7.1.7. In this Figure, which represents a further partition of the data shown in Figure 7.1.6, the detection probability data for the T_u condition are plotted cumulatively and histograms representing the detection probabilities achieved under the T_{10} and T_5 conditions superimposed. The lower curve in each of the four diagrams represents the cumulated probability of correct detection with increased time under the T_u condition, and similarly the upper curve represents the cumulated probability of incorrect detection. The shaded area bounded by the two curves represents, for any given time, the proportion of presentations about which no decision had been made. The four diagrams, which relate to large and small targets at long and short ranges, illustrate clearly the decrease in overall probability of correct detection and the increase in search time that occurs under the T_u condition as the detection task becomes more difficult.

Under the T_5 and T_{10} conditions detection probabilities also fall with increasing difficulty of the task. For three of the four range/target size combinations (a) (b) and (c) the T_5 and T_{10} values are higher than the corresponding values obtained in the same times under the unpaced T_u condition. The fourth range/target size combination, small targets at long ranges, is an exception in that the values of the detection probabilities achieved under the T_5 and T_{10} paced conditions are not greater than those

FIGURE 7.1.7

The effect of search time on detection probability for large and small targets at long and short ranges



achieved in the same times under unpaced conditions. As can be seen in Figure 7.1.7 (d) the T_5 and T_{10} values fall almost exactly onto the cumulative curve of the T_u data. This suggests that in this, the most difficult of the four situations, none of the targets, which under the T_u condition required more than 5 seconds, or more than 10 seconds, search time for correct detection, could be correctly detected in less time under the T_5 and T_{10} paced conditions.

Values of I_5 and I_{10}, as defined on Page 28, were calculated for each of the four sets of data shown in Figure 7.1.7. These values are shown in Table 7.1.15.

TABLE 7.1.15

Values of I for large and small targets at long and short ranges.

	I_5	I_{10}
Large targets/short ranges	0.72	0.72
Large targets/long ranges	0.55	0.54
Small targets/short ranges	0.22	0.29
Small targets/long ranges	0.00	0.04

As indicated in Section 7.1.6 it would be expected that pairs of I_5 and I_{10} values would be approximately equal and that the values would decrease with increasing difficulty of the detection task. The data shown in Table 7.1.15 are in good agreement with this expectation. Although there is some discrepancy between the I_5 and I_{10} values for the 'small targets at short ranges' data these two values are not significantly different. The I_{10} value of 0.04 for small targets at long ranges is not significantly different from zero indicating, as already noted, that the detection probability for the T_{10} condition falls almost on the T_u cumulative curve.

The broken lines in each diagram in Figure 7.1.7 indicate the detection probabilities that would be achieved in the various search times under paced conditions, if it is assumed that the value of I remains effectively constant for each condition throughout the entire range of search times. These broken lines are based on the mean of each pair of values given in Table 7.1.15. It can be seen that as the difficulty of the detection task increases the length of paced search time that is required before detection probability reaches its asymptotic value would also increase. For the data relating to small targets at long ranges shown in Figure 7.1.7. (d) the mean I value is almost zero and therefore the broken line predicting performance under unpaced conditions is almost superimposed on the line representing the cumulated probability of correct detection under unpaced conditions.

Since relatively few values were available for the very short search time conditions, T_1 and $T_{2.5}$, little information could be obtained from partitioning these data to derive mean values relating to large and small targets at long and short ranges, as in some cases these means were based on as few as nine readings. This resulted in the 95% confidence limits associated with the means being so large (approximately $\pm$ 0.35) that the values became almost meaningless.

It is nonetheless of interest to note that the calculated values of I_1 and $I_{2.5}$ for the very limited data available relating to large and small targets at long and short ranges, agreed well with the corresponding values given in Table 7.1.15 for the T_5 and T_{10} conditions, except in two cases. These were the I_1 and $I_{2.5}$ values for large targets at long ranges which were substantially lower than the corresponding values for the T_5 and T_{10} conditions. However, owing to the large confidence limits associated with the detection probabilities there was no evidence that the I values were significantly different.

7.2 Confidence level

In this experiment, as in previous ones, the subject was required to indicate after each response the extent to which he was confident that he had correctly located the target. These scores ranged from 7, which indicated that the subject was completely sure of the correctness of his response, to 2, which indicated that he was extremely uncertain. Under the two paced conditions the confidence score of 1, which indicated that the subject was unable to make any response, was not used. This was to prevent a high proportion of 'no response' outcomes which might have occurred under the short search time conditions. Instead the subjects were required to indicate what they regarded as the most likely target location and, if very uncertain, assign a confidence level of 2. Under the unpaced conditions, data for which are taken from Experiment I, the 'no response' confidence level score of 1 was allowed but it occurred on only two occasions.

The confidence level scores recorded for the two paced conditions, T_5 and T_{10}, and the one unpaced condition T_u, are shown in Table 7.2.1. The analysis of variance carried out on these data is given in Table 7.2.2. The results show that three out of the four main factors, search times, ranges and targets significantly affect confidence level. The fourth main factor, navigational uncertainty, is non-significant. These results are analogous to those obtained for the detection probability data, and the significance of ranges and targets agrees well with the results of previous experiments.

Only two of the interactions reach the 5% significance level.

These are the interactions between ranges and uncertainties, and between targets and uncertainties. This is a rather unexpected result in view of the fact that in previous experiments no interaction effects involving the navigational uncertainty factor had been found. There is no obvious explanation of why such effects should have been found in this experiment since the interactions do not involve the search time factor, and all previous work had indicated that the difference between the two uncertainty conditions had no effect on the measures of detection performance made.

In the following section the effects of search times, ranges and targets on confidence level are considered in more detail but no further analyses are carried out on the interaction effects.

TABLE 7.2.1

Confidence levels for the three search time conditions

Search time: 5 seconds (T_5)

Target	Uncertainty 1									Uncertainty 2											
	Range (miles)									Range (miles)											
	1			2			3			1			2			3			4		
3	7	7	$\underline{5}$	5	7	6	6	6	6	7	$\underline{5}$	6	7	7	7	$\underline{6}$	$\underline{5}$	5	$\underline{5}$	$\underline{6}$	$\underline{6}$
14	7	7	$\underline{6}$	7	7	7	6	7	6	7	7	6	7	7	7	6	6	7	2	5	7
17	7	2	5	$\underline{4}$	$\underline{5}$	$\underline{3}$	5	$\underline{2}$	$\underline{6}$	4	6	6	$\underline{4}$	$\underline{3}$	$\underline{3}$	$\underline{5}$	$\underline{3}$	$\underline{4}$	$\underline{3}$	$\underline{5}$	$\underline{4}$
16	5	6	7	6	5	4	$\underline{6}$	$\underline{4}$	6	$\underline{5}$	6	5	4	$\underline{2}$	6	$\underline{6}$	5	$\underline{3}$	3	$\underline{6}$	3
15	$\underline{2}$	$\underline{2}$	5	3	$\underline{3}$	$\underline{2}$	$\underline{2}$	$\underline{5}$	$\underline{3}$	6	$\underline{6}$	$\underline{5}$	$\underline{5}$	$\underline{4}$	5	$\underline{3}$	$\underline{2}$	$\underline{4}$	$\underline{5}$	$\underline{2}$	$\underline{2}$
13	$\underline{2}$	$\underline{5}$	$\underline{7}$	7	$\underline{2}$	4	$\underline{2}$	$\underline{4}$	$\underline{3}$	6	$\underline{6}$	4	$\underline{5}$	$\underline{5}$	5	$\underline{4}$	$\underline{4}$	$\underline{3}$	$\underline{4}$	$\underline{4}$	5
1	$\underline{3}$	$\underline{4}$	2	$\underline{3}$	$\underline{2}$	$\underline{3}$	$\underline{2}$	$\underline{3}$	$\underline{5}$	$\underline{4}$	$\underline{4}$	$\underline{5}$	$\underline{2}$	$\underline{3}$	$\underline{5}$	$\underline{4}$	$\underline{3}$	$\underline{2}$	$\underline{6}$	$\underline{4}$	$\underline{3}$

Search time: 10 seconds (T_{10})

Target	Uncertainty 1									Uncertainty 2											
	Range (miles)									Range (miles)											
	1			2			3			1			2			3			4		
3	6	7	7	7	7	7	$\underline{4}$	7	7	6	$\underline{5}$	6	5	$\underline{6}$	6	7	$\underline{4}$	7	$\underline{6}$	$\underline{3}$	3
14	6	7	6	7	$\underline{5}$	6	5	7	6	7	7	7	7	7	7	$\underline{4}$	7	$\underline{3}$	7	$\underline{7}$	5
17	2	7	7	$\underline{5}$	4	$\underline{3}$	6	7	$\underline{2}$	7	6	7	$\underline{4}$	6	$\underline{4}$	$\underline{4}$	6	$\underline{3}$	$\underline{3}$	$\underline{5}$	$\underline{5}$
16	$\underline{5}$	7	5	5	6	7	6	5	5	5	4	4	5	5	3	5	6	$\underline{4}$	$\underline{4}$	5	5
15	$\underline{2}$	$\underline{4}$	$\underline{6}$	$\underline{5}$	$\underline{2}$	4	6	$\underline{6}$	$\underline{4}$	$\underline{6}$	$\underline{3}$	$\underline{3}$	$\underline{3}$	6	6	5	$\underline{5}$	$\underline{2}$	$\underline{4}$	$\underline{5}$	$\underline{5}$
13	$\underline{6}$	6	$\underline{6}$	4	6	5	$\underline{3}$	$\underline{5}$	$\underline{5}$	$\underline{7}$	7	$\underline{4}$	7	4	6	$\underline{6}$	6	$\underline{3}$	$\underline{2}$	$\underline{5}$	$\underline{5}$
1	5	$\underline{5}$	$\underline{2}$	$\underline{2}$	$\underline{3}$	$\underline{4}$	$\underline{4}$	$\underline{4}$	$\underline{4}$	$\underline{5}$	$\underline{4}$	5	$\underline{4}$	$\underline{2}$	$\underline{3}$	$\underline{2}$	$\underline{5}$	$\underline{4}$	$\underline{2}$	$\underline{3}$	$\underline{5}$

Search time: unlimited (T_u)

Target	Uncertainty 1									Uncertainty 2											
	Range (miles)									Range (miles)											
	1			2			3			1			2			3			4		
3	7	$\underline{7}$	7	7	5	7	$\underline{6}$	$\underline{4}$	$\underline{6}$	7	6	5	6	7	$\underline{5}$	7	5	$\underline{4}$	$\underline{7}$	4	6
14	7	7	6	7	7	7	6	5	7	7	2	5	7	6	7	7	7	5	7	$\underline{7}$	$\underline{7}$
17	7	4	5	7	6	6	7	7	4	7	7	7	$\underline{7}$	$\underline{2}$	6	$\underline{2}$	$\underline{6}$	$\underline{5}$	$\underline{2}$	$\underline{5}$	$\underline{4}$
16	5	5	6	7	6	3	4	4	4	7	7	$\underline{5}$	7	6	7	4	4	4	5	6	$\underline{3}$
15	4	6	$\underline{6}$	4	$\underline{1}$	$\underline{2}$	3	$\underline{3}$	$\underline{3}$	6	$\underline{5}$	$\underline{7}$	$\underline{5}$	3	$\underline{6}$	6	$\underline{6}$	$\underline{3}$	5	4	$\underline{5}$
13	7	$\underline{7}$	$\underline{4}$	5	$\underline{7}$	$\underline{6}$	3	$\underline{6}$	5	6	$\underline{6}$	6	7	$\underline{5}$	$\underline{4}$	3	$\underline{5}$	$\underline{4}$	$\underline{5}$	$\underline{1}$	$\underline{5}$
1	$\underline{5}$	$\underline{4}$	$\underline{3}$	6	$\underline{1}$	$\underline{3}$	$\underline{6}$	$\underline{6}$	$\underline{1}$	6	4	$\underline{4}$	5	$\underline{5}$	$\underline{4}$	$\underline{2}$	5	$\underline{2}$	5	$\underline{4}$	$\underline{3}$

Confidence levels underlined relate to incorrect responses.

TABLE 7.2.2

Analysis of variance on the confidence level data given in Table 7.2.1

Source	D.F.	S.S.	M.S.	V.R.	Significance
Search times (S)	2	15.68	7.84	4.87(c)	$p<0.01$
Ranges (R)	2	46.34	23.17	14.39(c)	$p<0.001$
Uncertainties (U)	1	0.38	0.38	- (c)	N.S.
Targets (T)	6	294.18	49.03	30.45(c)	$p<0.001$
S x R	4	3.00	0.75	- (c)	N.S.
S x U	2	2.74	1.37	- (c)	N.S.
S x T	12	26.28	2.19	1.36(c)	N.S.
R x U	2	10.04	5.02	3.12(c)	$p<0.05$
R x T	12	25.80	2.15	1.34(c)	N.S.
U x T	6	22.78	3.78	2.35(c)	$p<0.05$
S x R x U	4	1.48	0.37	- (b)	N.S.
S x R x T	24	29.28	1.22	- (b)	N.S.
S x U x T	12	19.92	1.66	1.00(b)	N.S.
R x U x T	12	20.40	1.70	1.02(b)	N.S.
S x R x U x T	24	31.20	1.30	- (a)	N.S.
Residual (a)	252	425.88	1.69(a)		
Pooled residual (b) (Residual (a) + SRUT)	276	457.08	1.66(b)		
Pooled residual (c) (Pooled residual (b) + SRU, SRT, SUT, RUT)	328	528.16	1.61(c)		
TOTAL	377	975.38			

In this analysis the data relating to the 4 mile range condition have been excluded as only half as many readings were available for this range as for ranges 1 - 3 miles.

7.2.1. The effect of search time on confidence level

The analysis of variance given in Table 7.1.2 shows that the effect of search time on confidence level is significant. The mean confidence levels for each of the three search time conditions are given in Table 7.2.3.

TABLE 7.2.3

Mean confidence level for each search time condition

Search time condition	T_5	T_{10}	T_u
Confidence level	4.71	5.03	5.20

It can be seen from this table that mean confidence level falls with decreasing search time, as would be expected. The difference between the confidence levels for the T_u and the T_5 conditions is significant at the 1% level while the other differences, i.e. those between the T_5 and T_{10}, and the T_{10} and T_u conditions are significant at the 5% level. This fall in confidence level with decreasing search time can be attributed not only to the fact that, when required to locate the target in a shorter time, subjects are likely to be less certain of their response, regardless of whether or not it is correct, but also to the fact that the values shown in Table 7.2.3 relate to all decisions, both correct and incorrect. Since the proportion of correct detections also decreased with decreasing search time it is reasonable that mean confidence level should also fall. This could indicate that subjects are to some extent aware of their level of performance although the absolute differences between the values shown in Table 7.2.3 are small.

It was therefore of interest to determine the effect of search time on the confidence levels associated with correct and with incorrect detections separately. The relevant values are given in Table 7.2.4.

TABLE 7.2.4

Mean confidence levels for correct and incorrect detections

Search time condition	CORRECT DETECTIONS		INCORRECT DETECTIONS	
	Mean confidence level	N*	Mean confidence level	N*
T_5	5.66	66	3.90	81
T_{10}	5.86	77	4.10	70
T_u	5.68	87	4.40	60

*N = Number of readings on which each value is based.

Within each of the search time conditions shown in Table 7.2.4 the mean confidence level associated with correct detections is significantly higher than that associated with incorrect detections. There are no significant differences between the mean confidence levels associated with correct detections for the three time conditions but for those associated with incorrect detections the mean value for the T_5 condition is significantly lower than that for the T_u condition. These results indicate that for those detections that were made correctly the reduced search time had no effect on confidence level but for those detections that were incorrect reduced search time resulted in significantly lower confidence level, i.e. the subjects assessed their performance more accurately since they indicated, on average, a lesser degree of certainty in those detections which in fact proved to be incorrect.

As explained in Section 7.1.1 it is not possible to associate any specific search time with the T_u condition. It is therefore more appropriate to plot these data cumulatively against search time.

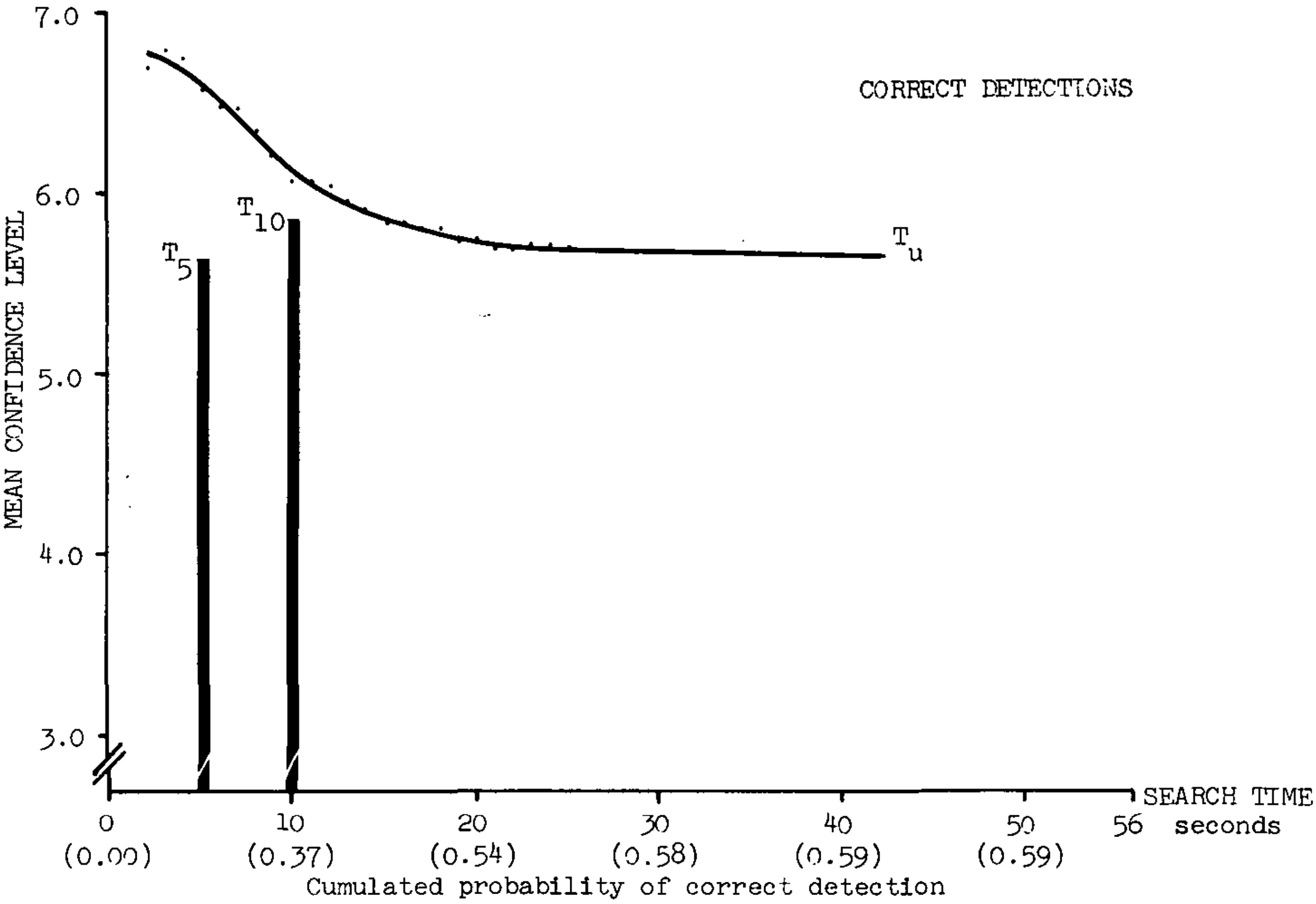
In the case of confidence levels various different ways of cumulating the data are available since the values range from 1 to 7 and are associated with both correct and incorrect decisions. It was decided that the most appropriate way to cumulate the data, in order to compare them with those obtained for the paced conditions, was to separate the data associated with correct and incorrect detections and for each set of data plot a cumulative average as shown in Figure 7.2.1. Any point on the curve relating to correct detections, for example, represents the average confidence level associated with all correct detections made up to and including the time against which it is plotted. The curve for incorrect detections is plotted in the same way.

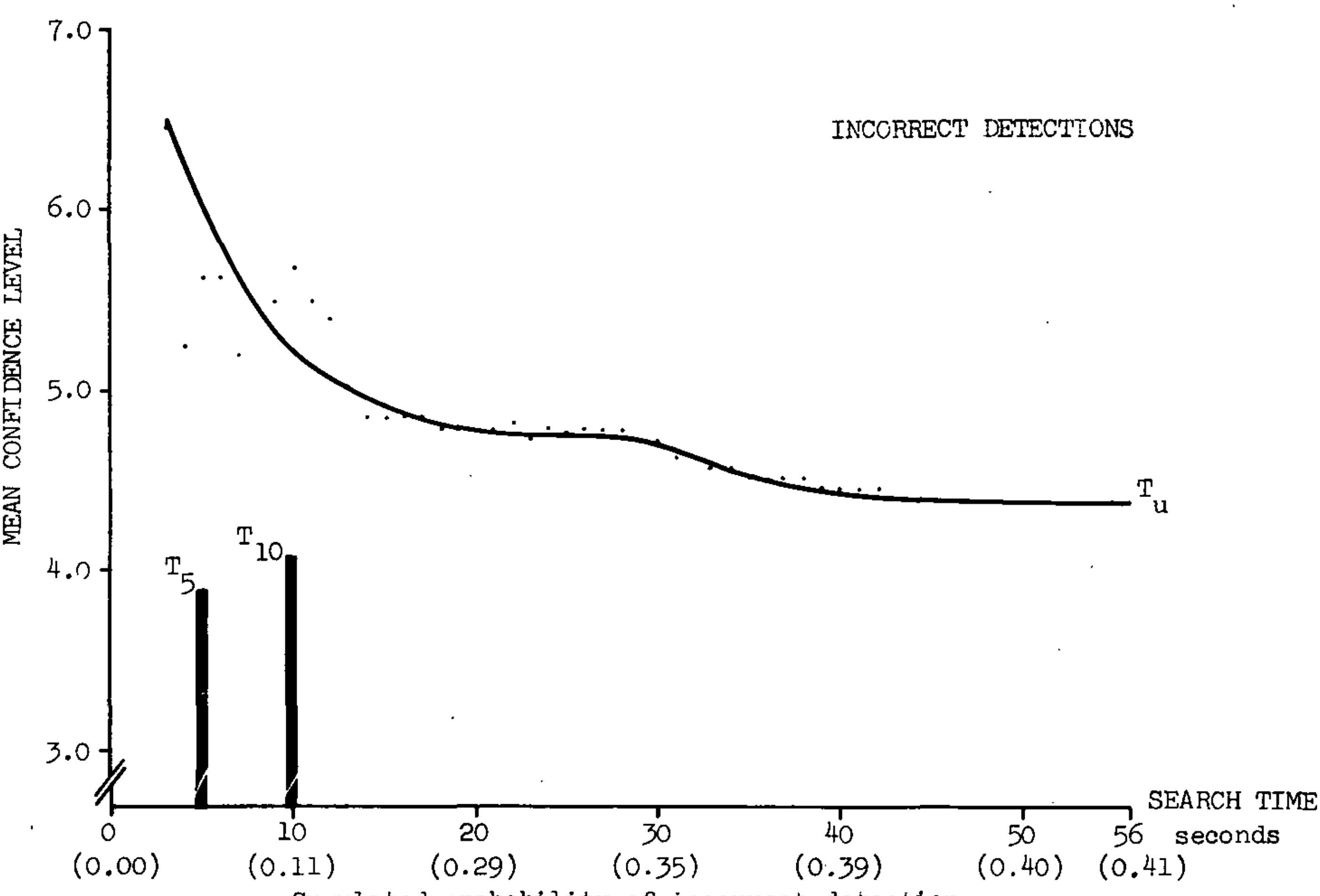
For both correct and incorrect detections the cumulative mean confidence level falls as search time increases. This is reasonable since under the unpaced conditions the responses made after longer search times tend to be those associated with more difficult targets. For the incorrect detections there is initially some fluctuation about the curve which can be ascribed to the fact that only very few incorrect responses were made in these short search times.

In each case the mean confidence levels for the paced conditions are lower than those for the responses made in corresponding times under unpaced conditions. This would be expected since under the unpaced conditions subjects responded only if they were ready, whereas under paced conditions they were required to make a response. Data for the paced conditions therefore relate to all responses, whereas those for the corresponding unpaced times relate only to those responses the subjects had chosen to make. Detailed comparison is therefore not meaningful although it is of interest to compare Figure 7.2.1 with the corresponding detection probability data shown in Figure 7.1.1.

FIGURE 7.2.1

The effect of search time on mean confidence level under paced and unpaced conditions





7.2.2 The effect of range on confidence level

The analysis of variance given in Table 7.2.2 shows that the effect of range on confidence level is highly significant ($p < 0.001$). It would be expected that mean confidence level would fall as range increases and the targets become more difficult to detect. This effect can be seen in Table 7.2.5 which gives the mean confidence level at each range under each search time condition.

TABLE 7.2.5

Confidence levels at each range for each search time condition.

Search time condition	Range (miles)			
	1	2	3	4
T_5	5.21	4.71	4.40	4.29
T_{10}	5.45	5.00	4.90	4.48
T_u	5.74	5.40	4.67	4.76
Overall mean	5.55	5.12	4.73	4.57

Differences within the main part of this table must reach 0.46 to be significant at the 5% level (one-tail test), or, if the 4 mile range condition is involved, 0.57. Within the 1 and 2 mile range conditions the differences in mean confidence level between the T_5 and T_u conditions are significant and within the 3 mile range condition the difference between the T_5 and T_{10} conditions is significant. Other confidence level differences within range conditions are not significant and, although some of the differences between ranges within search time conditions reach the 5% significance level there is no consistent pattern.

In Table 7.2.5 values are also given for the mean confidence level at each range averaged over all time conditions. As in the case of the detection probability data these values are of less interest than the ones that show the effect of range on confidence level for each time condition separately. The data shown in Table 7.2.5 are plotted in Figures 7.2.2 - 7.2.4 together with the regression lines of confidence level on range for each of the three time conditions. It can be seen that the effect of range on confidence level is linear for each time condition although for the T_u condition there is some deviation of the points around the line. However, as shown in Table 7.2.6 which gives the regression analysis, this deviation is not significant.

TABLE 7.2.6

Regression analyses on range variation for each search time condition

Search time condition	Source	D.F.	S.S.	M.S.	V.R.	Significance
T_5	Range	3	18.37	6.12	3.80	$p<0.025$
	Linear regression	1	17.14	17.14	10.71	$p<0.005$
	Deviation	2	1.23	0.62	-	N.S.
T_{10}	Range	3	14.63	4.88	3.03	$p<0.05$
	Linear regression	1	13.65	13.65	8.48	$p<0.005$
	Deviation	2	0.98	0.49	-	N.S.
T_u	Range	3	29.90	9.97	6.19	$p<0.001$
	Linear regression	1	25.67	25.67	15.94	$p<0.001$
	Deviation	2	4.23	2.12	1.32	N.S.
	Residual*	328	528.16	1.61		

* This value for the residual variation is taken from the analysis of variance given in Table 7.2.2. The value can only be regarded as an estimate of the residual variation in the three separate sets of data for the same reasons as outlined below Table 7.1.8. in the case of the detection probability data.

FIGURE 7.2.2

The effect of range on confidence level under the 5 second paced condition (T_5)

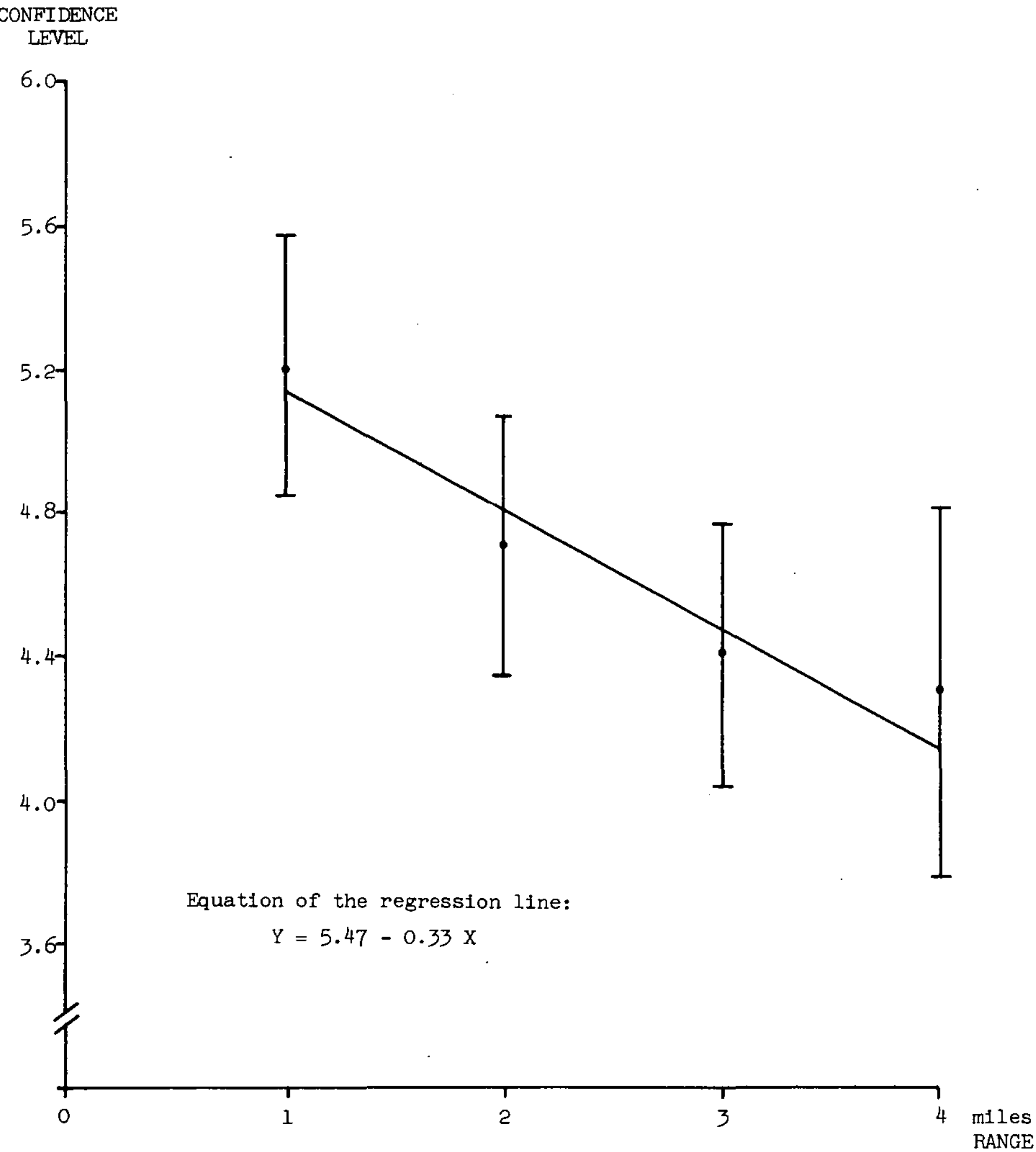


FIGURE 7.2.3

The effect of range on confidence level under the 10 second paced condition (T_{10})

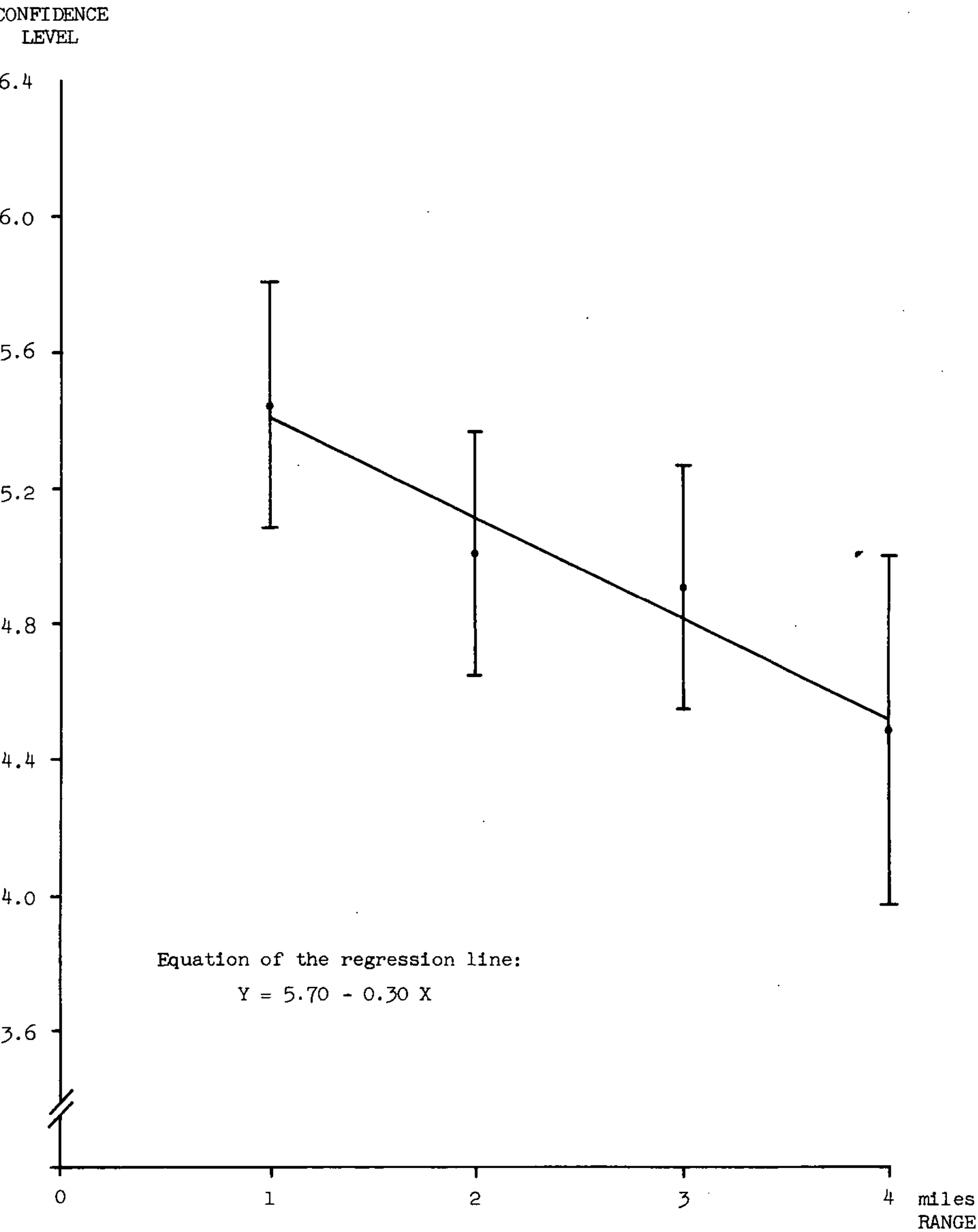


FIGURE 7.2.4

The effect of range on confidence level under the unpaced condition (T_u)

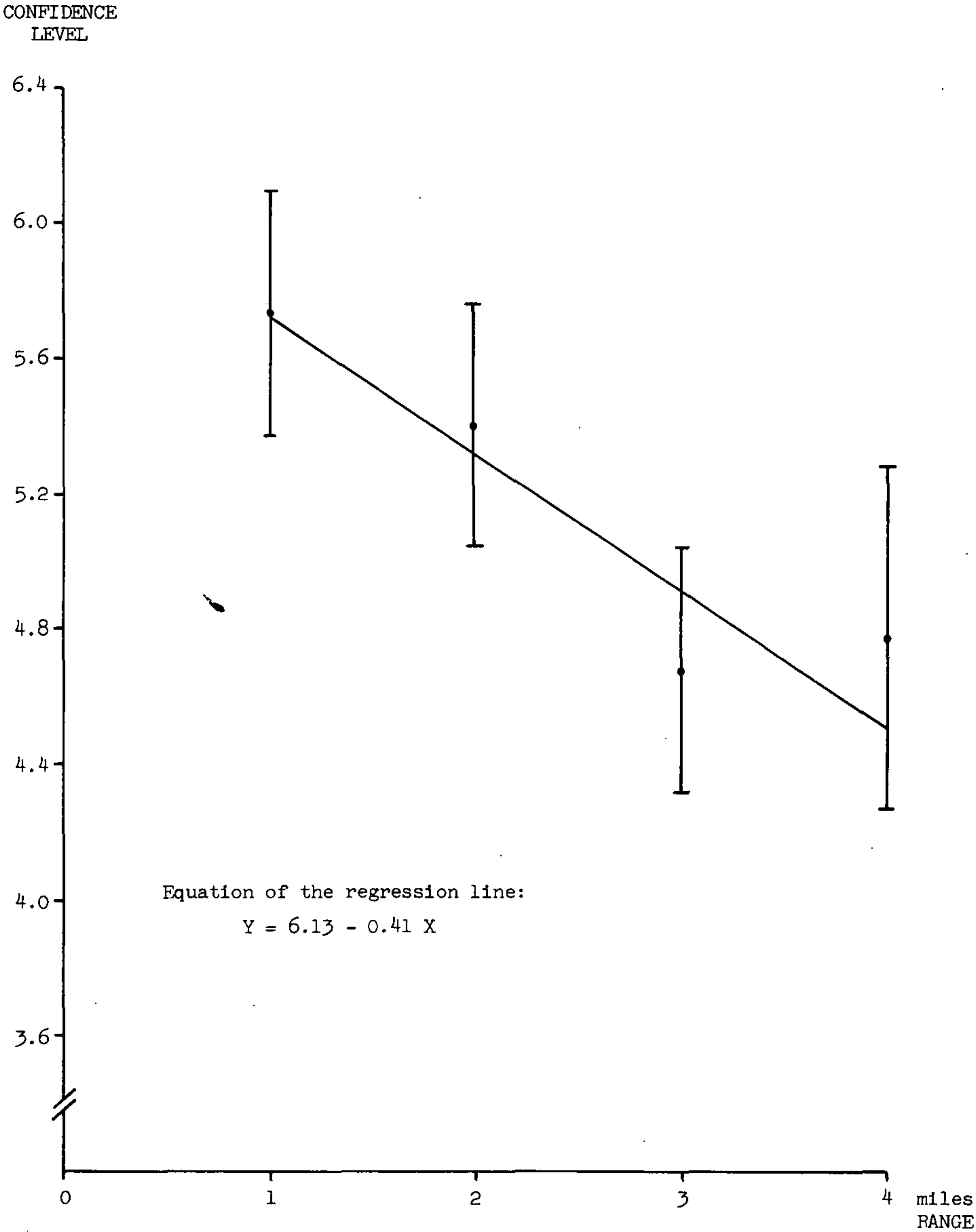


FIGURE 7.2.5

Regression lines showing the effect of range on confidence level under paced and unpaced conditions.

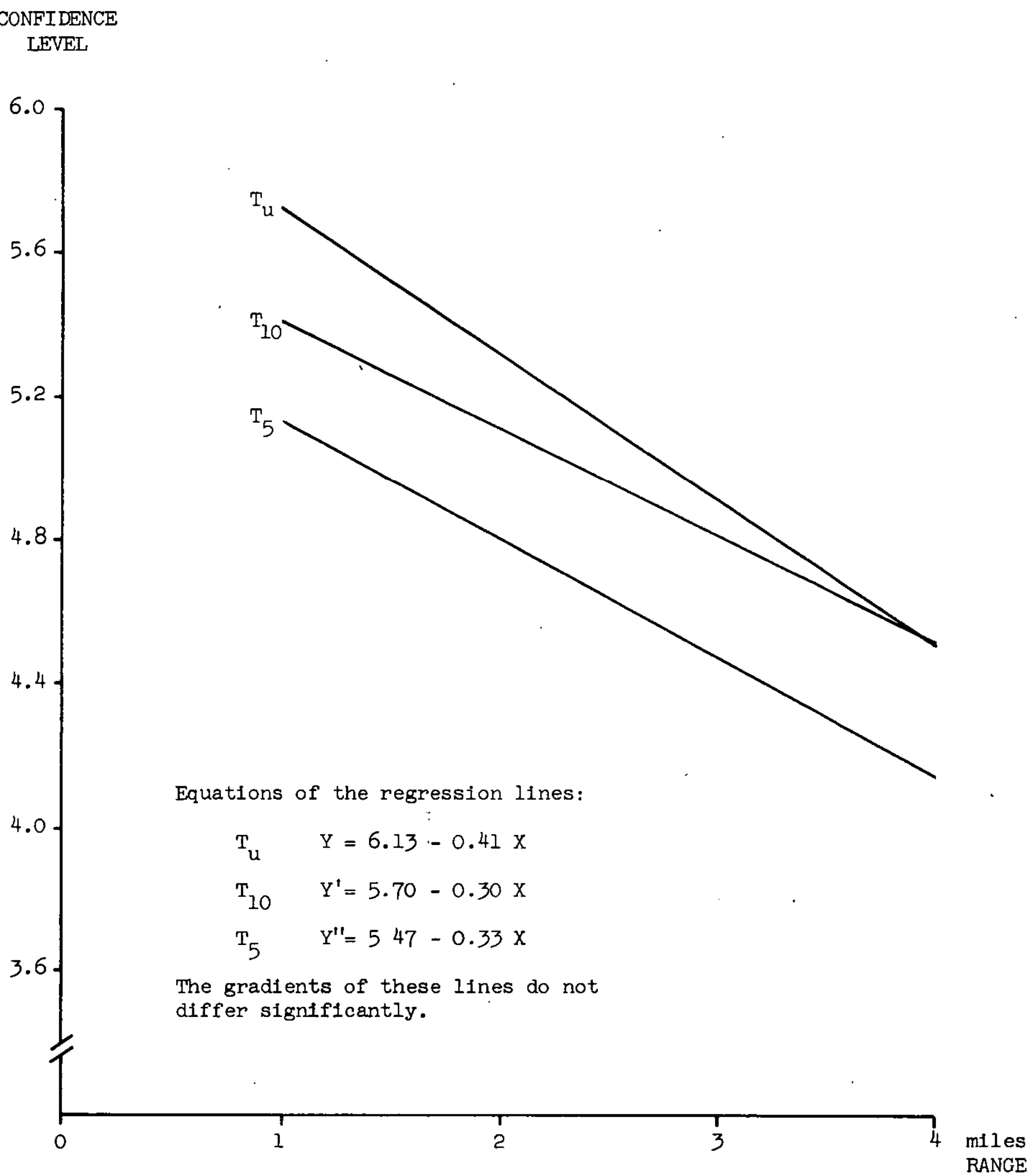


Figure 7.2.5 shows the three regression lines plotted together for comparison purposes. The lines relating to the T_5 and T_{10} conditions are almost parallel and, as would be expected, the T_5 line is lower than that for the T_{10} condition. The line relating to the T_u condition is slightly steeper than the other two lines, largely because of the unexpectedly low value for the 3 mile range. However, calculation of the linear component of the R x T interaction showed that the gradients of the lines were not significantly different, i.e. the lines did not deviate significantly from parallel.

7.2.3. The effect of target differences on confidence level

The analysis of variance given in Table 7.2.2. shows that target differences have a highly significant effect on confidence level but the interaction between search time and targets fails to reach the 5% level of significance. The mean confidence levels for each target under each condition of search time are given in Table 7.2.7.

TABLE 7.2.7

Mean confidence levels for targets under each search time condition

Target	T_5		T_{10}		T_u	
	Confidence Level	Rank	Confidence Level	Rank	Confidence Level	Rank
14	6.38	1	6.19	1	6.33	1
3	6.05	2	5.86	2	5.95	2
16	4.90	3	5.05	4	5.19	4
17	4.24	5	4.90	5	5.38	3
13	4.33	4	5.14	3	5.10	5
15	3.62	6	5.38	6	4.43	6
1	3.43	7	3.67	7	4.00	7

The coefficient of concordance, W, for the correlation between the rank orders of the target under each search time condition was a highly significant value, indicating that, as can be seen in Table 7.2.7. the rank orders of the targets according to mean confidence level were scarcely affected by the search time conditions.

Differences between mean confidence levels in Table 7.2.7. must reach 0.77 to be significant at the 5% level. The differences between the T_u and the T_5 conditions do not reach significance for any of the large targets but for three of the four small targets. the mean confidence level is significantly lower for the T_5 condition than for the T_u condition. Within each of the search time conditions differences in confidence level between targets high and low in the rank order are mostly significant, but there is some overlapping between targets ranked in the middle,

Mean confidence levels for the large and small target groups are given in Table 7.2.8.

TABLE 7.2.8

Mean confidence level for large and small targets

	Search time condition		
	T_5	T_{10}	T_u
Large targets (3)	5.78	5.70	5.82
Small targets (4)	3.90	4.52	4.73

The mean confidence values for large targets under each search time condition are not significantly different and the trend of lower confidence with reduced search time is not entirely consistent. For the small targets the trend is consistent and significant, the difference between confidence levels for the T_5 and T_u conditions being significant at the 1% level. Thus it is clear that the confidence levels associated with small targets are more seriously affected by the reduction in search time than those associated with the large targets. This result is analogous to that shown in Table 7.1.10 for the detection probability data.

7.3 Map-briefing times

Previous experiments had shown that the time the subject required to familiarise himself with the target area, and the approach to it, as shown on the 1" = 1 mile map, bore no definite relationship to his subsequent performance. In the present experiment no detailed analysis was carried out on these data. However, it was of interest to determine whether the subjects who were subsequently required to detect the targets under paced conditions took significantly different times in map-briefing. The mean map-briefing times taken under each of the search time conditions are shown in Table 7.3.1.

TABLE 7.3.1

Mean map-briefing time for each search time condition.

Search time condition	T_5	T_{10}	T_u
Mean time taken for map-briefing (seconds)	114.5	106.1	89.6

It can be seen from this table that the average time taken by the subjects for map-briefing increases as the time allowed for searching the display decreases. This trend, which is significant at the 5% level (two-tail test), suggests that subjects may have attempted to compensate for the shorter search time by spending longer in familiarising themselves with the information given on the map.

7.4 Psychometric measures

As explained in Section 3, Experimental Design, the three groups of 21 subjects assigned to the T_5, T_{10} and T_u conditions were balanced in terms of the mean scores obtained on Heim's A.H.5 test of intelligence since, as shown in Experiment I, these appeared to be correlated with detection performance. The small differences between the three mean scores were not significant, although the mean for the T_{10} group was marginally higher than those for the other two groups. None of the means differed significantly from the population norm for students, and there was no significant difference between the standard deviation values for each group. These data are given in Table 7.4.1. It was also found that there was no significant difference between the means or the standard deviation values for the E (extraversion-intraversion) and N (neuroticism) scores for each group as determined from the Eysenck personality inventory.

It was of interest to determine whether the relationship between intelligence score and detection performance, in terms of the number of correct detections made, found in Experiment I for the T_u group, also held for the T_5 and T_{10} groups. It might be expected that the subjects scoring higher on the test would be less affected by the short search times than those scoring lower. If this were so, then the value of Kendall's tau for the correlation between performance and intelligence score should increase as the search time is decreased, since reduction in search time would tend to accentuate the differences between subjects.

Values of Kendall's tau were calculated for the correlation between performance and intelligence score for the subjects in the T_5 and T_{10} groups. These values of tau were then compared with the value obtained in Experiment I for the T_u group. The relevant data are shown in Table 7.4.1.

TABLE 7.4.1

The correlation between scores on Heim's test and detection performance for each group of subjects.

Subject group		T_5	T_{10}	T_u
Scores on Heim's test	Mean	41.8	44.8	41.7
	s.d.	±7.3	±7.2	±7.4
Kendall's tau		+0.42	-0.02	+0.49
Significance		$p < 0.004$	N.S.	$p < 0.002$

It can be seen from this table that for two of the subject groups, T_5 and T_u, there was a significant correlation between number of correct detections made and the scores on Heim's test for the individuals in the groups. For the remaining group, T_{10}, there was no evidence of correlation, the value of tau being almost zero. There is no obvious reason for this lack of correlation as it is unlikely that the slightly higher mean intelligence score could account for it. The data do not support the theory that the more intelligent subjects would be less adversely affected by the reduction in search time. On the contrary, the most significant value of tau is that for the subjects tested under the T_u unpaced condition.

8. DISCUSSION

It is clear from the results described in the previous section that there are marked differences between performance under the paced and unpaced conditions. The data obtained in this experiment enabled these differences to be analysed in two separate ways, and the main part of this discussion is concerned with the results obtained from these analyses:

(i) The overall detection probabilities achieved under each of the search time conditions, one unpaced (T_u) and four paced (T_{10}, T_5, $T_{2.5}$ and T_1), were directly compared. The highest detection probability value was that obtained under the unpaced condition. Under the paced conditions there was a consistent decrease in detection probability with reduction in search time. It was also found that, whereas the detection of large targets was little affected by the reduced search time, the effect was much more marked for the small targets.

(ii) The detection probabilities achieved under each of the four paced conditions were compared with the cumulated detection probabilities achieved up to and including the corresponding time under unpaced conditions. The results showed that the overall probability of detection was greater in each of the paced search times than in the corresponding unpaced times. Further analyses of these results indicated that there was a definite relationship between paced and unpaced performance.

The decrease in overall detection probability that occurs as search time is reduced can be attributed to two main factors. Firstly, the reduction in search time reduces the amount of information that can be obtained from the display and, secondly, it reduces the time available for relating this information to that derived from the map. It should be noted that, under the conditions of this experiment, the time that the subject spent actually indicating the target position was outside the measured search time and need not be considered here.

If the mean fixation time remains constant then a reduction in the search time allowed would result in a directly proportional reduction in the number of fixations that could be made. However, there is some evidence that, when the subjects knows that only a limited search time is available, mean fixation time decreases (Richman, Enoch and Fry, 1958). This would tend to compensate for the reduction in search time, but it is likely that shorter fixation times would result in less information being obtained per fixation. This is consistent with the result, also found by Richman et al, that as mean fixation time decreased, the mean interfixation distance also decreased.

The information-processing component of the detection task involves relating the oblique terrain scene shown in the photograph to the information previously obtained from the map. Since maps show details of the terrain in plan view, and in a symbolically coded form, mental translation between the two types of information is necessary. The effectiveness with which this complex mental task can be carried out is likely to influence both the search pattern used and the accuracy of the response, but no information is available as to how such a task is affected by reduction in the time available.

The detection probabilities achieved under the four paced conditions could be directly related to the corresponding search times, but the unpaced condition, for which the overall detection probability was 0.59, was of a different nature since it was associated with a wide range of search times. Under the T_{10}, T_5 and $T_{2.5}$ paced conditions the overall detection probabilities (0.52, 0.45 and 0.41 respectively) decreased significantly in a linear manner with decreasing search time. This is consistent with the results reported by Boynton and Bush (1955) and Boynton (1960) that percent correct recognition was directly proportional to exposure time within a 3 - 24 seconds time range. However, under the conditions of the present experiment, it is unlikely that this linear relationship would continue very far outside the 2.5 - 10 seconds time range, and the low detection probability found for the T_1 condition, (0.29), is in accordance with this. This low value would be expected since in such a short search time very few fixations could be made and therefore no detailed information could be obtained from the display.

These overall detection probability values relate to all the range and target conditions tested, thus concealing the differences between presentations in which the target occupied a relatively large proportion of the display area and those in which the target was very small. The effect of these differences on detection performance under reduced search time conditions would depend on the interacting effects of a large number of factors, including the number of fixations made, the mean fixation time, the visual lobe size, the target size and the search strategy adopted. Detailed discussion of the results obtained is precluded by the lack of information available:

(a) The effective visual lobe size is not known. This is likely to be affected by several variables including target size, contrast and background complexity. These factors varied considerably in the targets presented in this experiment and one would thus expect corresponding variations in the visual lobe size. Some variation between subjects would also be expected.

(b) The area of the display searched is not known. Given unlimited time a subject might search the whole display but under paced conditions it is more likely that detailed search would be restricted to a central portion of the display, since almost all the targets were positioned in a central vertical section, approximately half the width of the display, and the subjects would learn to expect this.

(c) The search pattern is not known. It is unlikely that search would be either completely random, or that it would be systematic in the sense that a consistent linear 'reading' pattern would be followed. It would be expected that after some initial fixations from which the subject derives an overall impression of the main features in the display he adopts some sort of strategy by which he uses the information he derives from conspicuous features of the terrain to locate the general area in which detailed search is necessary. The ability of the subject to process information in this way is likely to influence both his search pattern and the accuracy of his response. A two-phase search process of this type was reported by Enoch (1959) who studied the eye-movements of photo-interpreters viewing vertical imagery. During the first, or 'orientation' phase the subject scanned the display in a characteristic pattern, before commencing the second 'specific' search phase in which use was made of any clues to target location obtained during the orientation phase. However, it is not known how reduced search time would affect each phase of this search pattern.

(d) The mean fixation time, and how it is affected by reduced search time under the conditions of this experiment, is not known. There is also no information about the percentage of the total search time occupied by fixations.

Extensive experimentation would be needed to obtain adequate information about each of these factors and the extent to which they are affected by limited search time. In the absence of such information it is only possible to discuss the results obtained, particularly those that relate to differences between large and small targets, in general terms.

The simplest case, that of targets occupying a relatively large proportion of the display, will be considered first. Two of the seven targets were markedly larger than the others and when viewed at short ranges (1 and 2 miles), they occupied on average 5% of the display area. In each case the target was a very conspicuous feature, which could be recognised without reference to other surrounding features in the terrain thus minimising the need to use detailed map information. The third target included in the large target group was of a rather different nature and is therefore considered separately.

Mean detection probabilities for the large targets under the T_{10}, T_5, $T_{2.5}$ and T_1 conditions were 0.92, 0.87, 1.00 and 0.87 respectively, but it should be noted that the last two values are based on extremely limited data. These values indicate that for the very conspicuous targets no significant deterioration in detection probability occurs as a result of a substantial decrease in the time available for search. Detection probability remains at a high level even when search time is reduced to 1 second, during which no more than five fixations, and probably less, would be made.

The high probability of detection achieved in the 1 second search time can be accounted for only if (i) the visual lobe within which these conspicuous targets could be detected was large and thus each fixation covered a substantial proportion of the display, and/or (ii) search was restricted to a limited central area of the display.

No information is available about either of these factors but it is clear that the search times allowed under the longer paced conditions were greater than necessary for these large targets for which very little search was required. The detection probability for these targets under unpaced conditions was 0.96, slightly higher than that for the T_{10} paced condition. The corresponding mean search time was 5.6 seconds, 67% of the responses being made in less than 5 seconds and 37% in less than 2.5 seconds. This again indicates that the longer paced conditions allowed longer search times than were actually required for large targets. It seems likely that these targets, which occupied a relatively large proportion of the display area, could usually be detected during the initial 'orientation' phase of the search process, this rendering the second 'specific' search phase unnecessary.

The third target included in the large target group was different from the other two in that it was relatively small, but was situated immediately adjacent to a large conspicuous feature, recognition of which enabled the target to be rapidly located. In previous experiments under unpaced conditions, and under the longer paced conditions studied in this experiment, the performance levels associated with this target were very similar to those for the two large targets, and therefore all three targets were grouped together for analysis. However, under the T_1 condition the mean detection probability for this target at short ranges decreased markedly to 0.25, indicating that this very short search time did not allow enough time for the two-stage detection process necessary. If this were so, it would be expected that this T_1 detection probability would be comparable to the corresponding values for the small targets at short ranges, and it was in fact found to be exactly equal to the mean value, but it must again be emphasised that only limited data were available.

The detection of small targets, particularly when presented at long ranges, is a much more difficult task, since the proportion of the display occupied by these targets averaged less than 0.5%. The probability of detecting these targets by a random search process spread over the whole display is small since much more detailed search would be required for targets of this size than for the large ones considered previously. Under these conditions it is necessary for the subjects to use the information derived from conspicuous features of the display, during the initial 'orientation' phase, to locate the target area. Detailed search of this limited area is then carried out during the 'specific' search phase.

Performance of a complex search task of this kind, involving both information processing and detailed search is likely to be more markedly affected by reduction in search time than the relatively simple task of finding large conspicuous targets. Even if mean fixation time decreases as the search time allowed is reduced, thus enabling more fixations to be made in a given time, it is likely that less information will be obtained per fixation. Thus, although the efficiency of the detection task may be increased, this would not entirely compensate for the reduced search time. A deterioration in performance would therefore be expected, and the results of this experiment, which showed that detection probabilities for small targets at long ranges were 0.31, 0.17, 0.06, 0.06 and 0.00 for the T_u, T_{10}, T_5 and $T_{2.5}$ and T_1 conditions respectively are in accordance with this. The decreasing trend was significant although the values relating to the $T_{2.5}$ and T_1 conditions were based on relatively few readings. A large decrease in detection probability occurred between the T_u

unpaced condition and the T_{10} condition, indicating that for these targets even the longest paced condition did not allow adequate time for this difficult detection task. This is consistent with the fact that under the T_u condition the mean search time for this target group was 16.5 seconds, and only 27% of all responses were made in less than 10 seconds. In view of this it is not surprising that only very low probabilities of correct detection were found for the T_5, $T_{2.5}$ and T_1 conditions.

These two groups of target and range conditions were chosen to illustrate some of the problems associated with the interpretation of the results of this experiment, since they represented the two extremes of target size, in terms of the average proportion of the display occupied. The other two groups, large targets at long ranges and small targets at short ranges, were intermediate in nature and intermediate in terms of the extent to which detection probability decreased as search time was reduced. Although the grouping of target size and range conditions is not precise the results discussed above indicate that in this experiment the effect of reduced search time on detection performance depends primarily on the size of the target.

The lack of information about fixation times and search patterns also precludes detailed discussion of the second main result found; that under paced conditions the overall detection probability achieved is greater in each case than the cumulated probability of detection up to and including the corresponding time under unpaced conditions. This comparison is between the proportions of targets correctly detected in the same time under two different conditions: an unpaced one, in which the subject responded voluntarily, knowing that if he wished he could take longer, and a paced one in which he was required to make a response at the end of the allotted time. The results clearly indicate that in a given time subjects are capable of making more correct detections than they chose to do under unpaced conditions.

One or both of the following reasons might account for this:

(a) The subjects actually detected the targets more quickly under the paced conditions.

(b) Having detected the target, they were forced to report it more quickly under the paced conditions, i.e. they were not able to delay responding in order to check or confirm what they thought to be the target position.

The first of these two possible explanations could be due to the fact that under the paced conditions the subjects were more highly motivated and less liable to distraction since they knew that they had to complete the detection task in a limited time. As indicated previously, it is probable that under these conditions mean fixation time decreased, and the task was carried out more efficiently, thus resulting in improved performance under paced conditions as compared with the corresponding unpaced time. However, it is unlikely that the increased search efficiency could entirely account for the large differences between the number of correct detections achieved in a given time under the paced and unpaced conditions.

The other possible reason - that under unpaced conditions subjects delayed responding in order to check the accuracy of their response could also account for this difference in performance, since any delay occurring between the time a target was detected and the time the response was made would have the effect of increasing the measured search time without substantially affecting the overall probability of detection.

The extent of the improvement in detection probability under the paced conditions depended on the difficulty of the detection task. It was much greater in absolute terms, for the large targets than for the small ones. This difference also tended to be greater for the shorter paced times than for the longer ones. For instance, under the T_1 condition the overall detection probability was 0.28 as compared with zero in the same time under unpaced conditions, whereas the corresponding values for the 10 second search time were 0.52 (paced) and 0.37 (unpaced). However, it is more meaningful to discuss this improvement in relative rather than absolute terms and an interesting result found in this experiment concerned a measure, designated I, used for this purpose.

Details of the derivation of these I values, and a formula from which they may be calculated, are given on Page 28. For the purposes of this discussion the I values can best be regarded as the proportions of 'forced' responses that were made correctly under the different paced conditions. 'Forced' responses were those that subjects had not chosen to make under unpaced conditions in the time concerned, whereas under paced conditions they were required to respond to each target presentation. It was found that the values of I remained effectively constant for different pacing conditions. In other words, although the number of 'forced' decisions decreased with increasing time the proportion of them resulting in correct responses remained constant. This result was found not only when all targets and range conditions were considered together (see Section 7.1.1) but also when they were divided into groups according to difficulty (see Sections 7.1.4, 7.1.5). It was also found that the value of I decreased with increasing difficulty, i.e. the more difficult the detection task the smaller the proportion of 'forced' decisions that were made correctly. The most difficult target group gave rise to I values close to zero, indicating that for this group virtually no improvement in performance was achieved under paced conditions.

These relationships, if valid, would allow performance under any paced condition to be predicted for any group of targets, from a knowledge of the search time distribution under unpaced conditions, and the performance achieved under one paced condition. There is no evidence that the relationship between paced and unpaced performance is valid for paced times longer than 10 seconds but it is reasonable to suggest that this would be so.

Calculation of the predicted detection probabilities under longer paced conditions shows that they increase to an asymptotic level, which is effectively reached in 20 seconds of paced search time. This asymptotic level is, by the nature of its calculation, the same as that obtained under unpaced conditions.

The detection probability achieved under the T_1 condition is of particular interest since under unpaced conditions no detections were made in less than 1.2 seconds and therefore all responses made under the T_1 condition could be regarded as 'forced'. The overall probability of correct detection under the T_1 condition was therefore equal to the I_1 value, i.e. the proportion of 'forced' decisions made correctly. In determining detection probability under the T_1 condition the normal experimental technique had to be modified, as described in Section 6.2, to take account of the very short search time. In spite of this the overall value of I_1, 0.29, agreed closely with the corresponding I values for the other paced conditions. It was also in good agreement with the proportion of target presentations that had been rated as 'very easy to detect' by two skilled navigators at the start of this series of experiments.

Partitioning of the T_1 data into two groups relating to large and small targets, enabled the corresponding I_1 values to be calculated for each group. In the case of small targets the agreement with I values for the other paced conditions was good, but for the large targets the I_1 value, 0.48, was lower than the corresponding values (0.60, 0.61 and 0.59) for the other paced conditions. This low value is based on very few readings and it is not significantly different from the other values, but in any case this effect would be expected as a result of the anomously low detection probability, under the T_1 condition, for one of the targets in the large target group, which has already been discussed. As would also be expected, the effect was found to be much more marked for the I value relating to large targets at long ranges, than for the value relating to short ranges. There was also some evidence that the $I_{2.5}$ value for large targets at long ranges was lower than the other I values for this group. In all other instances the I values for the different paced conditions within any target group were in good agreement.

Although the apparent constancy of the I values is of some interest, it is not possible to discuss this result in formal terms since the experimental material used in this study was not closely controlled in terms of target size, shape, contrast etc. and, as indicated earlier in this section, much relevant information is not available. However, some general points can be made. Of particular relevance is the fact that I values derived in this way are likely to be very sensitive to the conditions under which the experiment was carried out, and especially the instructions given to the subject.

An important feature of this experiment was the fact that under the $T_{2.5}$, T_5 and T_{10} paced conditions each of the subjects was required to attempt to detect each of the targets. The conditions of this experiment therefore did not allow the subject to adopt any internal criteria of certainty on which he might base his decision of whether to report what he thought to be the target position, or whether to make no response. He was required to indicate what he considered to be the most likely target position regardless of how uncertain he was. In this way both correct and incorrect responses were maximised and 'don't know' responses eliminated. Had such responses been allowed, the likely effect of reducing search time would have been to cause the subject to alter his response criteria rather than, as in the present experiment, to force him to abandon it altogether.

The conditions under which the unpaced experiment was carried out should also be noted. Although the subjects were instructed to carry out the detection task as quickly as possible, no direct means of motivation such as monetary rewards based on good performance were used. Had, for instance, the subjects been paid according to speed and accuracy, rather than a flat hourly rate, it is likely that performance under unpaced conditions, in terms of the number of correct detections made in a given time, would have been more closely comparable to, if not better than, that under the paced conditions studied in the present experiment.

According to whether these incentive payments favoured speed or accuracy it would be expected that the cumulative probability curves would be compressed towards shorter times and/or the ratio of correct to incorrect responses would change. It was not possible to determine from the data obtained under paced conditions in the present experiment the form of the cumulative detection probability curves for these conditions since the subjects were asked to respond only at the end of the allotted search time although in some cases the detection task might have been completed before this time had elapsed.

Had subjects been allowed to respond before the maximum time if they wished and these shorter search times recorded, a series of cumulative curves would have been obtained which could have been compared with that for the unpaced condition. For this reason it would have been of interest to have determined these data. Without such information it can only be suggested that the cumulative curves for the paced conditions would have been similar in form but would have become increasingly steep as the maximum search time allowed was reduced. The final level reached by each curve would have corresponded to the overall levels determined in the present experiment. Such data would also have allowed a more detailed study of the relationship between paced and unpaced performance.

There is no obvious explanation of the relationship between paced and unpaced performance found in the present experiment, as indicated by the apparent constancy of the I values. No published work could be found that reported similar findings. It would be of interest to determine whether similar results could be obtained from a more closely controlled experimental situation, such as the recognition of complex forms against a background containing easily confusable forms. Since this result was obtained under static simulation conditions it is unlikely to be of direct relevance to the dynamic high-speed, low-level target recognition problem, but it would also be of interest to determine whether analogous results could be obtained in the dynamic situation, if cumulated acquisition probabilities were plotted against range and compared with the corresponding acquisition probabilities determined at various fixed ranges along the route. Such an experiment would be of some relevance in connection with the use of 'frozen' displays.

Analysis of the confidence level data obtained in this experiment showed that, as would be expected, significantly lower degrees of confidence were associated with responses made in shorter paced times. These differences were, however, relatively small, possibly because each subject was only exposed to a single time condition and adjusted his confidence scores accordingly. There was no apparent interaction between range and search time in the confidence level data and for each time condition the relationship between range and confidence level was linear. These results are analogous to those found for the detection probability data. In general, no results of particular interest were found from the analyses of the confidence level data in this experiment, although they did indicate that subjects were to some extent aware of their level of performance.

One point of interest was noted in the short analysis carried out on the map-briefing time data. It was found that there was a significant trend of increase in the mean time taken for map-briefing with decrease in the maximum time allowed for searching the display. Although this effect could be due to differences between the three groups of subjects exposed to the different time conditions, T_u, T_{10} and T_5, it could also be due to the subjects tending to compensate for shorter search time by adopting a higher criterion of familiarity with the information shown on the map.

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APPENDICES

APPENDIX I

This report includes a further analysis of the data previously analysed in Experiment I. For convenience, a summary and a table of the main results of this experiment are given below.

SUMMARY OF EXPERIMENT I

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 skilled 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.

APPENDIX II

The basic Latic Square design used in this experiment is shown below. Subjects (designated 1 - 7) are arranged in the matrix so that each appears once in each row, and once in each column. This matrix was replicated three times for each of the main experimental conditions, and once for each of the subsidiary ones. In each case presentations of particular target and range combinations to a subject were randomly ordered.

	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