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Display luminance and responses to transient light stimuli

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Display luminance and responses to transient light stimuli

by

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A doctoral thesis submitted in fulfilment of the requirements for the award of Doctor of Philosophy in Ergonomics of the Loughborough University of Technology, April 1977.

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Abstract

The subject of enquiry is the effect of high intensities of ambient luminance on task performance by human subjects, and the task employed, the detection of transient light signals in an illuminated display encompassing the whole of the subject's visual field. Experimental conditions were designed to test one particular prediction from previous work, that high intensities of environmental stimulation tend to reduce the range of cues utilised from the environment in performance of a task. In the case of high intensities of luminance the prediction would be of a reduction in the size of the visual field, or 'tunnel vision'.

The data produced does not bear out this prediction. Subjects show a decreased consistency of response when observed under the higher intensities of luminance so that their detection rate for peripheral signals is comparatively lower than for other intensities, but not in a sufficiently clear-cut fashion to be 'tunnel vision' as predicted.

This decreased consistency of response is found to originate in a difference in the temporal pattern of response. All subjects show a regular cyclic fluctuation in responsiveness to all signals. While the frequency of the fluctuation is the same for all subjects, in the case of the higher luminance subjects the periods of reduced responsiveness last for a longer time.

The type of analysis employed does not appear to have been used before in conjunction with this type of data. It is likely that such analysis applied to new or existing data would reveal a sensitivity to variations in display luminance over a wide range, and to other experimental variables as well.

Several areas of research are considered in a search for an explanation of the cyclic fluctuations found. A tentative model is constructed from elements of the theories of arousal, attention and sensory oveloading. The implications for experimental design and industrial work situations are considered.

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Introduction

Introduction.

1. Lighting and visual research.

Lighting is a subject of importance to everyone who can see. Light is not only a vehicle for information about the world, it also regulates the activity of many animals and plants. In a human society with an advanced technology, artificial lighting provides a high degree of independence from the sun, particularly where indoor occupations are concerned.

In times past, and in some societies today, artificial indoor lighting was an expensive luxury even for places of work. Today cheap, convenient lighting is taken for granted and lighting generally has reached a high standard of intensity. In the field of industrial lighting the emphasis is now on balancing economic considerations with the desire to provide the best environment for workers. The problem has been to determine what type and intensity of lighting is necessary for maximum efficiency.

It is now firmly established that increasing the intensity of illumination on a task will improve performance. Functional visual acuity improves with increased intensity especially in conjunction with other factors such as improved contrast (Spicer 1969). Over a wide range of intensities of illumination (Blackwell 1959) the smallest detectable contrast and size of the target object decrease as display illuminance increases. Blackwell's work is well supported by other studies. However, improvement is not indefinite and performance reaches a plateau at an optimum intensity of illumination (Boynton and Boss 1971).

Other studies have investigated the effect of intensity of ambient illumination on reading performance (Tinker 1952), subject preference in a realistic work situation (Saunders 1969), and task performance in relation to age (Bodmann 1967). Fluorescent and tungsten lighting have been compared in their effects on performance (Lion 1964).

In general the emphasis has been on performance on the task to the exclusion of other dependent variables. The duration of testing of subjects rarely approaches that of a working day, so that extrapolation of results to a working situation must be approached with caution. Independent measures of fatigue, for example, are rarely taken. If subjects are compensating for strain over the short period of the experimental session, this may not be revealed in their task performance.

An approach which takes account of this problem is the comparison of performance with the expressed preferences of the subjects, under different conditions of task illumination. Boyce (1973) found a general correspondence of preference with performance data. This is not always the case, however. Bodmann (op. cit.) using a search task, found preferred values to be limited in the upper direction. This was the case even though performance continued to improve throughout the luminance range for the oldest age group. Boyce (1970) also found no deterioration in performance at intensities which half the subjects reported as too high. In these cases, the higher intensities may well have had a deleterious effect on the subjects, but they may have been able by increased effort to prevent it from becoming apparent in their performance.

These studies emphasise the importance of determining the effect of high intensities of illumination on performance and on the subject as a whole, but for practical reasons the higher ranges of illumination intensity have been little explored. Lighting designers are unlikely to be interested in levels higher than those at which optimum performance has been reached. To use higher levels would increase installation and running costs and also the problems involved in eliminating glare. Experimenters are aware of this fact. To quote Boyce (op. cit.):

" It was the intention that these experiments should relate to the actual practice of lighting design .... there would seem to be little point in extending the illuminance range above the value for which the differences between the performance of the age groups are likely either to disappear or become constant. This consideration has determined the highest illuminance used. "

The fact remains that high intensities of luminance do occur and will continue to do so, for example for such tasks as colour discrimination, inspection of small objects, and small-scale assembly work. Even where artificial installations only give a moderate level of illumination, positions beneath or near large windows may receive high intensities on a bright day.

It would be dangerous to assume that no-one is exposed to higher levels than those recommended. In addition, experimental performance data is task-specific and it is quite possible that a level beneficial to someone performing one kind of task is detrimental to someone else doing a different job in the same room or looking at objects of higher reflectivity.

One particular area which has not been explored in relation to high luminance intensities is that of extra-foveal activity. Many tasks, particularly inspection tasks and those involving instrument panels, rely on extra-foveal perception of changes in the environment. If extrapolations to these situations are made from data on foveal perception, the calculations are likely to be in error because account has not been taken of differences in the perceptual processes involved.

For this reason it is important to study the effect of luminance intensities on performance over the whole of the visual field. It is also important to control the visual contents of the whole of that field. Too often, published experimental details specify, say, a 30° display without giving any information about what else was in the subject's field of view, or the luminance values there.

The size of the functional visual field seems to be particularly sensitive to the effects of environmental variables, and can sometimes indicate the effects of stress when performance on a simple task is not affected. Recommended standards of lighting do not specifically take account of this indicant, and so may not be sufficiently accurate for tasks where extra-foveal perception is important. The section following examines the effect of environmental variables on the visual field, with special reference to the use of measurement of the functional visual field as an indicant of stress.

2. Visual field investigations.

Experiments relating to the effect of environmental variables on the visual field are best seen in the context of a group of studies on the topic of cue utilisation. These studies investigate the effect of environmental and psychological variables on the range of information which the subject uses from his environment in performing a task. Manipulation of these variables can cause changes in the subject's efficiency of detection of cues over the visual field. and also in his utilisation of cues from all modalities, together with conceptual cues. The experiments differ widely in detail, but considered together they demonstrate the active nature of perception, which is dependent on the subject's own state as well as that of his environment.

Easterbrook in 1959 stated that emotional arousal acts to reduce the range of cues that an organism uses. This may influence behaviour in ways that are either organising or disorganising, depending on the behaviour concerned. For example, people in dangerous situations may panic and act in ways that the deteched observer can see are not conducive to their own safety and are not the result of a correct understanding of the situation. Conversely, people can ignore pain resulting from their own injuries or perform acts of apparently super-human strength, until the danger has passed.

The results of experiments conducted to examine Easterbrook's hypothesis have tended to support it. This applies whether the experimental display is a cognitive or a physical one. Easterbrook's concept has since been widened to include not only anxiety and motivation as the experimental variable producing the effect, but also other stimuli such as heat and noise. In this case it may not be the variable itself, but the intermediate variable of stress or arousal which causes the reduction in the range of cues utilised.

Bursill (1958) for example used a central tracking task and peripheral light signals and found that a greater proportion of the peripheral signals were missed when the subjects were exposed to hot and humid conditions. Cornsweet (1969) used a choice reaction task in which additional information was given by peripheral cues, but the subject was not specifically told about these. Electric shocks, presumed to increase arousal, enhanced the use of peripheral cues regardless of the differing degrees of motivation provided by shock schedules. Callaway and Dembo (1958) manipulated the subject in a more direct fashion by using drugs, such as amyl-nitrite and methamphetamine. The drugs seemed to have the effect of narrowing attention by reducing the subjects' responses to sudden changes in their environment.

The drugs are thought to stimulate the reticular formation and affect the filtering effect of the reticular formation on lateral sensory pathways.

Other experimenters have manipulated the subject psychologically rather than physically. Leibowitz and Appelle (1969) used a central task of varying difficulty in conjunction with a peripheral light detection task. Luminance thresholds for the detection of peripheral stimuli rose with the difficulty of the central task. Bahrick, Fitts and Rankin (1952) investigated the effect of various incentive schemes on subjects performing a central and a peripheral task simultaneously. Performance on the central task always improved during bonus trials, but performance on the peripheral task never improved and was sometimes adversely affected. Tolman (1948) and Bruner et al (1955) have shown in experiments on rats that strong motivation (in this case food or water deprivation followed by food or water rewards on completion of learning) tends to speed up learning at the cost of less efficient cue utilisation. Similarly, overlearning reduces the use of cues introduced after learning is completed. The effect is a mechanisation of behaviour and a rigid conception of the situation. Postman and Bruner (1948) asked subjects questions about tachistoscopically presented pictures. The experimental group was shown sub-threshold exposures and (presumably because of frustration) showed a lack of learning and reasoning ability with a narrowing of the range of internal resources; a very similar effect to that seen in the rats of Bruner (op. cit.).

Some experimenters have categorised their subjects on the basis of a subject variable and compared performance between groups of subjects so categorised. Solso, Johnson and Schatz (1968) examined the question of the total amount of information perceived in displays shown to subjects for short lengths of time. The subjects were divided into high- and low-anxiety groups. The amount of information perceived proved to be the same for the two groups, but the high-anxiety groups perceived more stimuli in the outer perimeter. Eysenck and Willet (1964) used a search task with high- and low-drive subjects and found the performance of the latter group to be superior. Schmidt (1964) divided subjects into two groups on the basis of scores on the Taylor Manifest Anxiety scale. Their recognition of test objects at different viewing distances was tested and the visual angle measured at which they could first identify the objects. High-anxiety subjects showed a larger visual field at one of the viewing distances studied.

Some experiments have involved a realistic or real stress situation. Berkun (1964) exposed combat trainees to realistic situations of stress and recorded performance on a task connected with the situation. The stressful situations were found to affect performance on the task, so that subjects missed important cues, for example whole paragraphs in an instruction manual. The better performers were found to show less anxiety on the Taylor Manifest Amxiety scale. Experience reduced the effect of the stress situations but increased the effect of the control situations, presumably because of boredom. Weltman and Egstrom (1966) used a peripheral light detection task in conjunction with a central task in various risk situations with novice divers. Central task performance did not interfere with peripheral detections, but the reaction time to the peripheral stimulus was longer in situations of greater risk.

Subjects in all these experiments have been exposed to a wide variety of situations, and the concept of "narrowing of attention" has been used in different ways. Results are not entirely consistent, but it seems that where the expected effect does not appear, the experiment has been conducted in a laboratory and there has been no serious threat to the subject's well-being. Where conditions have been more stringent, the results support Easterbrook's hypothesis that emotional arousal reduces the range of cues the organism uses.

These experiments on the topic of cue utilisation are relevant to the present study since they show that manipulation of experimental conditions, physical or psychological, can cause changes in the subject's efficiency of detection over the visual field. The present experiments were designed to detect any such "narrowing of attention" should it occur in a situation where the experimental variable is intensity of background luminance.

The following sections examine two areas of interest in relation to the experimental methods and conditions employed in the present experiments. Firstly, vigilance studies have investigated the subject's behaviour in situations where he is required to keep watch for long periods for the occurrence of a signal. Many of the methods and findings from vigilance literature are relevant to any experiment involving a detection task.

Secondly, the choice of signal parameters to be used in a detection task is very important. Knowledge of the characteristics of transient signals and their effects on detection performance, is summarised.

3. Vigilance tasks.

Many different types of experiment have been gathered under the umbrella term 'vigilance study' and it is therefore difficult to define the term precisely. There do however appear to be two common factors. Firstly, subjects are required to maintain a watch for, and report the presence of, a significant stimulus. Secondly, the interest of the experimenter lies chiefly in the effect of an independant variable on changes in performance over time. The reason for the latter feature is probably an historical one, since performance decrement over time is important in many real-life tasks such as radar monitoring, and work stations where a large number of dials and monitors must be observed.

Vigilance experiments in the visual modality often employ similar apparatus to psychophysical experiments. Often the only difference is that vigilance experiments are not concerned with establishing thresholds but in recording changes in performance over time or between different groups. Psychophysical methods specifically cancel out the variable of time by taking an average value of all the measures recorded in an experimental session, or by randomising blocks of trials under different conditions, to the same effect. In contrast, the vigilance experimenter divides his data into successive blocks, either arbitrarily or in relation to some real event within the session, and compares scores over time.

For example, Bakan (1955) established subjects' detection threshold for a light stimulus and then presented the stimulus at this level during a period of 90 minutes. If the subject did not respond to the stimulus, it was presented at progressively higher intensities until a response was made. He found that as the session progressed, the intensity of the signal had to be progressively increased to ensure detection. This represents a rise in threshold with time. Tasks in which the stimulus intensity is relatively low are more likely to show a performance decrement with time, for this reason.

This is part of a more general finding from vigilance tasks in which the subject is required only to detect the presence of a signal; that the more difficult tasks show greater decrement. Thus, for example, detection of a brief signal is more likely to show performance decrement than detection of a longer signal.

The effect of having several signal sources as opposed to only one is not completely clear from previous experimentation. There appear to be interaction effects involving such other factors as the complexity of the task and the spatial separation of the sources. In general, however, multiple source tasks show less decrement, perhaps because the extra observing activity involved lessens the effects of boredom. Centrally located signals elicit a higher detection rate than peripheral ones, again possibly because of the observing processes involved. Subjects tend to search the central area of a display, or watch central signal sources more than those in the periphery. Where a decrement is observable, peripheral sources are more likely to show the decrement.

Experiments in which two tasks are performed simultaneously seem to show that the extra workload imposed will improve performance if the tasks are easy, or at least will prevent the occurrence of a performance decrement. This however depends on the modalities involved. The combination of two auditory tasks, or of an auditory and a visual task may improve performance, but when two visual tasks are combined, detection rate may be better on either alone. This again is because of the active nature of the observing process in the visual modality.

The timing of the presentation of the task is particularly important. Rest pauses can halt decrement or at least interrupt a rapid decline in performance. The pause does not need to be very long, or even involve relaxation to be effective. Unless the subject is required to fixate for long periods, a change of activity rather than actual physical rest is all that is required. Other types of work introduced for short periods, even if they are energetic, will suffice to produce a beneficial effect on performance on the main task.

Total time spent on the task has an important effect on vigilance decrement, because of the expectations of the subject. Thus decrement appears earlier in a long session than in a short one, presumably because the subject rations his effort. The subject is prepared to maintain maximum vigilance for longer when he knows he will be released shortly. A similar effect often appears near the end of the session, when performance improves (the end-spurt). These effects however depend on the knowledge of the subject about the length of the session, and whether he has any means of knowing the time. Subjects in vigilance experiments seem to markedly underestimate the time they have been working, and if deprived of watches may not show the end-spurt. It is difficult to control the subject's expectations, since he has to be told the approximate length of time for which he will be needed, and naturally will try to use this information.

The most usual measure of performance on vigilance tasks is the number of signals correctly detected, expressed as a function of time in order to reveal the presence of performance decrement. If the same number of signals is presented to each subject or group of subjects, comparisons can then be made. False responses made when no signal has been presented can also be analysed. False responses, or errors of commission, are an indication of the subject's criterion for responding, both in terms of the degree of certainty he needs to respond, and of the way he sees his task. Some subjects may see the detection of every signal as their prime responsibility, even at the cost of false responses; others may respond only when they are absolutely certain of the presence of a signal. False responses can therefore be manipulated by the amount of learning allowed, a process which allows the subject to establish his criterion for response; by the experimenter's instructions,and by incentive or disincentive schemes. False response rates are highly individual, depending on the amount of learning a subject requires and on his interpretation of the experimental situation.

Reaction time is a useful measure of vigilance performance particularly when the detection rate is high. In this case, it may prove to be the only measure of differences between the experimental conditions. Some studies involve a signal which remains present until detected in which case reaction time is the only measure of performance. In general, reaction times show an inverse relationship with detection rate, that is, as the subjects respond less frequently they also respond more slowly.

Occasional very long reaction times may be evidence of 'blocking', first named by Bills (1931). He observed that when subjects were performing a colour-naming task, they produced some very slow responses, sometimes associated with errors.
Broadbent (1953) compared the performance of subjects on Leonard's 5 - choice serial reaction task, both paced and unpaced. In the

unpaced condition slow responses, or blocks, were balanced by extra fast reactions. In the paced condition, the pace of presentation being determined by the average speed of the unpaced condition, subjects were unable to compensate in this way and errors resulted.

Attempts have been made to establish the relationship between personality and performance on vigilance tasks, by correlating subjects' performance scores with scores on tests such as the Maudsley Personality Inventory. Subjects may be ranked according to their scores on the extraversion-introversion scale of the M.P.I. According to personality theory (for example, Claridge 1967) extraverts, having a lower basal level of arousal than introverts, should perform less well in vigilance situations, since a characteristic of the latter is a low level of stimulation. Experimental findings are somewhat equivocal on this point, possibly because performance decrement and false responses are a better indication of differences than detection rate. The effect of the personality variable may depend on the exact nature of the task and the stimulation provided. Extraverts do seem to benefit more from having an additional task to perform than do introverts (Bakan 1959).

4. The detection of transient signals.

Transient signals have long been used to gain knowledge about the visual system. This is because the experimental data so obtained is easily classifiable; in terms of whether or not the subject indicated that he saw the stimulus. This binary information can then be conveniently analysed, usually in terms of response probability. When the stimulus is varied in intensity or some other characteristic a series of such probabilities is obtained and a threshold curve may be plotted. Commonly, that value of the stimulus parameter which gives a probability of 50 % is termed the threshold value. Variations in this value when other variables are employed give information on the effect of those variables on the visual functioning of the subject.

An example of the way in which these methods are used is the study of dark adaptation. When a subject is exposed to a sudden decrease in illumination adaptation to the new level takes some time. During this time visual performance improves as adaptation takes place. This process can be recorded by means of threshold measurements and the 'dark adaptation curve' results.

Alternatively, the threshold for a particular stimulus may be defined as the minimum value of the stimulus parameter sufficient to produce a response from the subject. This type of definition is usually employed when measurements are taken against a background of complete darkness, and an absolute threshold is obtained. When an illuminated background is used the result is termed an incremental threshold.

Stimulus parameters affecting detection thresholds.

Size The detectability of a stimulus increases with its size. This relationship, however, interacts with other variables. To take an extreme example, at low intensities of luminance the apparent brightness of a stimulus is a function of both its luminance and its size, up to sizes of about half a degree of visual angle. This phenomenon is known as summation.

Duration In a similar manner, the Bunsen-Roscoe law expresses the summation of intensity and duration of a stimulus flash for durations of up to about 200 msec.

Colour Threshold sensitivity varies according to the wavelength of the stimulus light. The greatest sensitivity appears at 550 - 560 nm.

Contrast and intensity Contrast is fundamental to vision. If an object is of the same colour and luminance as its background, and there is no directional lighting, its presence will not be detected by the static observer since the image it casts on the retina will be identical with that of the background. Threshold curves can be plotted in the same way as for other stimulus parameters.

Where the background is totally dark, the probability of response is proportional to the absolute intensity of the stimulus. Where there is a background luminance, this relationship no longer holds and threshold curves may be plotted for the relationship between the luminance intensities of stimulus and background. The contrast may be negative or positive; that is the stimulus luminance is lower or higher than that of the background, and the contrast can be expressed by numerical formulae. These are not comprehensively descriptive, however, and the effect of stimuli with given numerical values of contrast will depend on the absolute value of the background luminance. In other words, detectability is not purely a function of the ratio between the stimulus and background luminances.

Location The detectability of a stimulus depends on its location in respect to the subject's visual field. In photopic conditions the fovea is the most sensitive part of the retina and sensitivity decreases towards the periphery. Location is usually expressed as the angle of displacement of the stimulus from the subject's line of sight to a fixation point.

Transient stimuli and reaction time.

Reaction times change with stimulus parameters in much the same way as do response thresholds. Times shorten with increases in intensity, duration, size, and contrast of the stimulus, and with decreasing eccentricity of location. In addition, spatial and temporal summation apply, within limits, to affect reaction times.

Response time is made up of three elements; perception, decision and motor response times. Motor response and perception times are likely to show only small variance, especially in a well practised subject, so that the differences in total response latency elicited by changes in stimulus parameters are largely due to decision time. This can be demonstrated by choice reaction time experiments in which subjects must decide which of two or more stimuli is the 'wanted' one; for example which of two lights is the brighter. The closer together are the two stimuli on the relevant parameter, the longer is the reaction time.

Reaction time is therefore a measure of the difficulty of the discrimination which the subject is required to make. When he has to distinguish the presence or absence of the signal then (to use the terminology of signal detection theory) the length of the decision part of the reaction time depends on the discriminability of the signal (stimulus) from the noise (background). The greater the contrast of the stimulus, the longer it lasts, and the more receptors it stimulates the easier is this discrimination and the shorter the reaction time.

5. The research problem.

A survey of research literature shows that the effects of high intensities of illumination have not been extensively examined.

The literature also suggests that study of the functional visual field provides a promising approach to the topic.

Research on vision and lighting has provided a substantial amount of knowledge about the effect of light intensity on task performance, but other dependent variables such as expressions of preference and the long-term effects of compensation for unfavourable lighting conditions have not received attention in proportion to their importance. In particular the effects of lighting intensities above the optimum level have not been thoroughly studied.

The literature on attention studies suggests that measurement of the functional visual field is important in assessing the effects of environmental variables on behaviour. Light intensity has not been used as an environmental variable in this context.

Vigilance experiments have employed separate signal sources some distance apart but the subjects in these experiments are not required to fixate. Differences in detection rate between subjects observing separated sources and those observing a single source are therefore due to differences in detection behaviour in terms of head and eye movements rather than to changes in visual function over the field of view.

Psychophysical experiments are designed to determine threshold values and not to examine supra-threshold behaviour. Average detection rate and reaction time are the measures usually employed, and the effects over time of experimental variables are specifically excluded for the purposes of this type of experiment.

The present study was carried out to test the effects of high intensities of lighting on the human visual system. It is known that performance on many tasks can be improved by increasing the intensity of the ambient lighting, up to an optimum level beyond which performance does not improve. The consequence has been twofold; an emphasis on efficiency as the dependent variable, and little interest in determining the effects of intensities above the optimum level.

The aim of the present research was to test the effects of intensities of illumination greater than those usually employed in experiments on vision, on a visual function sufficiently basic to permit detailed analysis of any changes in that function. In particular, data was to be gathered from the whole of the visual field since knowledge about extra-foveal vision is rather sparse, but does indicate that measurement of the size of the visual field is important.

The detection of transient light stimuli seemed to be the best task to use. Comparison with results from similar experimental arrangements in the literature is possible, both in designing the experiment and in assessing the results. The data produced is suitable for detailed numerical analysis of changes in the pattern of responses, both spatially and temporally. Finally, manipulation of the luminance of the stimuli gives control over the difficulty of the task.

Introduction to the experiments: design considerations

Introduction to the experiments: design considerations.

Several of the experimental studies described in the Introduction suggest that one aspect of a subject's performance on a visual detection task which may be affected by experimental manipulation is responses to stimuli in the periphery of vision. Signals may elicit no response when presented from this region, or the reaction time of the response may lengthen. This has been termed the 'tunnel vision' effect.

In order to investigate these possibilities in relation to the experimental variable of intensity of display luminance, stimuli were presented in the central and peripheral visual fields of the subject, from an illuminated display. The intensity of display luminance and the stimulus parameters were controlled so that any difference in detection behaviour occurring over time or between conditions of intensity of display luminance could be attributed to the main experimental variable.

The display.

A criticism which may be made about some of the 'cue utilisation' experiments is that when central and peripheral tasks are clearly differentiated (for example Bursill op. cit.) it is difficult to define the mechanism producing narrowing of attention. One cannot assume that the subject's poorer response to peripheral stimuli under conditions of stress is due to an involuntary narrowing of attention taking place in the central or peripheral nervous system. It may equally well be the result of the subject's strategy when subjected to stress; to devote his energies to the apparantly more important, or more easily performed task and thereby reduce the cost of performance.

It is not possible to completely remove this source of error by experimental design since the subject may make his own definition of central and peripheral, or of main and subsidiary task, but by removing any obvious division the experimenter can make more information available for analysis even if he cannot prevent such behaviour. Accordingly signal lamps on the display used for the main experiment were arranged in a random manner, and distributed in such a way as to appear of equal density over the display.

The display was designed to cover the whole of the subject's visual field for two reasons. Firstly, it ensured control of all visual stimulation impingeing on the subject. Secondly, signals could then be presented in all regions of the visual field and maximum information obtained about differences in response in different regions.

Illumination of the display.

Illumination conditions on the display are described in terms of luminance, as this measure is the most relevant to subjective experience and the stimulus intensity is also expressed in this way. The unit used is candelas per square metre. Four intensities of display luminance were used, 120, 280, 440 and 600 cd/m^2. Equivalents in terms of illuminance are hard to define, since they depend on the reflectivity of the surface being considered, but the luminance values can be estimated as similar to a range of 500 - 3500 lux in normal conditions. The upper levels are well in excess of most working levels currently being recommended.

The signal.

The flash of a small lamp against an illuminated background was the signal to be detected. Light stimuli may be presented in two ways, as a discrete flash to which the subject must respond within a limited time, or as a steady light which remains on until the subject has responded to it. A disadvantage of the discrete flash method is that it may not be clear whether the response is to the onset or offset of the stimulus. In other words, there are really two stimuli to which the subject may respond. However, the discrete flash is more useful than the steady light stimulus when there is more than one possible location for the stimulus, or when there are likely to be false responses, since any response within the time-limit is likely to be to the stimulus immediately preceding it if the inter-signal interval is considerably longer than the duration of the signal. Accordingly the discrete flash was chosen and the limited time-period set at 1·5 sec. after the onset of the stimulus.

Duration of the signal.

The duration of each flash of a signal lamp was set at 0·5 sec. At durations between 50 and 200 msec., time-intensity trading takes place as a consequence of which the subject responds to the total energy presented. In order to isolate the effects of intensity it is necessary to employ a flash duration safely above this region.

Inter-signal intervals.

Three inter-signal intervals were chosen, 5, 8, and 11 sec., giving an average interval of eight seconds. The intervals were varied to make it difficult for the subject to predict the time of arrival of the next signal.

Fixation.

Subjects were instructed to look at a fixation point in the centre of the display during all trials. They could not be expected to maintain perfect fixation for any length of time, since as well as tiny constant movements of the eyes (saccades) slow drifting movements occur and constant correction is made for these. The angle of separation of the signal lamps (10°) was however sufficiently large for movements within the normal range to be unimportant for interpretation of the results.

Rest periods.

The task was not intended to be a vigilance task as such, and so trials were short with rest periods inbetween. The rest periods were also necessary to provide physical relief from concentration on the fixation point. The subject was free to move while resting but not to look outside the illuminated display area, in order to prevent disturbance of retinal adaptation to the display luminance. The rest periods lasted for about two minutes.

Signal luminance.

To test for 'tunnel vision' effects in subjects detecting signals against an illuminated display background, the performances of subjects observed under different conditions of display luminance are compared for the spatial and temporal pattern of responses. If overall performance (in terms of the proportion of signals correctly detected) varies widely between experimental groups, it may not be possible to compare such patterns with any validity. Therefore measures were taken to equate overall detection rate between conditions, by establishing the details of display and signal luminance intensities relating to various detection thresholds.

Signal/background contrast is known to affect detection thresholds and this effect also varies with the absolute intensities involved (Blackwell 1959). Therefore, simply equating contrast ratios between conditions of display luminance would not equalise the difficulty of the task. Similarly, equating performance in only one area of the retina, say the fovea, may not be sufficient, since the decrease in efficiency from the fovea to the periphery may vary from one condition to another.

Accordingly pilot experiments were undertaken to determine the levels of performance associated with various combinations of the display luminance intensities to be used and a range of intensities of signal luminance. This data was then used in setting up conditions for the main experiment.

The interviews.

After subjects had completed all their trials they were interviewed by the experimenter. Certain questions were asked of every subject, but the interview structure was loose and supplementary questions were asked when necessary to clarify a point. The aim was to obtain a picture of the subjective experience of performing the task so that the data could be interpreted more fully.

The Eysenck Personality Inventory.

After the experiment subjects were asked to complete the Eysenck Personality Inventory (Form A). Studies have suggested that performance on vigilance tasks, and tasks used in experiments on cue utilisation and the effects of noise, may be related to the subject's score on the extraversion/introversion scale (for summary see Davies and Tune 1970). The present experiment has elements of a vigilance task and the Inventory was administered to test the relationship of subjects' scores with their performance.

Pilot experiment I

Pilot experiment I.

" To examine the effect on performance of a visual detection task, of different intensities of display luminance while contrast is held constant ".

1. Purpose and summary.

This experiment was a preliminary investigation providing data to be used in designing the main experiment. Its purpose was to establish the intensities of signal lamp luminance appropriate at the different intensities of display luminance.

In the main experiment, the signal detection performance of the subjects was to be directly compared, the only experimental variable being that of the display luminance under which the subjects were run. For this direct comparison to be made, signal lamp luminances had to be established for each display luminance, at which all subjects would respond to an approximately equal proportion of signals out of those presented, to provide a common baseline of performance.

In this first pilot experiment, the display luminance was kept constant, and the luminance of the signal lamps changed to give four intensities. The subject fixated the centre of the display and gave a simple response when he saw a signal. Detections were then analysed in relation to the contrast ratio, signal lamp/display luminance, for each intensity of display luminance.

2. Apparatus and experimental design.

Display design.

The display was housed in a large box, open on the side opposite to the display. The interior of the box was illuminated by 'artificial daylight' fluorescent tubes in the roof of the box and concealed behind angled panels (figures 1 and 2).

The subject sat at the open side of the box and when in position with his chin on the rest, was able to see only the interior of the box. The adjustable chin rest was cushioned with paper tissues for comfort. The subject held the response button in his preferred hand, keeping his arms folded out of sight. The chair was adjustable in height.

Signal lamps.

The display contained eight signal lamps. These were pre-focus tungsten bulbs centred behind Opal Perspex discs set into the hardboard of which the display was constructed. The interior of the box, except for the fixation point and the Perspex discs, was painted a uniform Flake Grey of reflection factor approximately 55%. The fixation point was a circular paper disc of two shades of red, a pale pink in the centre with a stronger red surround, and subtended $1^{\circ}14'$ at the eye. The "central" four lamps each subtended 24' at the eye and the "peripheral" ones, 18'. The displacement angle subtended at the eye between the fixation point and the lamps was approximately 23° for the "central" and 45° for the "peripheral" lamps.

Signal lamps are sometimes here referred to as "central" or "peripheral". This refers only to the positions of the lamps relative to the fixation point, and is purely a matter of convenience. In fact all the lamps are peripheral in the physiologically accepted use of the term, that is, beyond about 2° from the point of fixation. The four lamps nearest to the fixation point are here referred to as central and the remaining four as peripheral.

Display illumination.

The ambient illumination was controlled both by the number of fluorescent tubes used, and by reducing the voltage to the tubes. Where possible, in order to minimise flicker, the use of fewer tubes was preferred to dimming, in which case 'on' tubes were alternated spatially with 'off' tubes. The side lighting behind the angled panels was always on, but dimmed where necessary. A diffuser was placed in the roof of the box beneath the overhead tubes, consisting of a lattice-work of semi-opaque plastic which prevented a direct view of the tubes from the position of the subject.

Signal lamp luminance.

The luminance of the signal lamps was measured using an optician's lens held in a clamp in front of the lamp, and a photometer. The purpose of this was to magnify the lamp to allow measurement using a 1° field photometer. The lens magnified the lamp aperture to fill the field of the photometer. The transmission factor of the lens was found to be negligible. Once the minimum and maximum luminances of the lamps were known, arbitrary values of contrast were chosen and the corresponding voltages recorded in the appropriate ambient illumination. Thus the luminance levels could be set for each experimental session without further readings.

Variable luminance control of signal lamps.

The luminance of the signal lamps was controlled by means of a potentiometer in the lamp control box, and when a change in luminance was required the voltmeter in the circuit was adjusted taking as a constant reference the voltage applied to one particular lamp. Apart from this adjustment procedure, the lamps were always lit for 0·5 sec. during the experiment. The experimenter could initiate a signal by pressing one of eight labelled buttons on the control box.

Recording responses.

The initiation of a signal automatically started a reaction time count on a Venner clock which was stopped by a response from the subject or by being reset if there was no response. After a response the reaction time was displayed on the clock in milliseconds and remained there for three seconds before disappearing automatically. In addition the total number of the subject's responses, true or false, were counted automatically and therefore the number of false responses could be calculated by deducting the number of valid responses from the total.

Subject selection.

Seven volunteer subjects were used, six males and one female. They were required to be non-smokers, aged 18 - 20, and have normal vision without glasses or contact lenses. The reason for the first two requirements was to eliminate two possible causes of differences in visual performance, smoking and age, while the reason for the latter was to eliminate physical interference from spectacle frames or lenses, and gross abnormalities of vision. When a time was arranged for the subject to attend for the experiment he was told that it would take 'under two hours'. In fact each session took about an hour.

Experimental design.

The design is shown in figure 3. Each subject experienced only one intensity of ambient illumination during the experiment but there were four different lamp luminances for each intensity of illumination. The variables, contrast (lamp luminance) and signal schedules were varied for each subject in a Graeco-Latin design. The levels of lamp luminance corresponded to contrast ratios of 2•0, 3•0, 4•0 and 5•0.

Four different signal schedules were derived from random number tables. Within each schedule signal lamps were lit in random order and each lamp was used an equal number of times. Schedules were arranged to occur an equal number of times within all the different conditions of contrast and display luminance.

3. Procedure.

The equipment.

Lighting was set to the required level about half an hour before the subject's arrival so that the fluorescent tubes could warm up and stabilise. The room lighting was on when the subject arrived but was switched off when trials began.

Instructions to the subject.

The features of the display were pointed out to the subject, the response button was placed in his preferred hand, and he was asked to practise pressing the button. This was to ensure that unfamiliarity with the response would not be a factor in responses during the first trial relative to the other trials.

The chair and chin rest were adjusted until the subject's eyes were level with a mark on the cabinet doors corresponding to the height of the fixation point. Instructions to the subject were to look at the fixation point all the time during the trial, and to press the response button as soon as he saw a signal lamp flash.

Experimental procedure.

When the subject arrived he was shown the two experimental rooms. He was then tested on the perimeter. During this procedure all lights including those in the display box were switched off, and black paper blocked light from doors and windows. The subject was tested on the perimeter for the outer limits only of the binocular field, on the 0°, 90° and 45° meridians.

The subject was then tested on the Keystone apparatus. This presents specially prepared cards for monocular or binocular viewing through an eyepiece with lenses. The card is illuminated and can be placed in two positions corresponding to near or far viewing. The Rapid Snellen Chart for near vision was used. During this time the lighting in the experimental box had been switched back on and it was found that the display luminance quickly returned to its former level.

The subject was then seated at the display, seat and chin rest adjustments made, and instructions given. The subject was told also that there would be a rest period in a little while. To give such information is in a way undesirable, as it influences the subject's expectations, but it serves to make the first trial equal with subsequent trials: the subject will be expecting regular rests in any case, as the session goes on.

There were four trials within the session, identical except for the luminance of the signal lamps, and the signal schedule, which had been controlled for in the design. There were forty signals and therefore thirty-nine intersignal intervals in each trial, and each trial lasted just over five minutes. Between trials the subject was told to rest without looking outside the box (in order not to disturb adaptation of the eye to the ambient illumination) and to ignore the lamp used for calibration. During each trial a record was kept of reaction times and the total number of responses.

4. Results and discussion.

Graphs 1 - 6 (Appendix A) refer to this experiment. Results are shown as (arithmetical) average detection rates for the one or two subjects in each condition, expressed as a percentage of the total number of signals preented (40 per trial). Seven subjects were employed, two for each condition of display luminance except 600 cd/m^2.

Graph 1 shows a linear relationship between detection rate and lamp luminance up to about 2400 cd/m^2, but after this a plateau is reached at about 50% detection rate (or 'threshold' as commonly defined) at the contrast ratios of 3.0, 4.0 and 5.0 in the 600 cd/m^2 condition. When responses to central and peripheral signals are separated (graphs 2 and 3) it can be seen that while peripheral responses vary little with lamp luminance, central responses increase with lamp luminance up to 90% of total detections.

In graphs 4 - 6, detection and contrast, central responses again show the clearest trends. Performance improves with increased contrast, and subjects are separated in terms of display luminance. There is no point at which all four curves overlap, and it is not valid to extrapolate.

This experiment did not fulfill the function for which it was designed, due to the unexpectedly large effect of display luminance on performance with contrast held constant, and was not completed. A further experiment was therefore carried out to resolve the problems raised, and this is described in the next section, pilot experiment II. The relationship between display luminance and performance will be discussed further there.

Subject interviews.

Subjects were questioned about their experiences at the conclusion of the experimental session. None of them seemed to realise that the luminance of the signal lamps was changed during the session. Three subjects complained of eye-strain, and two of flicker which they said they could see on the back wall of the box. Both immediately attributed this to the fluorescent tubes, and said that it disappeared after a while. Four subjects could not give any colour to the signal lamps, while one thought they were pink.

These impressions did not seem to bear any relation to the level of display luminance which the subject had experienced.

Figure 1.

Pilot experiments: apparatus.

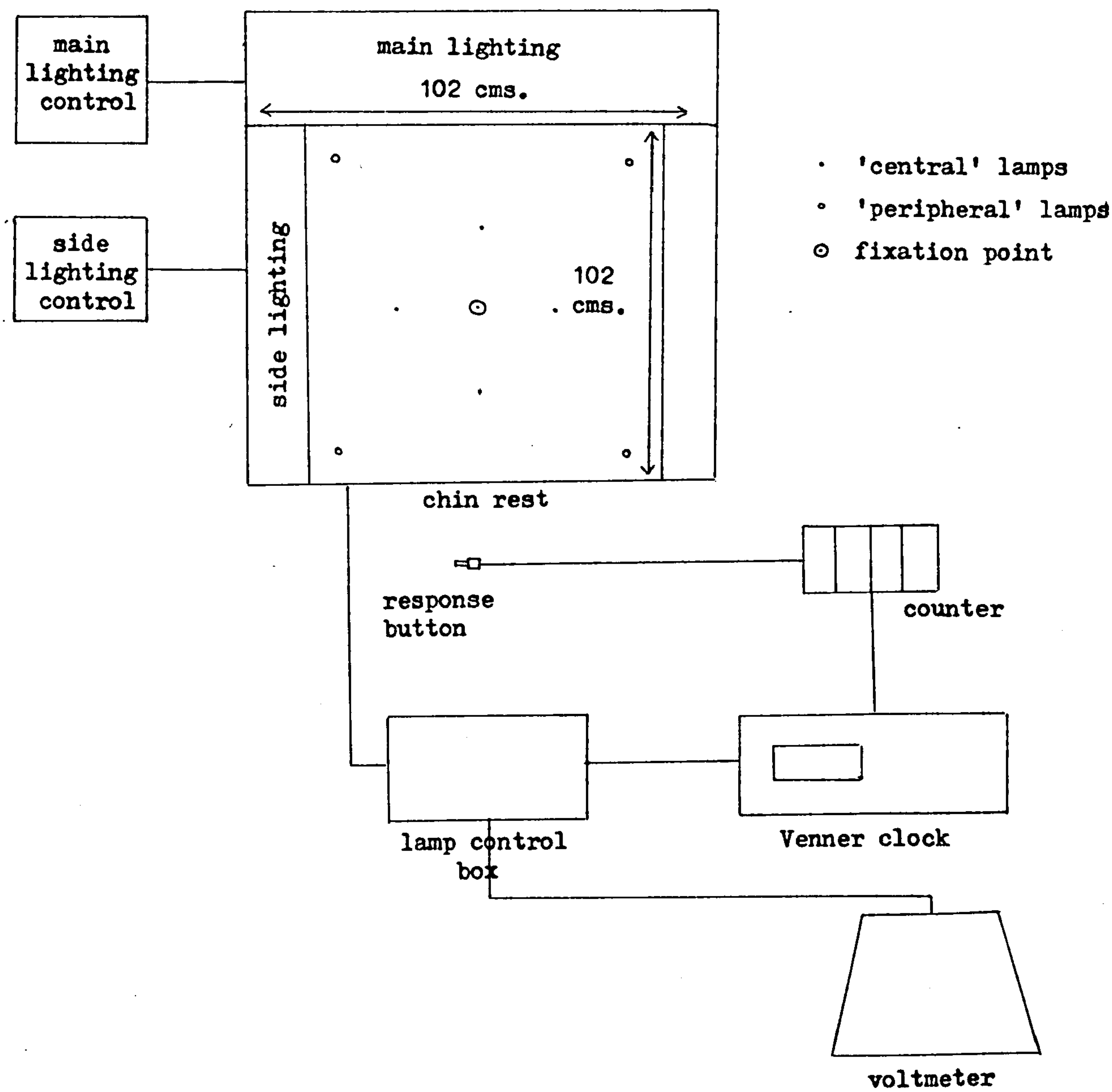


Figure 2.

Pilot experiments: apparatus.

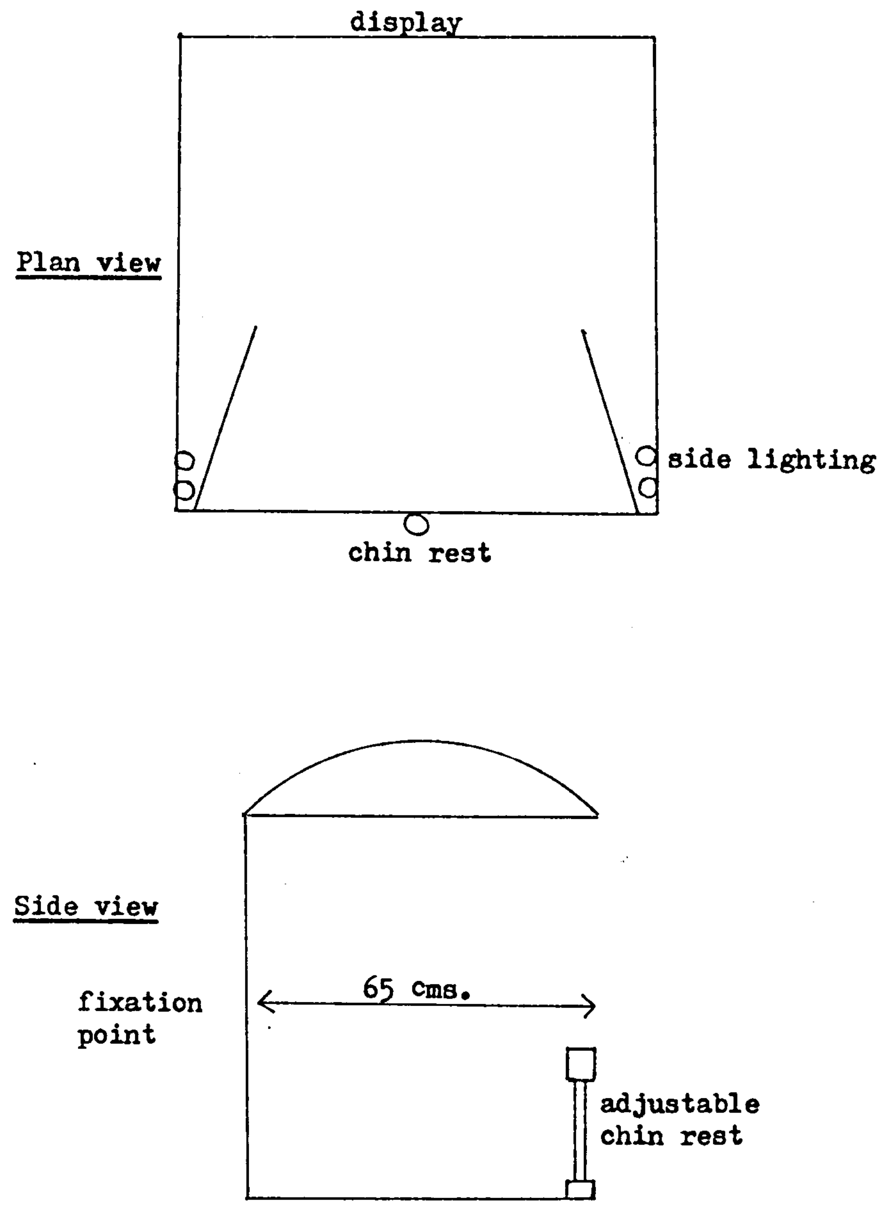


Figure 3. Pilot experiment I: design.

			lamp luminance (cd/m^2)			
Background luminance (cd/m^2)	I1	600	3600	3000	2400	1800
	I2	400	2400	2000	1600	1200
	I3	190	1140	950	760	570
	I4	100	600	500	400	300
contrast ratios $\frac{b - B}{B}$			5·0	4·0	3·0	2·0

b: signal lamp luminance (cd/m^2)

B: display luminance (cd/m^2)

Figure 4.

Pilot experiment I: - Results.

Subject	lamp luminance	detections central /20	detections peripheral /20	total	false responses
S1	3600	18	3	21	9
	3000	18	0	18	18
	2400	16	4	20	28
	1800	14	1	15	9
S2	2400	16	6	22	0
	2000	13	4	17	0
	1600	7	3	10	0
	1200	8	2	10	0
S3	1140	2	0	2	1
	950	2	0	2	0
	760	3	0	3	0
	570	1	0	1	1
S4	600	9	1	10	4
	500	3	0	3	1
	400	1	0	1	1
	300	0	0	0	6
S6	2400	20	8	28	6
	2000	17	7	24	4
	1600	14	1	15	0
	1200	4	1	5	1
S7	1140	11	0	11	2
	950	6	1	7	1
	760	6	0	6	9
	570	0	0	0	1
S8	600	0	0	0	0
	500	1	0	1	1
	400	0	0	0	0
	300	0	0	0	0
Totals		210	42	252	103

Pilot experiment II

Pilot experiment II.

" To examine the effect on performance of a visual detection task, of different intensities of display luminance while signal luminance is held constant."

1. Purpose and summary.

Pilot experiment I showed that for each degree of contrast, as display luminance increased, performance improved. Detection rate at each intensity of display luminance was shown to be closely related to lamp luminance, and each degree of contrast produced widely differing detection rates between conditions of display luminance. The effect was so large that insuffient data was available to plot threshold curves for each intensity of display luminance, which was the purpose of the experiment. Therefore a second experiment was designed on the basis of repeated intensities of signal lamp luminance, rather than the signal/display luminance contrast ratio as before.

2. Apparatus and experimental design.

The apparatus was exactly the same as that used for the first pilot experiment, except that the visual testing apparatus (Keystone and perimeter) was moved to an adjoining laboratory which had become available. This meant that lighting in the experimental room did not have to be disturbed.

Subject selection.

Criteria were widened because of the difficulty experienced in finding suitable subjects for the first experiment. Subjects were required only to have normal vision, uncorrected. Twenty subjects, including university students and staff, were used. There were ten men and ten women.

Procedure.

The experimental procedure was exactly the same as in the first experiment, except that visual testing was carried out in an adjoining laboratory, and that there were five trials per session instead of four.

Experimental design.

Each subject experienced all conditions during four separate sessions. Each session involved one intensity of display luminance and five intensities of signal lamp luminance, with a rest period between each trial as before.

There were five intensities of signal lamp luminance as set out in figure 6 and these were common to each condition of display luminance. In this way the contrast varied according to the intensity of display luminance. Taking contrast as $\frac{b - B}{B}$ (where b is the signal lamp luminance and B is the display luminance) the contrast was in the range -0·3 to +29·0. (A minus-sign occurs when the lamp luminance is lower than the display luminance).

Conditions were randomised over subjects, to eliminate order effects. Display luminance was varied in a series of 4 x 4 Latin squares, and lamp luminance in a series of 5 x 5 Latin squares, in such a way that each combination appeared only once during the whole series of 20 trials for each subject. The Latin square design is shown in figure 5. There were 40 signals and 39 intersignal intervals in each trial, as before, and 20 different signal presentation schedules. The schedules were derived from random number tables. All the schedules were used, in a differently randomised order, for each subject.

3. Results.

Raw results are presented in Figure 7.

Graphical presentation.

Graphs 7 - 13 (Appendix B) refer to this experiment.

Graphs 7 - 9, detection rate and signal lamp luminance, show a great similarity with graphs 1 - 3, drawn from data in pilot experiment I. However, this similarity cannot be examined in detail, because the latter only show responses over a segment of the lamp luminance continuum for each intensity of display luminance, and so the two sets of graphs are not directly comparable. As in experiment I, responses to 'peripheral' signals change with display luminance far less than do responses to 'central' signals. Also as before, a plateau in performance at 90% is shown, although these results are averaged over 20 subjects and a few did attain 100% in the conditions with the highest contrast ratios.

Inspection of the values of contrast corresponding to those in the first experiment (2·0,3·0,4·0 and 5·0) in graphs 10 - 12 shows that similar trends can be seen. The 'peripheral' responses are undifferentiated in respect to display luminance. 'Central' responses show differences from a contrast ratio of about 2·0, and reach an optimum at about 12·0.

Graph 13, log signal contrast and log display luminance, demonstrates that the relationship between difference thresholds set at various percentages is a consistent one, the contrast value sufficient to produce a given detection rate decreasing with increasing display luminance in a linear fashion. These results are consistent with the established finding that $\frac{b - B}{B}$ progressively decreases as the illumination level is increased.

Statistical analyses.

Four statistical analyses were carried out on the data.

i) Four-way analysis of variance.

It was not possible to analyse subject variance or interactions between subjects and other factors, in a design in which each subject acts as his own control.

The analysis was carried out by computer programme and the results are summarised below.

A - signal lamp luminance
B - subjects
C - display luminance
D - central vs. peripheral signals

All the main effects were significant at the 0·1% level of confidence or better.

The following interactions were found to achieve significance:

CD	-	1% level of confidence
AD	-	0·1%
AC	-	0·1%
ACD	-	0·1%

ii) Partial correlation.

A partial correlation analysis was carried out to distinguish the effect of display luminance within the total correlation between contrast and performance.

The three parameters were:

1. contrast (signal/background)
2. performance (detection scores)
3. display luminance

The results of the correlations were:

contrast and display luminance	$r_{1,3} = -0{\cdot}634$
performance and display luminance	$r_{2,3} = -0{\cdot}507$
performance and contrast	$r_{1,2} = +0{\cdot}915$

$r_{12,3} = +0{\cdot}891$ (that is, the correlation between performance and contrast with the effect of display luminance taken out). By further analysis the contribution of display luminance was found to be 5·1%.

$r_{23,1}$ is not significant (that is, the correlation between performance and display luminance with the effect of contrast taken out).

iii) Three-way analysis of variance. Carried out by computer programme with false responses replacing detection rate as the data analysed. No significant factors emerged from this analysis, though it would seem that subjects vary widely in their false response rate. As before, it was not possible to analyse for the factors of subjects because of the experimental design.

iv) T - test between men and women subjects. $t = 1.153$ (n.s.)

Note: Subsequent references to 'pilot experiment' results in this thesis refer to the second pilot experiment throughout.

4. Discussion.

Blackwell (1959) in his series of experiments with highly trained observers, obtained a great number of smoothed threshold curves plotted on the relationship between log target contrast and log background luminance, varying target size and signal duration over a wide range. A typical curve is shown in figure 8.

These targets were presented in the centre of the subject's visual field, and the contrast values are extremely low. It will be seen from figure 8 that for a target size comparable with that used in the present experiment (between 10' and 60') the curve levels off at between 10 and 100 foot-lamberts. Graph 13 shows no such trend. The relationship between target contrast and background luminance, as commonly described (see also for example figure 9; from Marsden 1964) does not seem to apply in the conditions of the present experiment.

The main difference between the conditions of the present experiment and those of the experiments in figures 8 and 9 is the part of the subject's visual field to which the stimuli were presented. All targets in the present experiment were in the periphery of the field as normally defined. It may be that the threshold curves shown in graph 13 eventually reach a minimum and level off at higher intensities of luminance than those tested. In this case graph 13 confirms the shape of Blackwell's curves, for peripheral stimuli.

On the other hand, the curve may denote a different shape, such as a U-shaped function. marsden (1964) writing of a large body of work in this field, has pointed out:

> " At low luminances these functions ... would be expected to fail as vision is taken over by the rods ... at high luminances these functions are again questionable, describing as they do a curve with a minimum at infinity. "

If threshold contrast values are not to decrease indefinitely as background luminance increases, they must eventually stabilise or, more likely, rise. This effect may be revealed at lower intensities of luminance for peripheral stimuli.

A explanation of Blackwell's curve is that the ambient illumination affects the retinal receptors in such a way as to facilitate the registering of changes in brightness over small areas of the field, or in other words to reduce the 'just noticeable difference'. This effect ceases to operate at higher intensities of illumination, presumably because no further facilitation is possible. The results described above may not show this cessation, showing that this facilitation can operate over a wider range in the more peripheral parts of the retina.

Alternatively, it is possible that contrast alone is not the only factor which should be considered. Each unit on a contrast scale in fact represents an increase in the absolute luminance of the target equal to the ambient luminance, and therefore at higher intensities a unit increase in contrast represents a larger increase in absolute target luminance than at lower intensities of ambient luminance. Detection thresholds may respond to absolute signal luminance as well as to target/background contrast ratios. In the present experiment, because peripheral stimuli were being used, absolute signal luminances were much higher than would normally be used for foveal targets. This may cause a distortion of the normal function so that threshold contrast values continue to diminish with increasing intensity of background luminance, at intensities higher than normal for foveal threshold curves.

5. <u>The subject interviews.</u>

Subjects were interviewed immediately after the experimental sessions. Unfortunately a failure of recording equipment meant that detailed records of some interviews were lost, but the remainder were transcribed (Appendix C).

1) Two subjects (S1, S2) were evidently unable to distinguish between false and correct responses, since they grossly under-estimated the number of false responses they had made. The others were more accurate in their estimates and this suggests that they knew when they had made a false response.

2) Four of the subjects mentioned phenomena which they thought of as originating in themselves rather than in the display, and which they thought of as responsible for their false responses.

3) All subjects gave a good estimate of the length of each trial.

4) Four of the subjects had some difficulty in keeping the whole of the display in view all the time. This would seem to be a manifestation of Troxler's effect which is a disappearance of patterning in parts of the visual field with prolonged fixation on one point. Normally, the continual small movements of the eyes or saccades will ensure constantly changing stimulation of an area of the retina. However, with a relatively undifferentiated display as in the present experiment, it is likely that saccades will not suffice to prevent this kind of disappearance completely. The

one subject who maintained he had no difficulty also said that he was constantly moving his head (and therefore the orientation of the display and the image on his retinas, even if he kept his eyes firmly on the fixation point). This would seem to be a strategy which reduces or removes Troxler's effect. All but one subject said they found it easy to fixate on the fixation point.

5) Most subjects realised that their performance varied. Their explanations were the brightness of the signal lamps, the length of the flashes, and subjective factors such as tiredness.

6) Only one subject seemed to fully realise that the ambient lighting changed from session to session. This is surprising in view of the fact that most subjects had their four sessions on consecutive days, and that there was a four-fold change in luminance from dimmest to brightest. This seems to suggest that there was no difference in 'discomfort' from one condition to another.

The interviews suggest that the precautions taken to avoid giving the subjects pre-conceived ideas about the nature of the experiment were successful, since interpretations varied. They also show the important effect on performance of the nature of the visual display, in this case a relatively undifferentiated one. It is reasonable to assume that the phenomena mentioned by the subjects (such as after-images, phosphenes, and the fading of the display with fixation) were noticeable and affected performance only because the display was so undifferentiated (Cohen 1958). It is likely that after-images and phosphenes are always present to some degree but are usually masked by patterning in the visual field. Similarly, if Troxler's effect occurs frequently, it may be unnoticed because there is only a small resultant reduction in patterning and objects in the periphery of the visual field are less clearly seen in any case.

The wide differences between subjects in their ability to distinguish true from false responses shows that the internal ('false') and external ('true') stimuli were similar, in those cases where entoptic phenomena were held responsible for the false responses. On other occasions false responses may have been due to different criteria of response between subjects or at different times.

Two subjects mentioned that the signal flashes appeared to vary in length when in fact the lamp luminance was varied. This suggests that the time-intensity trading which takes place in responses to very short flashes has not entirely disappeared even with a flash lasting half a second.

Figure 5.

Pilot experiment II - Latin Square design.

S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
I2 b3 L	I3 b4 M	I4 b5 P	I1 b3 F	I2 b4 L	I3 b4 E	I4 b4 E	I1 b1 L	I3 b2 A	I2 b1 J
b5 F	b3 T	b3 M	b4 B	b1 Q	b2 L	b2 R	b2 J	b1 K	b3 M
b2 J	b2 A	b1 K	b2 L	b3 S	b1 T	b5 S	b5 P	b5 S	b5 C
b4 G	b5 N	b2 D	b1 S	b5 G	b4 O	b1 T	b4 I	b3 Q	b2 I
b1 Q	b1 G	b4 J	b5 J	b2 D	b5 F	b3 P	b3 C	b4 I	b4 O
I1 b5 B	I4 b3 Q	I2 b2 F	I3 b1 H	I4 b1 J	I1 b1 R	I2 b3 M	I3 b3 D	I4 b5 E	I1 b2 A
b3 K	b4 P	b3 Q	b4 D	b5 K	b4 Q	b4 Q	b1 N	b3 H	b5 D
b1 I	b2 C	b4 A	b5 C	b4 R	b2 N	b5 A	b2 B	b1 R	b3 G
b2 H	b1 S	b1 D	b3 P	b3 O	b3 A	b2 D	b5 O	b2 F	b4 R
b4 P	b5 K	b5 T	b2 Q	b2 F	b5 B	b1 L	b4 S	b4 G	b1 Q
I3 b2 S	I2 b5 O	I1 b4 N	I4 b2 R	I3 b3 N	I4 b3 P	I1 b5 O	I2 b2 M	I1 b3 B	I3 b4 L
b5 M	b2 E	b2 G	b1 N	b2 H	b2 E	b3 N	b4 F	b1 J	b3 F
b3 D	b1 J	b5 L	b5 T	b1 I	b1 C	b1 G	b3 H	b4 L	b2 P
b1 E	b3 L	b3 S	b4 G	b4 P	b5 I	b4 C	b5 T	b2 C	b5 K
b4 O	b4 R	b1 H	b3 E	b5 C	b4 S	b2 K	b1 K	b5 T	b1 T
I4 b4 C	I1 b1 I	I3 b5 R	I2 b1 I	I1 b2 E	I2 b3 M	I3 b3 H	I4 b1 E	I2 b4 N	I4 b3 S
b2 T	b5 F	b1 I	b4 M	b1 M	b4 K	b4 B	b4 A	b2 M	b1 E
b3 A	b3 D	b4 O	b5 O	b4 A	b2 G	b2 F	b5 Q	b3 D	b2 N
b5 R	b4 B	b2 E	b2 K	b5 B	b4 H	b5 J	b2 G	b5 O	b4 H
b1 N	b2 H	b3 B	b3 A	b3 T	b5 D	b1 I	b3 R	b1 P	b5 B

Symbols: I1,2,3,4 ...... display luminance
b1,2,3,4,5 ...... signal lamp luminance
A - T ...... signal schedule

continued ...

Figure 5.

Pilot experiment II - Latin Square design - continued.

S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
I1 b5 D	I4 b3 F	I4 b2 F	I2 b2 A	I1 b2 T	I3 b1 E	I3 b5 G	I4 b1 M	I1 b4 B	I2 b5 J
b1 H	b1 B	b5 R	b4 G	b3 D	b5 H	b4 P	b4 R	b5 N	b2 C
b4 G	b4 P	b3 O	b1 T	b1 I	b4 C	b3 L	b2 T	b3 C	b4 D
b3 Q	b5 Q	b4 K	b3 H	b5 C	b2 P	b1 T	b3 A	b2 H	b1 A
b2 O	b2 E	b1 L	b5 E	b4 G	b3 S	b2 E	b5 B	b1 D	b3 M
I2 b4 N	I3 b5 T	I1 b3 B	I3 b4 P	I2 b5 A	I4 b2 L	I1 b4 F	I3 b2 K	I2 b1 L	I4 b4 E
b5 P	b3 I	b1 S	b2 O	b1 K	b1 T	b2 Q	b5 S	b2 J	b2 P
b1 I	b4 N	b4 Q	b3 B	b2 J	b5 K	b5 R	b1 N	b3 E	b3 F
b3 R	b2 J	b5 C	b1 L	b4 B	b4 B	b1 C	b4 I	b5 F	b5 L
b2 S	b1 R	b2 P	b5 S	b3 R	b3 N	b3 J	b3 G	b4 S	b1 Q
I4 b4 J	I2 b1 L	I3 b1 E	I1 b2 D	I4 b1 B	I2 b4 Q	I4 b5 M	I2 b3 P	I3 b5 G	I1 b1 N
b3 C	b3 M	b4 T	b5 C	b5 P	b1 A	b4 N	b5 H	b1 O	b4 K
b2 B	b2 D	b5 N	b3 R	b4 F	b5 I	b3 S	b4 C	b4 I	b2 H
b1 K	b4 G	b3 M	b1 N	b3 L	b2 D	b2 I	b1 D	b2 R	b5 T
b5 T	b5 A	b2 H	b4 J	b2 Q	b3 J	b1 D	b2 Q	b3 K	b3 S
I3 b4 M	I1 b4 S	I2 b2 I	I4 b2 I	I3 b1 H	I1 b5 R	I2 b5 K	I1 b3 J	I4 b5 M	I3 b2 I
b5 F	b3 H	b5 D	b5 K	b2 M	b4 O	b3 H	b2 F	b3 T	b3 R
b3 A	b1 K	b1 G	b1 F	b5 N	b2 F	b4 A	b5 O	b4 P	b1 O
b1 L	b2 C	b3 J	b3 Q	b3 S	b3 G	b1 B	b1 L	b1 Q	b4 G
b2 E	b5 O	b4 A	b4 M	b4 O	b1 M	b2 O	b4 E	b2 A	b5 B

FIG. 6. EXPERIMENTAL DESIGN (II)

I background luminance cd/m^2	b lamp luminance cd/m^2	contrast $\frac{b-B}{B}$
120	3600	29.0
120	2800	22.3
120	2000	15.7
120	1200	9.0
120	400	2.3
280	3600	11.9
280	2800	9.0
280	2000	6.1
280	1200	3.3
280	400	0.4

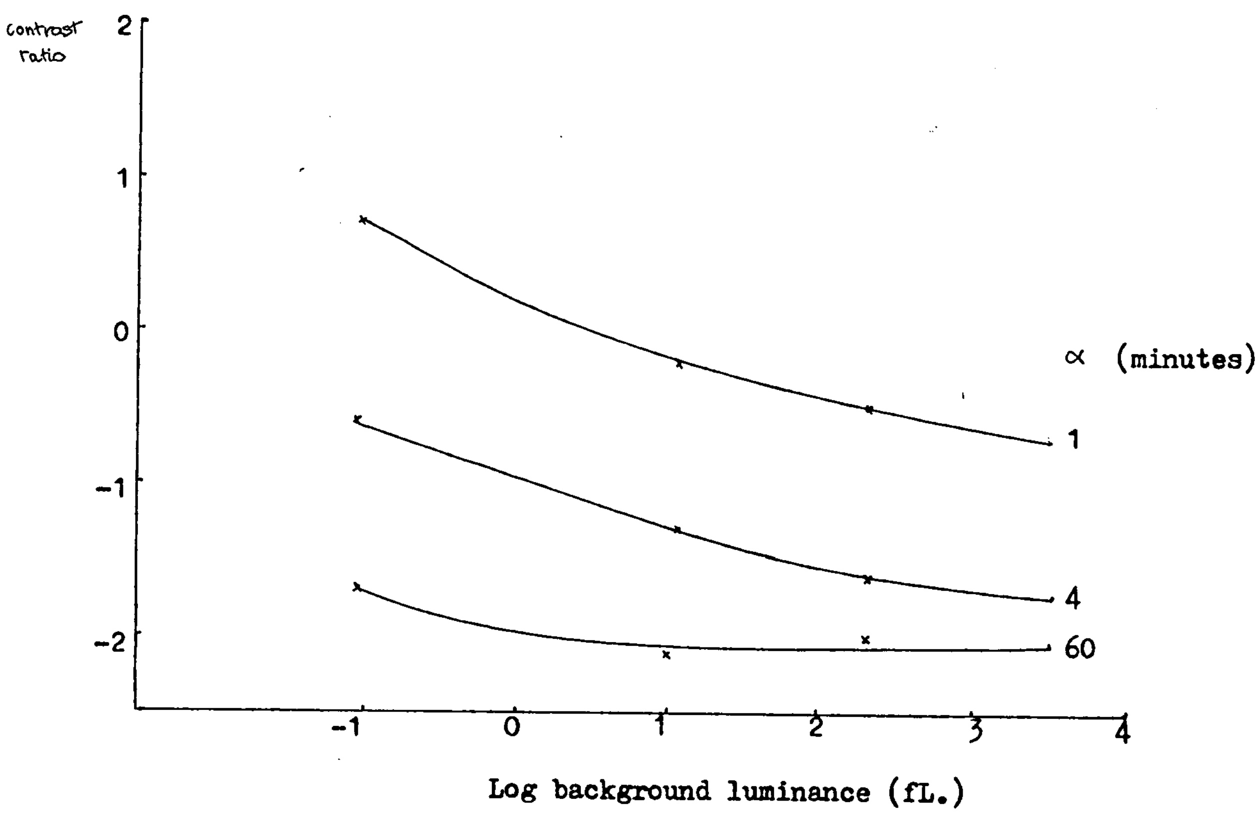
I background luminance cd/m^2	b lamp luminance cd/m^2	contrast
440	3600	7.2
440	2800	5.4
440	2000	3.5
440	1200	1.7
440	400	-0.1
600	3600	5.0
600	2800	3.7
600	2000	2.3
600	1200	1.0
600	400	-0.3

Figure 7. Raw Results Exp. II Detection/$_{40}$: All Signals

I	b	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	Condition Totals
600	3600	10	14	16	20	20	10	19	17	17	20	13	27	23	27	19	13	22	9	22	14	352
600	3800	7	9	8	20	16	8	12	14	8	14	12	20	20	15	21	12	23	8	13	11	271
600	2000	3	10	7	11	9	0	11	10	6	8	9	11	15	11	17	12	10	7	7	7	181
600	1200	4	1	7	6	2	0	3	7	0	5	3	4	7	15	11	8	13	0	4	1	101
600	400	6	0	2	0	0	0	1	4	0	1	4	0	3	2	5	0	2	0	0	0	30
440	3600	10	15	18	29	16	10	21	20	11	21	20	32	25	24	31	19	23	16	19	16	396
440	2800	9	11	15	19	8	7	17	21	15	15	15	28	23	17	29	12	19	14	17	11	322
440	2000	9	7	6	11	5	9	17	20	7	13	9	21	11	8	20	5	11	8	5	9	211
440	1200	2	3	3	2	0	1	8	14	2	7	8	7	7	9	13	6	7	1	6	2	108
440	400	2	1	1	1	1	1	2	17	0	0	5	0	0	0	8	0	1	0	0	1	41
280	3600	5	27	24	31	32	13	23	19	19	27	22	37	30	33	36	22	30	18	28	22	499
280	2800	21	13	24	16	27	6	21	20	20	22	17	22	29	30	33	14	23	21	22	21	422
280	2000	5	12	17	10	22	8	20	26	7	17	19	22	22	20	27	12	19	6	13	20	323
280	1200	1	8	7	6	11	1	12	15	4	10	7	20	16	12	15	9	16	1	12	10	193
280	400	0	0	7	0	0	1	7	11	0	5	0	4	9	1	1	3	8	0	2	3	62
120	3600	23	28	33	39	39	21	40	28	20	38	40	37	36	38	40	23	28	33	30	36	650
120	2800	21	30	27	40	39	22	33	25	14	32	36	35	30	36	39	29	25	37	26	32	608
120	2000	16	20	24	28	38	10	29	16	21	29	21	28	26	37	35	17	22	32	28	21	498
120	1200	15	11	12	14	23	0	18	21	7	27	20	16	22	26	25	11	16	17	22	18	341
120	400	0	2	7	5	6	0	6	8	2	1	3	1	11	3	8	2	8	1	3	4	81
Subject Totals		169	222	265	308	314	128	320	333	180	312	283	372	365	364	433	229	326	229	279	259	5690

Figure 8.

Threshold contrast and background luminance.



50% accuracy. Diameter of target indicated in minutes of arc: one-second duration of signal.

After Blackwell (1959).

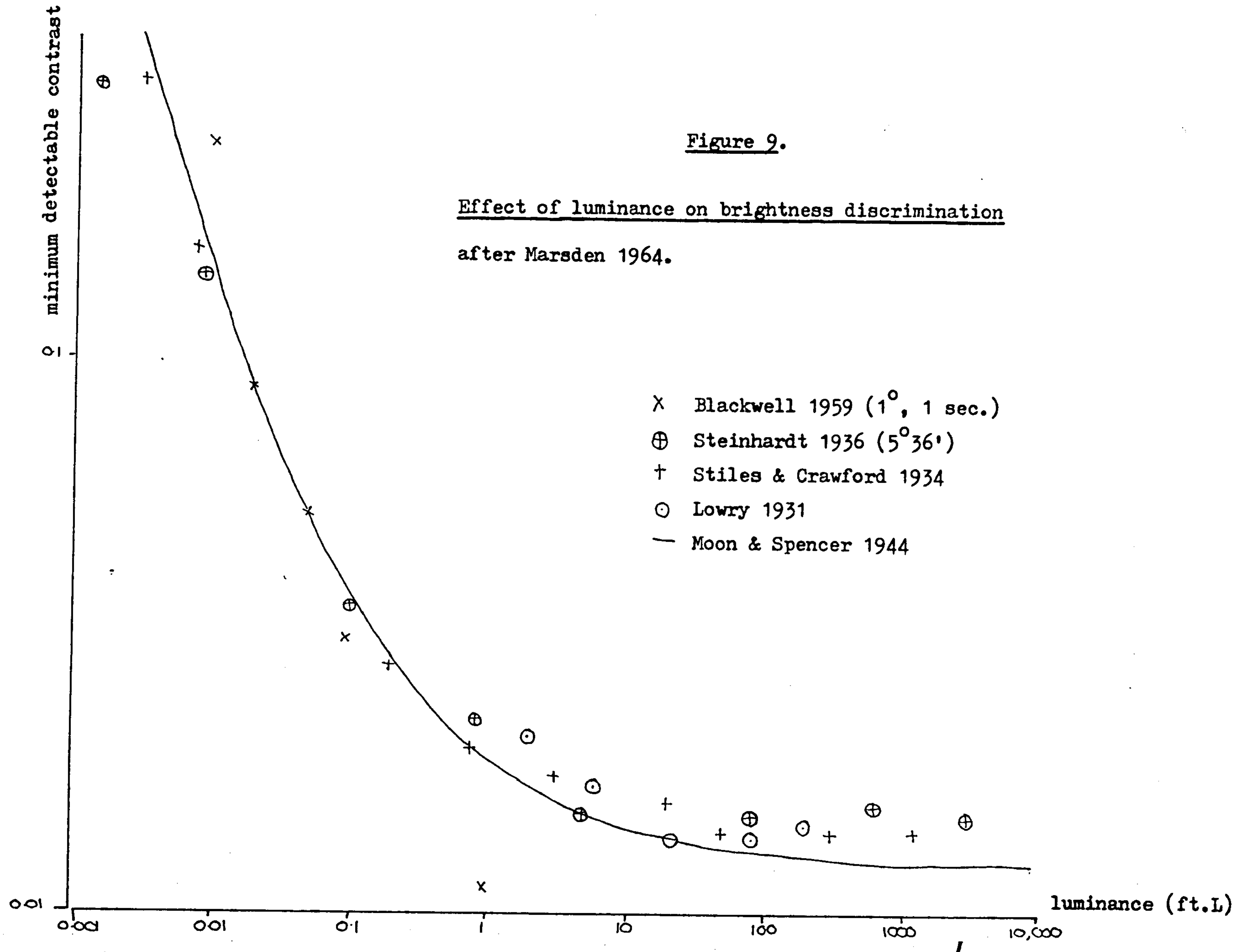


Figure 9.

Effect of luminance on brightness discrimination after Marsden 1964.

Main experiment: Methods

Main experiment: methods.

Purpose.

The purpose of the experiment was to investigate signal detection performance under different conditions of display luminance. Two aspects of performance were recorded: positive responses to the signal, and response reaction times. Each signal originated from a different location in the display, so that both spatial and temporal aspects of performance could be studied in relation to the proportion of signals detected.

Apparatus.

The theoretical considerations outlined above ('Introduction to the experiments') determined the form of the apparatus. The display was to cover the whole of the subject's visual field, the luminance of the display was to be controlled over its whole area, and signal lamps were to be distributed over the display in a visually homogenous manner.

Display design.

Signal size affects detectability and so it was important to arrange the signal lamps as nearly as possible at equal distances from the subject's eyes. The face of the display took the form of fifteen panels (figure 10), which when assembled approximated to a hemisphere of radius 60 cm., the centre of each panel being 60 cm. from the centre of the hemisphere (figures 11 and 12).

The panels were made of $\frac{1}{4}$" opal Perspex and were welded together. The display face was made of Perspex so that it could be illuminated from behind, so helping to provide even luminance by diffusion and avoiding the problem of the subject's shadow which could occur with front lighting. The display face was set into a wooden case on stilts which allowed room for the subject's legs and chair underneath (figure 13).

When the signal lamps were first run it was found that the shiny surface of the Perspex reflected signal flashes from the opposite sides of the display. Therefore, to give the display face a matt surface, large sheets of tracing paper were cut to fit the panels and were fixed to the seams and edges with double sided transparent tape, so that no joins were visible. The signal lamp currents were then adjusted, to give the same luminance when measured through the tracing paper as before it was applied.

Positioning the subject.

Positioning the subject's eyes in the correct position for viewing the display required some care, as analysis of the data obtained would take into account the visual angle of the signal in relation to the subject. An adjustable headrest was used behind the subject's chair. This was a modified typist's chair with an adjustable back and seat height, and sometimes used with an additional cushion. The box supporting the chair was set on lockable castors which ran on a pair of tracks set into the floor. The tracks ran at equal distances from each side of the centre of the display, and the pole to which the headrest was attached was fixed to the back of the box, so that when the subject was seated his head was central to the display. The purpose of the tracking was to ensure the correct position of the chair and to make it possible for the experimenter to position the subject accurately away from the display and then push him into place.

The process of positioning the subject was as follows. The height of the fixation point from the floor had been marked on the pole with paint. The seat height was adjusted so the subject's eyes were level with the mark. If the subject was very short the seat itself could be raised by means of an extra block under the chair. The headrest, which was padded with foam rubber, was then adjusted in height and horizontal length to give maximum support. The distance between the subject's eyes and the back of the pole was measured with a ruler. Marks painted on the tracking corresponded to distances from the fixation point. The chair could now be postioned so that the distance of the pole from the fixation point was 60 cm. plus the distance between the pole and the subject's eyes. The castors were then locked and a footrest put into place.

Display stimuli.

The same type of pre-focussed tungsten bulbs and Perspex plugs were used as in the pilot experiment. The bulbs were glued behind a hole drilled in the Perspex of the display, with the lugs set in flush with the front surface of the display. When unlit the lamps had the appearance of small grey dots and were 5 mm. in diameter.

The signal lamps were to be dispersed evenly over the display. The visual area was calculated for each panel, and this figure rather than the actual area was used, to allow for the slight foreshortening effect. The number of lamps was arbitrarily selected as 60 (the maximum capacity of the tape-reading equipment was 64 digits) and the number of lamps on each panel allotted according to the proportion of the visual area of the panel to that of the whole display. A small black circular fixation point was placed at the centre of the central panel. A black point was chosen as remarks by subjects in the pilot experiment suggested that a colour might introduce unnecessary complications.

A limitation was placed on the location of the lamps for purposes of analysis that they should be at visual angles (relative to the fixation point) of 05, 15, 25, 35, 45, 55, 65, 75, 85, or 95 degrees. The only further limitation was that no lamp should appear within 3 cm. of a seam in the Perspex as this would have been difficult to fit. Locations were decided from random number tables, taking the visual angle, and the angle of elevation from the horizontal, as the co-ordinates. Then the actual position of the lamp in the panel was calculated. The final form of the display is shown in figure 14.

Display luminance.

Illumination was provided by 15 fluorescent tubes of Artificial Daylight type, mounted on the inside of the removeable walls of the box housing the display. The inside of the box was painted white to assist diffusion of the light. The tubes were connected to the controlling apparatus in two groups, those mounted behind the rectangular display panels, and the rest. The good diffusion of light inside the box meant that it was possible to achieve a wide range of evenly spread luminances by manipulating the two groups of lamps. To reduce flicker as far as possible, the tube ends were covered with foil and black paper was wound round the tubes in a spiral fashion so as to partly cover them. This meant that the ends of the tubes, where most of the flicker originates, were covered and that the voltage could be increased which also has the effect of reducing flicker. A stabiliser was included in the circuit, effective up to a 5% variation in voltage.

Signal lamp luminance.

Calculations were made from the data obtained in the pilot experiment II to obtain values of signal lamp luminance which would give a 50% performance rate. This level of 50% was arbitrarily chosen since the purpose was to give a common basis to the tasks of the different groups of subjects, and not to induce any particular rate of performance. The results of these calculations were in terms of luminance and had to be translated into terms of current for purposes of calibration.

Measurement of the luminance of signal lamps in the new display by the method used in the pilot experiment proved to be too difficult, because there was nowhere to rest clamps holding lens and photometer for readings. Instead a rudimentary photometer, capable of measuring the luminance of a small area and light enough to be held accurately in position, was constructed. The photometer consisted of a photocell set into a tubular shield and connected to an ammeter. The photometer was calibrated on a photometric bench, using light shining through tracing paper of approximately the same yellow colour as the lit signal lamps. A graph was drawn showing the relationship between source luminance (as measured with the original photometer) and ammeter readings for a range of luminances. The ammeter readings for the desired luminances could then be extracted from the graph.

To measure the luminance of the signal lamps, a metal plate with a hole in the centre was taped over the lamp and the photometer held into this. The photometer head fitted exactly into the hole and so a constant area of exposure, and distance of the photocell from the source was achieved. Each lamp was checked using the photometer and it was found that the luminances varied by more than the 5% previously decided upon as acceptable. This was due to a slight variation in the bulbs themselves, the differing lengths of wire used to link them to the controlling apparatus and also to the slightly different angles at which the bulbs were set into the Perspex. Two methods of standardising the lamps were available, to alter the length of the wires, and to alter the plug in front of the bulb. The latter method was adopted. Various thicknesses of paper, tracing paper and Sellotape were obtained and the effect of each paper measured. Circles 5mm in diameter were cut with a paper punch and each lamp covered till it gave the same luminance reading as the dimmest lamp.

Control of signals.

Wires ran back from each signal lamp and passed through holes in the box sides to the controlling apparatus. The wires were sufficiently fine to cast no shadows. The lamps were controlled by a tape reader which was set to transmit impulses causing onset of the signal, each signal lasting 0·5 sec. One lamp only was used at any time. The sequence of lamps and the interval between signals was controlled by a punched tape programme. The current to the lamps, and so the luminance could be measured by an ammeter introduced into the circuit and for this purpose the same lamp was always used for calibration.

Recording responses.

The display apparatus was housed in a room separated from the controlling apparatus by a door, so the subject could not hear any of the apparatus being used. The response button was set into a piece of wood shaped to be held in the palm and operated by the thumb of the subject's (preferred) hand. A signal from the tape reader to a lamp simultaneously activated a Venner clock. When the response button was pressed, it stopped the clock and response time in milleseconds was shown on a digital display. The clock automatically reset itself three seconds after a response. If there was no response, the experimenter reset the clock ready for the next signal. A counter recorded the total number of times the button was pressed, so giving a record of false responses when the reading was compared with the number of valid responses.

Experimental design.

In the second pilot experiment the design was such that each subject was used as his own control, serving under all experimental conditions. This was principally to show up any large inter-subject differences. These did not occur, but the design restricted analysis and created practical difficulties in finding subjects to attend four experimental sessions. Therefore in the main experiment the design was changed so that each subject served for one session only. Four subjects were run under each of four conditions of display luminance, sixteen subjects in all. There were four trials in each session, separated by short rest periods as before.

Each trial consisted of the presentation of 60 signals, one from each location. The punched tapes controlling the tape-reader were produced by a random-numbers programme in a computer. Locations, and inter-signal intervals were randomised with the restriction that each location should appear once only in each trial, and that each of the three intervals (5, 8 and 11 secs) appear an equal number of times. There were actually only 59 intervals in a trial but a dummy interval was inserted after the last signal. A large number of tapes was produced so that each trial had its own schedule, and schedule need not appear as a factor in the experimental design. Tapes were simply allocated to each trial in order, each tape being used only once.

The duration of each trial was approximately eight minutes. Although this is longer than that of pilot experiment trials, the total time taken per session was the same as there were four trials instead of five. Subjects were allotted to conditions on the basis of order of appearance in a rotating fashion working through the conditions four times.

Subject selection.

Subjects were mainly first year university undergraduates but also included a few lecturers and research students. No payment was offered, and subjects were told on recruitment that the session would last 'under two hours'. In fact it generally lasted about one hour, the exact time taken depending on the length of the interview and the number of questions asked by the subject afterwards.

An interview was conducted with each subject as in the pilot experiments. Previous interviews had been useful in conveying the subjective nature of the task, and the questions asked and the style of the interview remained the same.

Experimental procedure.

The equipment.

The equipment was switched on about half an hour before the subject was due and the display luminance adjusted to the desired intensity. The current to the signal lamps was then set to give the required value of luminance. The first tape to be used was placed in the tape-reader and the display luminance checked again with a photometer just before the subject arrived. This was necessary because the voltage required depended on the temperature of the room and on whether or not the fluorescent tubes had been used earlier in the day. Generally however the luminance was found to be stable after having been switched on for about twenty minutes.

Instructions to the subject.

When the subject arrived he was shown the apparatus and the features of the display. He was then tested on the Keystone apparatus using two cards. The Rapid Screening Test card gives information on acuity and binocular coordination or depth perception, and the O.V.S. 9-3 test gives information about fusion. Both these cards are for far vision.

The subject was then positioned in the chair as described above, and the procedure explained to him. He then practised using the response button in his preferred hand. The subject was told that if for any reason he wished urgently to be released from the chair, he should press the response button several times in rapid succession. This measure was never used.

Instrctions to the subject were to keep looking at the fixation point during each trial, and to press the response button firmly as soon as he saw a lamp flash. These instructions were designed to avoid the high number of false responses which might have resulted if the subject had been told to press the response button as quickly as possible or every time he thought he saw a lamp flash. The subject was also told that there would be a short rest in a few minutes and that the experiment would begin as soon as the experimenter had left the room.

Procedure.

The door connecting the experimental room and the adjoining laboratory was closed and the first tape started. An indicator lamp on the tape reader was normally lit but went off when the first signal was presented, and came on again to signal the end of the tape. Three dummy signals were inserted at the beginning of each tape to allow the experimenter to be ready to record the response to the first signal.

The subject's responses were noted as they occurred. It would have been possible to arrange for automatic recording of responses but no labour would have been saved as the reaction times would still have had to be matched to lamp locations.

When the lamp on the tape reader came on to signal the end of the trial, the number on the total response indicator was recorded to give data on false responses.

<u>Summary: data available for analysis.</u>

1. Results of testing on the Keystone apparatus. Printed forms published by the manufacturers were used, on which the subject's responses could be ticked off and compared immediately with the normal range. By this means any subject giving abnormal responses could be rejected before taking part in the experiment, but this proved not to be necessary.

2. Forms were duplicated for recording responses during the experiment, one for each trial. At some time before the session, the punched tape to be used was decoded, and lamp numbers (locations) and intersignal intervals written on the form. During the trial as each signal was presented the response time was recorded in the appropriate place or a dash noted, which meant no response. These response sheets therefore provide a chronological record of the subject's performance.

3. At the beginning and end of each trial the number on the response counter was noted, for the purpose of calculating the number of false responses made.

4. Printed booklets containing the Eysenck Personality Inventory Form A were used, and the reponses on each scale were analysed by means of a template which isolated the questions relating

to that scale. The number of positive responses could be counted quickly through the template. (Eysenck 1963).

5. The subject answered questions about the experiment at the end of the session and notes were made of his answers.

Figure 10.

Construction of the display.

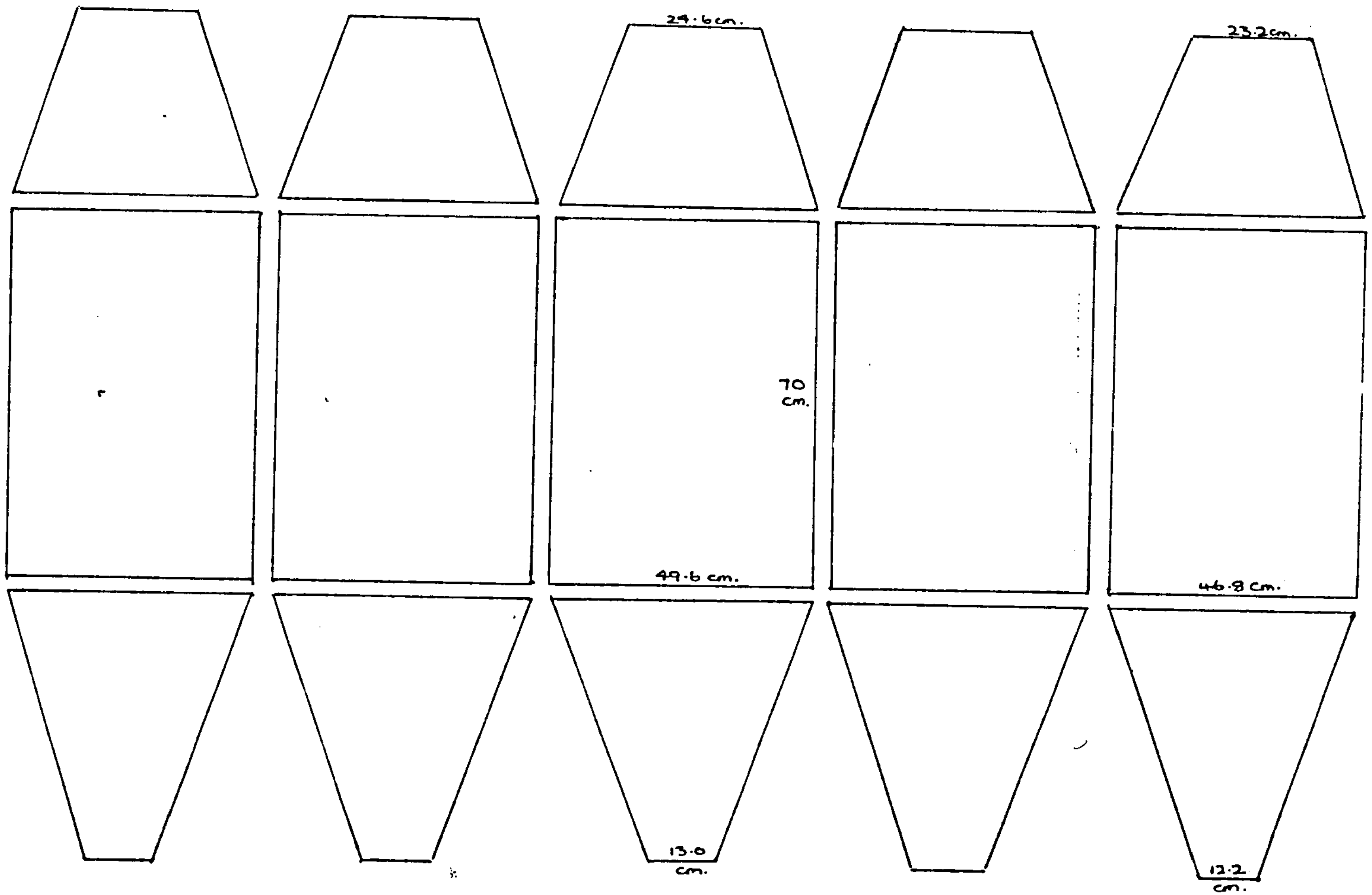


Figure 11.

The display: side view

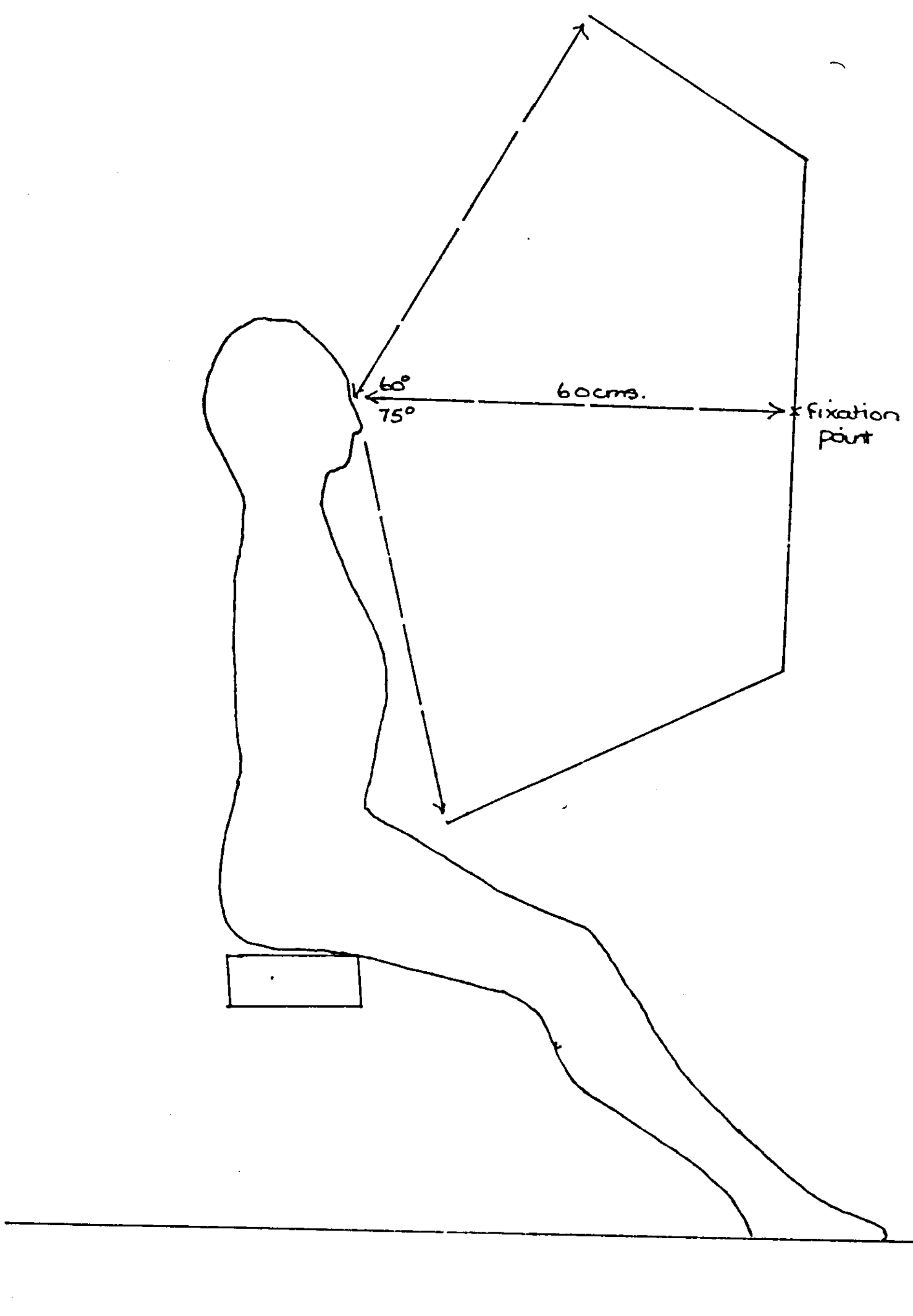


Figure 12.

The display: plan view.

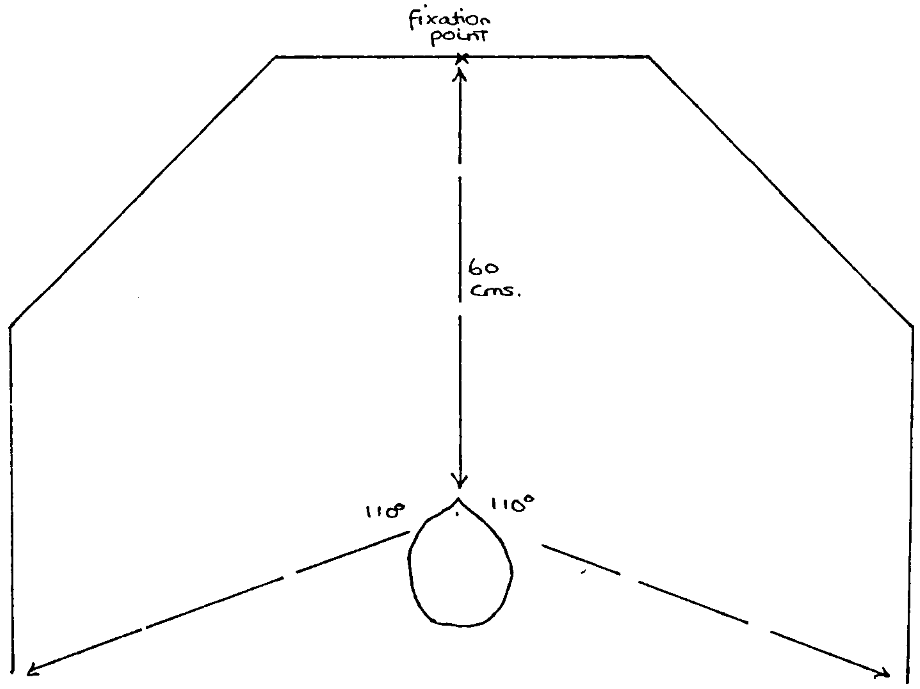
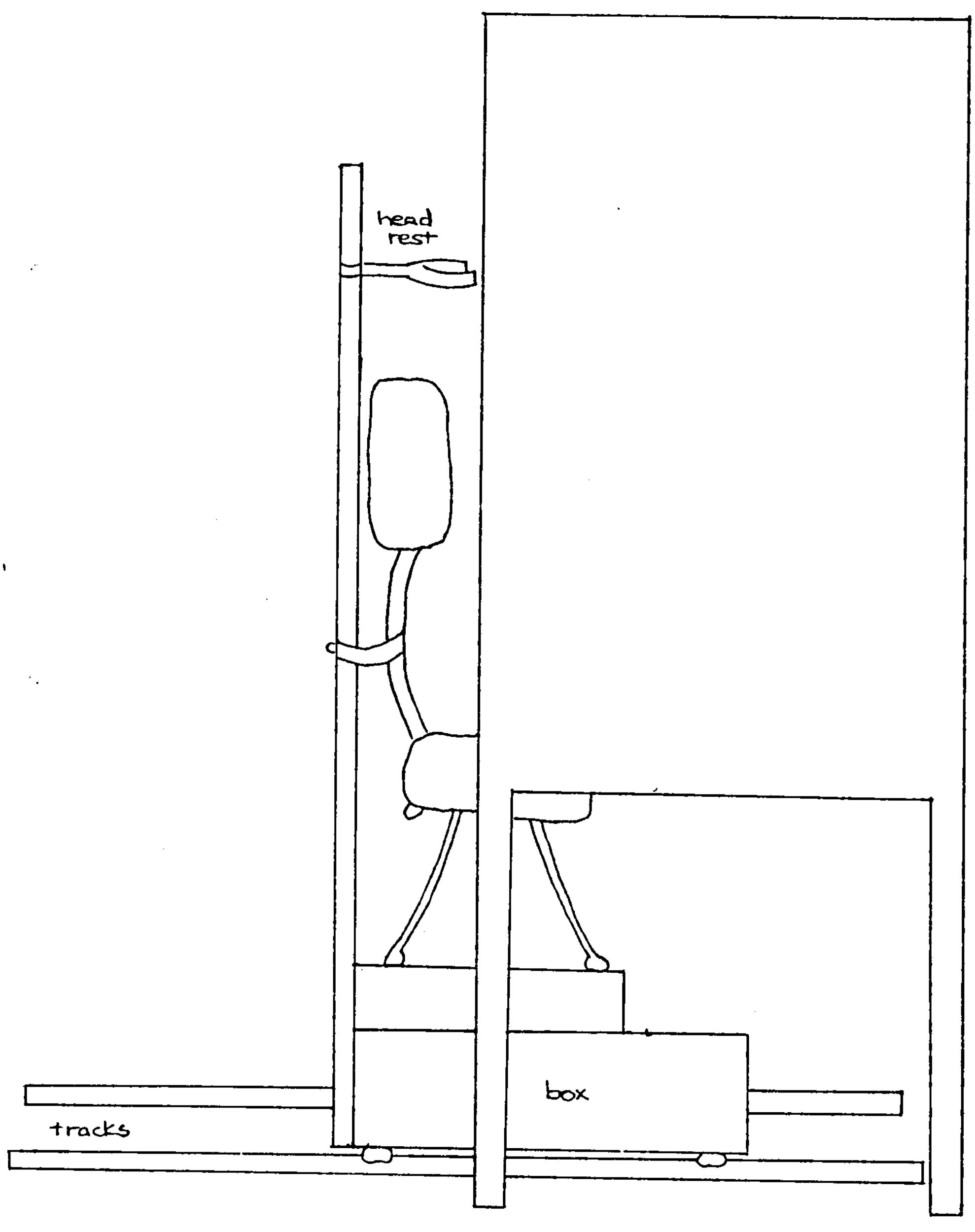


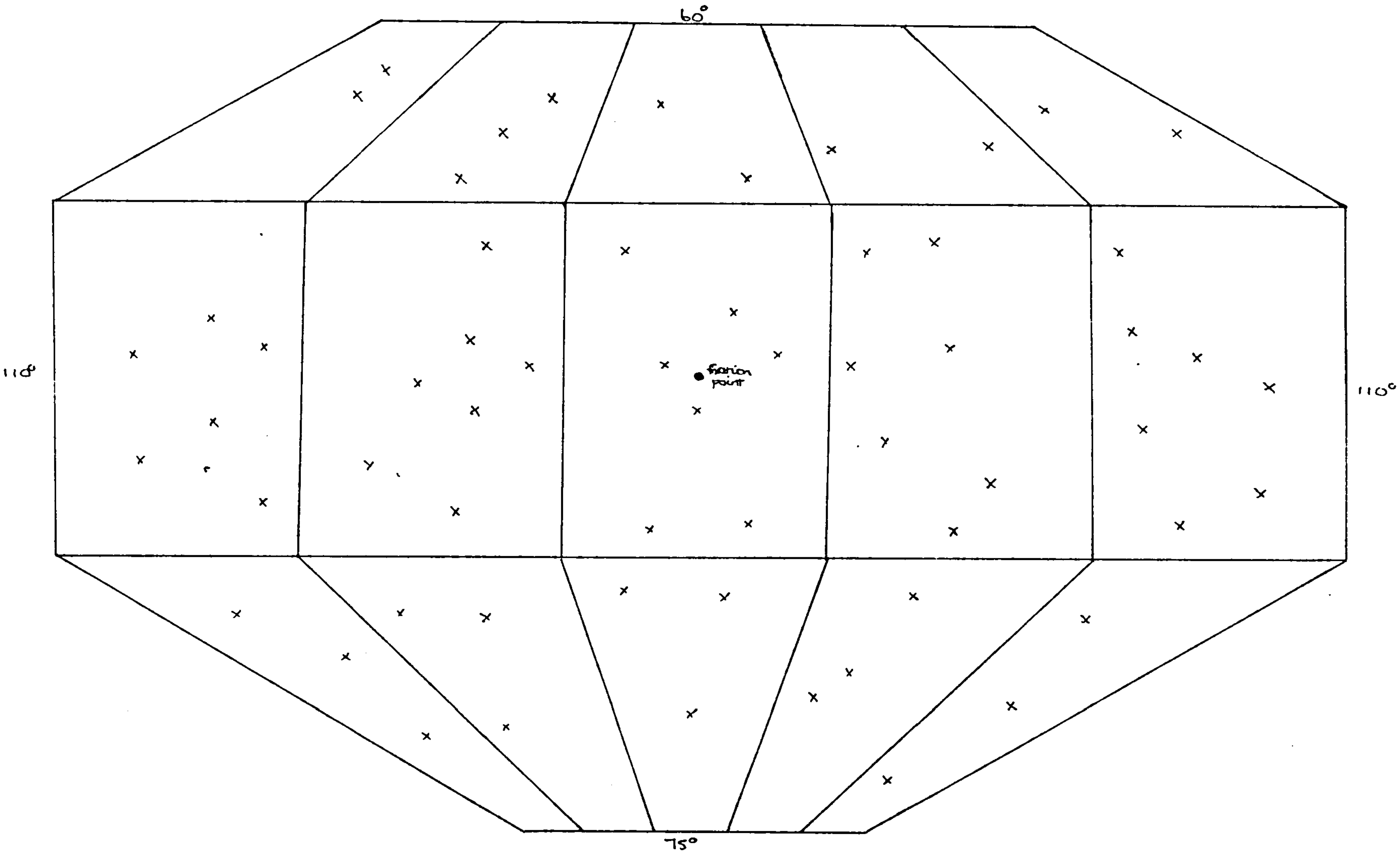
Figure 13.

Seating arrangements.



<u>Figure 14.</u>

<u>Perimeters of the display and lamp locations plotted according to visual angle subject/fixation point.</u>



Main experiment: results

Note: references to appendices are to Appendix D

references to graphs are to Appendix E, graphs 1 - 22

The main experiment - results.

Summary of experiment.

Data were obtained from sixteen subjects, each subject being employed for one session of four trials under one intensity of display luminance. The subjects were divided into four groups of four, each group experiencing a different intensity of display luminance.

Each trial consisted of the presentation of sixty signals, one from each location on the display, and differing from other trials only in the random order of presentation of signals and of intersignal intervals (signal schedules). The data recorded during each trial were the detection or non-detection of each signal, the reaction time of the subject's response, and false responses or errors of commission.

Methods of analysis.

The subject was considered to have detected a signal when he pressed the response button not later than 1·5 sec., and not earlier than 0·3 sec., after the onset of the signal. It is necessary to pre-set limits to the validity of a response because false responses may chance to follow a signal so closely that the experimenter has to decide whether or not to count it as a valid response. A pre-set limit removes the element of choice and improves the validity of the analysis. In the present case the problem was not likely to be a serious one, because the average interval between signals of eight seconds was sufficiently long to ensure that only a small proportion of false responses could follow a signal closely enough to be mistaken for a valid response. The criteria chosen must be arbitrary but inspection of the data shows that they exclude very few responses, if any.

The sixty signal lamps were located at ten different visual angles, but they were distributed over the angles in such a way as to give the appearance of even distribution over the display. In consequence, the number of lamps, and therefore signals, at each angle was different. This makes it difficult to compare directly the number of signals detected at each angle. Therefore for some analyses, the lamps were divided into three groups by location, resulting in groups of lamps at 0 - 45, 45 - 75 and 75 - 95 degrees of visual angle. The distribution of the lamps in the three groups is shown in Appendix 1.

6.1 Display luminance / trials / location of signal.

Raw data are shown in Appendices 2 - 5. These were re-analysed into three groups of lamps as explained above (Appendix 6) and a three-way analysis of variance was carried out on the re-classified data. The response measure was the number of signals detected out of a possible 20 in each lamp group, by each subject during each trial. The analysis of variance summary table is shown overleaf.

The analysis shows the main effect of location of signals to be highly significant ($p = 0 \cdot 001$) and the main effects of display luminance and trials to be of doubtful significance ($p = 0 \cdot 1$ for both effects). None of the interaction effects was significant.

Analysis of variance summary table.

Source of variation	S.S.	d.f.	M.S.	F	p
Between subjects	540·313	15			
A	213·938	3	71·3127	2·622	0·1
Ss. within groups	326·375	12	27·1979		
Within subjects	5363·667	176			
B	31·521	3	10·507	2·803	0·1
AB	21·188	9	2·354	0·864	n.s.
B x Ss within gps.	134·955	36	3·749		
C	4661·292	2	2330·650	261·228	0·001
AC	46·25	6	7·708	0·864	n.s.
C x Ss. within gps.	214·125	24	8·922		
BC	13·542	6	2·257	0·893	n.s.
ABC	58·749	18	3·264	1·291	n.s.
BC x Ss. within gps.	182·042	72	2·528		

A: display luminance (group)
B: trial
C: angle of signals

n = 16

6.2 Effect of display luminance on detections.

The main effect of intensity of display luminance (which is synonymous with group) on the number of signals detected, was of doubtful significance in the analysis of variance above. Graph 1 shows the total number of signals detected by the four members of each group, expressed as a cumulative total. Graph 2 shows the same data, plotted in a different way along the x-axis to remove the uneven effect of a different number of signals at each angle. A small difference between the groups can be seen clearly.

In order to clarify the ambiguous result of the analysis of variance, a non-parametric test, the Kruskal-Wallis one-way analysis of variance by ranks, was applied to the four populations of results taken from the detection data for the four groups of subjects in terms of the total number of signals detected by each subject. (Appendix 7). The test gave a significance to the difference between the groups of $p = 0{\cdot}001$.

This contradiction between the results of the two analyses may be due to the fact that the Kruskal-Wallis takes no account of the magnitude of the differences between the individual scores, but only of their relative positions on a ranking scale. If the differences are small but consistent, the non-parametric test may detect them better than the parametric test, but it may also ignore high variability in the scores between groups which the parametric test takes into account. The combination of the results of the two tests probably does indicate a difference between the groups in terms of overall performance. Graph 3 shows the distribution of overall scores between groups. Although the variance is high between members of each group, there is a difference in range. This graph illustrates the reasons for the difference in results between the two statistical tests.

6.3 <u>Effect of trials on detection rate</u>.

The main effect of trials on detection rate proved to be of doubtful significance in the parametric analysis of variance (6.1 : $p = 0{\cdot}1$). The Kruskal-Wallis was again applied to the four populations of results, from the four trials, but the result was non-significance. All groups gave their

Note: percentage detections at each visual angle have not been employed for purposes of graphical illustration. The large difference in the number of signals presented at each angle means that such illustration would be misleading, and therefore total detections have been used instead. The actual number of signals presented at each angle is shown in graph 5.

worst performance on trial four, except for the 120 group, which was flat throughout. (Appendix 8).

6.4 Effect of location of signal on detection rate.

The main effect of angle of signal was significant in the analysis of variance (6.1: p = 0·001) and this result was expected. However, there was no interaction effect with display luminance (group). In graph 5 the raw scores (total detections for each group) are plotted against angle of signal without any treatment. This can be compared with graph 4, in which the lamp locations are classified into three groups, to see the effect of the grouping necessary for the analysis. It can be seen that the groups differ mainly in the region 35 - 75°, although this information is lost upon conversion to the lamp-group classification.

6.5 Reaction times.

It was not possible to carry out a complete three-way analysis of variance on reaction times, because some subjects did not respond at all to signals at a particular angle, and so some data cells would be empty. However, separate analyses were carried out using average reaction times. Unfortunately due to an equipment error (reaction times proved to be registered by the subject's release of the response button rather than by his pressing it) reaction times for four subjects were not usable, but analyses were carried out for groups of unequal sizes using the results of the remaining twelve subjects.

6.6 Effect of visual angle on reaction time.

Graph 6 shows the mean reaction time (arithmetical average) for each group against the visual angle of the signal to which the response occurred. The graph is plotted from data in Appendix 9.

Analysis of variance summary table.

Source of variation	S.S.	d.f.	M.S.	F	p
Between subjects		11			
A	168527·84	3	56176·00	0·917	n.s.
Subjects wthn. gps.	490180·00	8	61272·50		
Within subjects		108			
B	514781·31	9	57197·90	19·340	0·001
AB	222090·65	27	8225·60	2·782	0·001
B x Ss within gps.	212891·00	72	2956·82		

A: display luminance (group)
B: angle of signal

n = 12
Data: Appendix 10.

The main effect of visual angle of signal is significant (p = 0·001). Reaction times lengthen as the visual angle increases. The interaction effect, groups/visual angle, is also significant (p = 0·001) The 120 group gave comparatively short times at 05 - 25°, and the 600 group gave much longer times at 65 - 85°.

6.7 Reaction time and display luminance.

The main effect of display luminance (group) was found to be non-significant. However, this could be due to the method of taking means for each data cell instead of raw scores, not a very satisfactory method since the means are made up of different numbers of data items. Therefore reaction times for the twelve subjects were categorised and the chi-squared test used to test for differences (Appendix 11). Reaction times in each category were counted for each group.

$X^2 = 170{\cdot}04 \qquad p = 0{\cdot}001$

Groups differed in the frequency with which they gave reaction times of different lengths.

Graph 7 shows this effect. The data is plotted as a percentage of the total number of reaction times for that group, since the frequency of reaction times of each duration depends on the total number of detections and also on the number of subjects in each group whose results were available for analysis. The graph shows that the 440 and 600 groups have fewer short reaction times, and more long ones than the 120 and 280 groups.

6.8 Effect of trials on reaction times.

Analysis of variance - summary table.

Source of variation	S.S.	d.f.	M.S.	F	p
Between subjects		11			
A	60377•12	3	20125•71		
Ss. within groups	226855•00	8	28356•88		
Within subjects		36			
B	17068•26	3	5689•42	2•425	0•1
AB	20324•33	9	2258•26	0•962	n.s.
B x Ss. within gps.	56302•00	24	2345•92		

A: display luminance (group)
B: trials
n = 12
Data: mean reaction time for each trial (secs).

The main effect of group and the interaction effect of groups by trials were non-significant. The main effect of trials is of dubious significance at $p = 0 \cdot 1$. As before, a chisquared test was performed on the classified data (Appendix 12).

$X^2 = 36 \cdot 57 \qquad p = 0 \cdot 01$

Graph 8 shows this effect. Most of the difference between trials lies in the drop in the number of very short times (300 - 500 msec.) after the second trial, and a corresponding rise in the number of medium times (700 - 900 msec.). Thus there is no overall trend to higher values, but a change in distribution. There is no overall difference between the groups in this respect.

6.9 Category of detections.

Each lamp was used four times during a session (once each trial) and so it could be categorised according to whether the subject detected the signal from that lamp 0, 1, 2, 3 or 4 times altogether (Appendix 13). The first and last categories correspond to never and always respectively. Graph 9 shows the total number of lamps (out of a possible 240 for each group) falling into each category. The X^2 test was used to test for differences in the total proportion of lamps in each category, between groups. (Appendix 14).

$X^2 = 36 \cdot 68 \qquad p = 0 \cdot 001$

Most of the difference lies between the 0 and 4 categories, and between the 120 and 600 groups. This can be seen most clearly in graph 10, the "never" and "always" categories having the most slope over groups.

Graph 11 shows the same data plotted in terms of visual angle (by groups of lamps). Again the main differences between groups lie in the "never" and "always" categories, and this effect also relates to visual angle. As the angle increases, the groups diverge in respect to the "never", and converge in the "always" categories. Graphs 12 and 13 show that the groups differ least in lamp group 2 ($45 - 75^{\circ}$).

Grouping of responses over time.

6.10 Runs.

Each trial consisted of the presentation of 60 signals. If responses are sorted into two types, positive response (signal correctly detected) and negative response (signal not detected) a sequence of binary events is formed. This may be tested for randomness using the one-sample runs test. In this case the test gives, for a sequence of 60 events, the mean and standard deviation of the sampling distribution for the particular number of positive responses involved. The number of runs (of either event) observed is then compared with the sampling distribution and a z-score computed, which is a measure of the deviation of the number of runs from the expected number. A low z-score indicates unusually few runs due to some kind of bunching, and a high z-score indicates unusually many runs and systematic short-term variations.

Z-scores were computed for each subject for each trial, and the distribution of these scores compared with a normal distribution (Appendix 15). Scores were transformed into the form $M_z = 50$ and $S^2 = 10$ so that a t-test could be performed. The mean was lower than that of the compared population, and this is significant ($p = 0{\cdot}05$).

This means that the sequences in the subjects' responses were less than random in the direction of unusually few runs - that is, their responses were grouped over time.

The sequence of signal presentations and inter-signal intervals making up each trial was randomised by computer programme. Therefore there is no reason to suppose that, for example, centrally located signals were appearing in groups. Something other than the order of presentation of signals was influencing the subjects' responses. More will be said on this subject in the next section.

6.11 Gaps.

A gap was defined as the space between two responses, or between a response and the beginning or end of a trial, during which the subject missed one or more signals. The number of gaps, and their length, was analysed for each subject and trial (Appendix 16). An analysis of variance was carried out on this data.

Analysis of variance summary table.

Source of variation	S.S.	d.f.	M.S.	F	p
Between subjects	9431·71	63	149·71		
A	3·57	3	1·19	0·0076	n.s.
Ss within groups	9428·14	60	157·14		
Within Ss.	236·25	192	1·23		
B	1·38	3	0·46	0·36	n.s.
AB	4·70	9	0·52	0·41	n.s.
B x Ss within gps.	229·98	180	1·28		

A: display luminance (groups)
B: trials
n = 16
Data: number of gaps in each trial by subject

Each subject's data showed an approximately equal number of gaps, even though the number of signals detected varied. The main effect of trials was not significant, and there were no interaction effects.

6.12 Gap length and display luminance.

The length of a gap was defined as the number of signals missed during the gap, although of course this does not define the actual duration of the gap in terms of real time. Data on gap length appears in Appendix 17. The chi-squared test was employed to test for differences in the proportion of gaps of each length between groups (Appendix 18).

$X^2 = 26 \cdot 1 \qquad p = 0 \cdot 02$

Graph 14 shows the distribution of gaps of each length over the groups. The 440 and 600 groups had more long gaps, fewer short ones, and produced therefore a poorer performance in terms of detection rate (6.2).

6.13 Gaps data from the pilot experiment.

To confirm this finding, some trials from the pilot experiment were analysed for the relationship between gap length and display luminance. Direct comparison with the main experiment would be invalid, since in the pilot experiment trials consisted of only 40 signals instead of 60, and detection performance varied widely, according to the signal/display luminance contrast ratio employed. Therefore, percentage detection rates out of 60 signals were calculated for the best and worst trials in the main experiment, to give a range (38·3 - 78·3 %). Equivalent values were then calculated for the pilot experiment out of 40 signals, and trials falling within this range were analysed employing chi-squared (Appendix 19).

$X^2 = 41{\cdot}45 \qquad p = 0{\cdot}01$

This test reveals a difference between groups with regard to gap length, similar to that in the main experiment. Results are plotted in graph 15.

6.14 Gap length and detection performance.

Gap length was tested against trials of different detection performance in the main experiment. Scores from all 64 trials were ranked and classified into four groups of scores, regardless of subject identity or the display luminance under which the trials were run. Chi-squared was performed to test the distribution of gap lengths over groups of trials (Appendix 20).

$X^2 = 54{\cdot}08 \qquad p = 0{\cdot}001$

This is to be expected if the number of gaps is similar for all subjects, while their length varies. Graph 16 illustrates the effect.

6.15 Gap length and contrast.

It is not possible to separate the effects of group (display luminance) from the conditions of contrast associated with each intensity of display luminance, in the main experiment results. However, analysis of pilot experiment results, using the same 150 selected trials as in 6.13 above, shows that gap length does not vary over trials employing different contrast values, within groups. The chi-squared results were:

Group 120	$X^2 = 15{\cdot}38$	$p = 0{\cdot}1$
280	$11{\cdot}38$	n.s.
440	$3{\cdot}25$	n.s.
600	$3{\cdot}57$	n.s.

(Appendices 21 - 24)

This analysis, therefore, shows that gap length varies with group (6.13) independently of contrast. A similar analysis of main experiment data is not possible because of the experimental design. However, analysis of pilot experiment results demonstrates that display luminance may be isolated from contrast and has an influence on gap length which is independent of contrast.

The inference is therefore that the variation in gap length in the main experiment data is directly related to the intensity of the display luminance, rather than to any relation of detectability of signals to varying conditions of display luminance.

6.16 Signal content of gaps.

Gap length was then analysed in relation to their signal content, that is, the location of the signals missed during the gap, for both experiments.

In the pilot experiment, there is no difference in the proportion of 'central' to 'peripheral' lamps in the gaps of different lengths.

$X^2 = 3\cdot402$ not significant (Appendix 25)

In the main experiment, there is a relation between gap length and signal location;

$X^2 = 43\cdot45$ $p = 0\cdot05$ (Appendix 26)

which is largely due to gaps of length one signal. When the analysis is repeated, omitting this length (Appendix 26);

$X^2 = 26\cdot35$ n.s.

the result is non-significance, that is, there is no difference in the signal content of gaps of length greater than one signal. That the exclusion of gaps of length one signal should have this effect is understandable, as they are the most likely to be caused by the signal schedule (i.e. the presentation of a particularly eccentric signal).

6.17

In summary, subjects show more long gaps and fewer short ones as the display luminance they experience, is increased (6.12). This appears to be related to the display luminance rather than to any differences in the detectability of the signals under different conditions(6.15). The length of the gap is also unrelated to the signals being presented at the time (6.16). Of couse the gaps contain a high proportion of signals from eccentric locations, but this proportion does not vary among gaps of different lengths. The gaps may be considered as lapses of attention lasting for a time dependent on the display luminance, but unrelated to signal lamp luminance or location, and occurring equally frequently under all conditions of display luminance.

6.18 Detections and half-trials.

Data from the main experiment were further analysed by dividing each trial into halves (thirty signals presented) and counting the detections in each half (Appendix 27).

Analysis of variance summary table.

Source of variation	S.S.	d.f.	M.S.	F	p
Between subjects	810•469	15			
A	320•906	3	106•969	2•622	0•1
Ss. within groups	589•563	12	40•797		
Within subjects	747•500	112			
B	47•281	3	15•76	2•803	0•1
AB	31•782	9	3•531	0•628	n.s.
B x Ss within gps.	202•437	36	5•623		
C	42•781	1	42•781	6•932	0•025
AC	26•157	3	8•719	1•413	n.s.
C x Ss within gps	74•062	12	6•172		
BC	14•032	3	4•677	0•693	n.s.
ABC	66•030	9	7•337	1•087	n.s.
BC x Ss within gps.	242•938	36	6•748		

analysis of variance - continued

A: display luminance (groups)

B: trials

C: half-trials

n = 16

Data: the number of detections in each half-trial.

Detections decrease between the first and second halves of the trials. This occurs in all groups and all trials, no interaction effects achieving significance. (Graph 17)

6.19

The effect shown in 6.18 might be due either to an increase in the number of gaps or to an increase in their length. The data on gaps were similarly analysed in half-trials, each trial being divided into two halves of thirty signals as before. Any gap overlapping the division was counted as a half gap. (Appendix 28).

Analysis of variance summary table.

Source of variation	S.S.	d.f.	M.S.	F	p
Between subjects	43·31	15			
A	7·15	3	2·830	0·791	n.s.
Ss. within groups	36·16	12	3·013		
Within subjects	253·87	112			
B	3·02	3	1·007	0·342	n.s.
AB	9·14	9	1·016	0·345	n.s.
B x Ss within gps.	105·96	36	2·943		
C	4·50	1	4·500	8·910	0·025
AC	12·19	3	4·063	8·046	0·01
A x Ss within gps.	6·06	12	0·505		
BC	2·19	3	0·130	0·275	n.s.
ABC	15·37	9	1·708	0·644	n.s.
C x Ss within gps.	95·45	36	2·651		

A: display luminance (group) n = 16
B: trials Data: number of gaps per half-trial
C: half-trials

The main effects of groups and trials were not significant, but the main effect of half-trials was significant, and so was the interaction effect of half-trials with groups. Thus the frequency of gaps increased during the trial but this occurred differentially between groups, group 120 showing a trend in the opposite direction. Since analysis had already shown (6.19) that the number of detections in each half-trial decreased but not differentially between groups, this means that where gaps decreased in frequency, they were also longer.

6.20 <u>The first detection after a gap.</u>

The number of signals detected at each visual angle when they occurred as the first signal detected after a gap was analysed (Appendix 29) and compared with all other responses (Appendix 30) for all subjects.

$X^2 = 40{\cdot}699$ $p = 0{\cdot}001$

Detections occurring immediately after a gap are more likely to be of signals presented from locations at less than 35° of visual angle, and less likely to be of more eccentric signals, than other detections (graph 18).

6.21

The location of the first signal detected after a gap (Appendix 29) was compared between groups (Appendix 31).

$X^2 = 23{\cdot}673$ not significant

Therefore, the effect in 6.20 is common to all groups.

6.22

Chi-squared was performed to test for differences in the proportion of detections of signals from different locations made after gaps of different lengths (Appendix 32).

$X^2 = 46{\cdot}75$ $p = 0{\cdot}001$

As in 6.16, most of the difference came from gaps of length one signal. Therefore chi-squared was repeated omitting these data;

$X^2 = 14{\cdot}889$ not significant

Detections at 75 - 95° are more likely to occur after gaps of length one signal than after other gaps, and the opposite applies to detections at 05 - 25°. Gaps of length two signals or more do not vary significantly among themselves. (Graph 19).

6.23

The reaction times of signals occurring immediately after a gap were compared to all other reaction times and differences were not found to be significant (Appendix 33).

6.24 <u>The Eysenck Personality Inventory</u>.

Each subject was asked at the conclusion of the experimental session to complete the Eysenck Personality Inventory Form A. The forms for subjects 1 and 2 are missing and therefore have not been analysed. No 'lie scale' measure was greater than 4 and so all the remaining 14 inventories were accepted for analysis.

The scores are obtained by counting on each questionnaire the number of answers indicating a high ranking on the extraversion/introversion, and neuroticism scales. Thus two scores are obtained from each questionnaire. Of the 57 questions in the inventory, 24 relate to each scale, and the remaining 9 relate to a 'lie score' which checks the validity of the whole test. Thus the possible score for one subject on each of the two scales is between 0 and 24. The raw data is shown in Appendix 34.

6.25 Extraversion/introversion.

The mean of the subjects' scores is 13•214 and the standard deviation 3•406. The Kruskal-Wallis non-parametric analysis of variance (Appendix 35) was used to test for differences in the scores of subjects from the four groups.

$H = 3{\cdot}391$ not significant

The Spearman rank correlation coefficient was used to test for correlation between scores on the scale, and detection performance, for all subjects (Appendix 36).

$r_s = -0{\cdot}0341$ not significant

The data are illustrated in graph 20.

6.26 Neuroticism.

The mean score is 11•643 and the standard deviation is 5•246. The Kruskal-Wallis test was applied (Appendix 37) to test for differences in the scores of subjects from the four groups.

$H = 1{\cdot}307$ not significant

The Spearman rank correlation coefficient with a correction for tied ranks was used to test for any correlation between scores on the scale, and detection performance for all subjects (Appendix 38).

$r_s = +0{\cdot}585$ $p = 0.025$ (one-tailed test).

Data are shown in graph 21. Correlation is not perfect, since it appears that the best performance was produced by subjects with medium scores, high scorers coming second best.

6.27

Neuroticism scores were then compared with gap length (Appendix 39). Subjects were divided into three groups on the basis of their E.P.I. neuroticism scores and the chi-squared test applied, employing four categories of gap length.

$X^2 = 33{\cdot}274 \qquad p = 0{\cdot}001$

The low-neuroticism group, average score 5·6, had fewer long gaps and more short gaps in their responses than the other two groups. (Graph 22). This accounts for their poorer performance overall.

Discussion

Note: references in parentheses e.g. (6.12) are to sections of the results

DISCUSSION

1. Performance and signal location.

The design of the display used in the main experiment was such that the signal lamps were at equal distances from the subject, and therefore all subtended the same visual angle; this means that there was no variation among signals in respect of size. Variations in performance with location of the signal source were free to appear purely as a function of location.

The main effect of location on detection performance (6.1: analysed in three groups of lamps) was highly significant, p = 0·001. The greater the eccentricity of the signal lamp, the less likely it was that the subject would detect the signal. There was no interaction effect with display luminance (group) and so this effect was common to all subjects.

The main effect of location of signals on reaction time was also significant (6.6: p = 0·001). Reaction times lengthen as the eccentricity of the signal lamp increases. There was also an interaction effect with group, p = 0·001, reaction times lengthening for signals at small and large visual angles as display luminance increased.

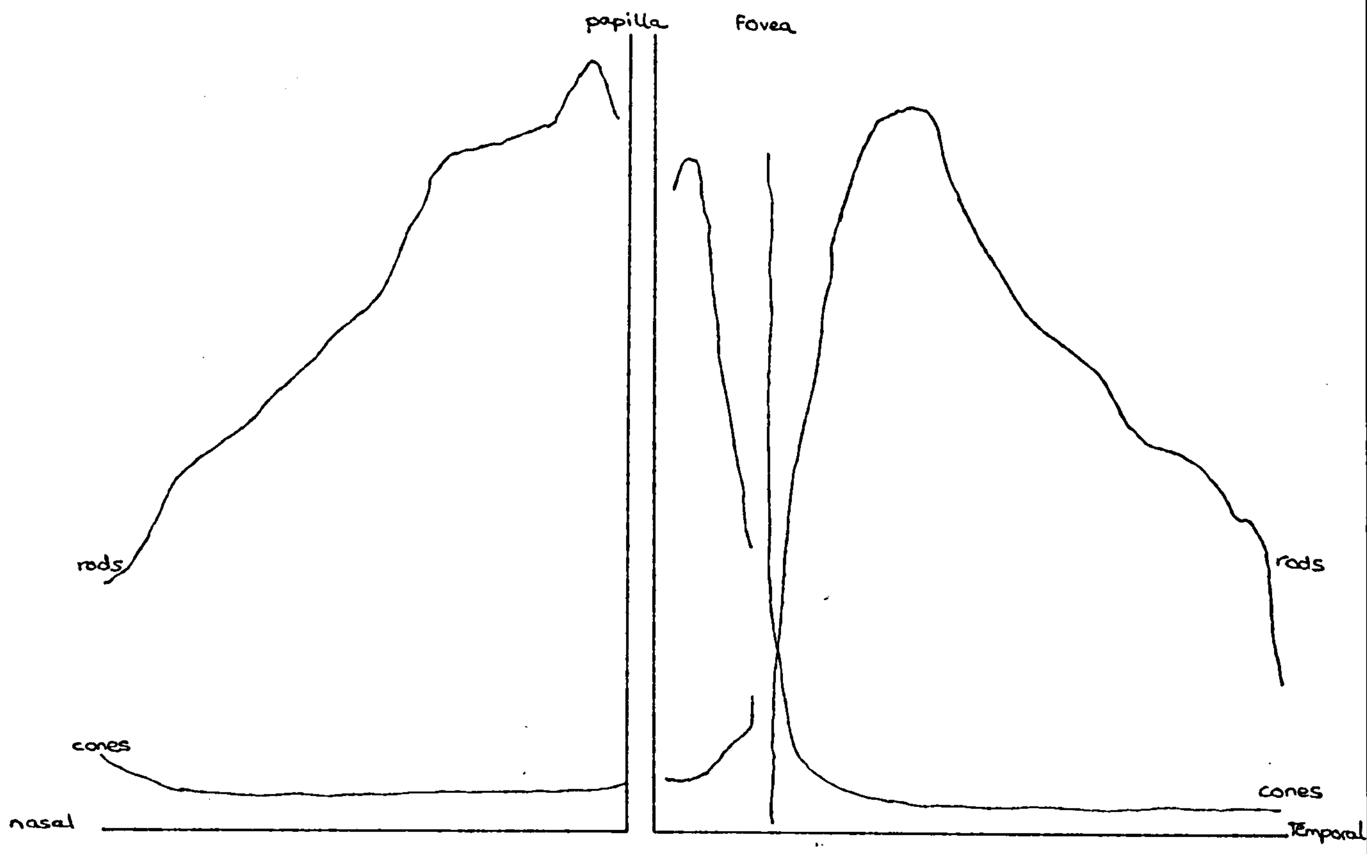
These results are consistent with previous work on the subject which has shown that in photopic vision, detectability decreases as the visual angle of thesignal increases. There are two directions in which an explanation may be sought. The first is to regard the detection of a signal as a function of acuity. The subject was required to detect a change in luminance of a part of a display rather than to identify an object subtending a small visual angle and showing dark against a lighter background, as is usually the case in acuity tests. Even so, the size of the luminous area when the signal appeared was sufficiently small, and the edge of the area sufficiently well defined, to stimulate only a small number of visual receptors in the manner of an acuity test. Therefore an explanation may be sought in terms of retinal mechanisms.

i. Physiology of the retina.

Two broad types of photoreceptor processes have been distinguished in the retina, on the basis both of anatomy and function, the rods and the cones.

The cones are colour-sensitive and each connects with the dendrites of some 25 nerve cells (Brindley 1970). They are packed most tightly in the fovea, the most sensitive area of the retina for photopic vision. The mechanics of focussing and fixation are directed towards obtaining a sharp image of the object of interest, on the fovea. The nerve fibres and blood vessels which cover the retina circumvent the fovea, increasing its relative sensitivity, and converge at the disk of the optic nerve, or blind spot. The cones decrease in density away from the fovea, and few are found outside 20° of visual angle from the centre of the fovea. Foveal cones also have directional sensitivity to light (the Stiles-Crawford effect).

The rods have a lower absolute threshold of sensitivity to light than the cones. Each connects with some 4 - 5 nerve cell dendrites (Brindley op. cit.). Rods reach their maximum density just outside the fovea, then diminish in density towards the periphery of the retina.



<u>Distribution of rods and cones along 180° - 0° meridian.</u>

after Osterberg (1935).

The retinal mosaic therefore decreases in fineness from the centre of the retina to the periphery, as the density of both rods and cones decreases. Colour vision is restricted to an area within 20^{o} of the centre of the fovea. Decrease in acuity from the centre to the periphery occurs not only with decreasing receptor density, but also because of the way the nerve cells are arranged. The cones connect with more nerve cells than do the rods, and less summation is involved in the transmission of information, allowing finer detail to be discriminated. In general terms, the fovea is the most efficient area for photopic vision, and for scotopic vision, the area just outside the fovea where the rods are most dense.

ii. Functional variations over the retina.

The result of the variation in receptor types and neural connections over the retina is a variation in functional efficiency. One consequence is that in dim light, rods become more important to vision than cones. Another is that identical stimuli will vary in detectability according to the part of the retina upon which their image falls.

An example of the latter effect is an experiment (Kirk and Michon 1961) in which conditions are similar in several respects to those of the present study. Subjects were required to fixate the centre of a dimly lit screen ($0{\cdot}3$ cd/m^2). Brightness discrimination thresholds were measured for signals from 40 locations, at 5 angular distances from the fixation point, ranging from 3^{o} to 23^{o}. The value of $\% \frac{\Delta B}{B}$ (contrast value) increased almost linearly with angular distance from the fixation point.

There are at least three reasons for this increase in threshold values as the stimulus appears further away from the fovea. Firstly, the arrangement of the retinal receptors means that the number stimulated by a stimulus of constant size varies over the retina. The probability of perception of a weak signal also varies, as while each receptor responds in an all-or-none fashion to stimulation, its sensitivity is affected by its state of saturation. The larger the number of receptors stimulated by the image, the greater the likelihood of response since more receptors will be in a state of sufficient sensitivity to respond.

Secondly, the peripheral receptors (that is, rods) transmit information in groups through a single nerve fibre, which does not allow discrimination between the individual receptors in a group, while the cones have a far higher ratio of nerve fibres to receptors. With a large stimulus, the summation effect in the peripheral receptors may aid detection, but otherwise information about the edges of the stimulus will be lost and the effect of contrast reduced.

Thirdly, the actual definition of the image falling on the receptors via the edge of the optic lens is less sharp than in the centre, and also the area of the retina outside the fovea is covered with neural layers which further reduce the sharpness of the image.

iii. The detection task and observing behaviour.

The second explanation of variation in detection rate with signal location is in terms of the observing behaviour of the subject. This refers not only to actual movements of the eyes which change the image presented to the retina, but also to the way in which the subject is 'paying attention' to different parts of the image. The subject of a detection experiment does not merely act as a perceiving machine, receiving signals into an eye like a camera and processing the results into a response. An active participation on his part is required, both in willingness to carry out the task and also in the performance itself. Before he can even make a decision about his response to a stimulus, he must actively receive it, particularly in the visual modality. Vision is different from the other senses in that it is possible to shut out the stimulus entirely, by closing the eyes or looking the other way. Focussing, too, requires deliberate effort.

In particular, visual experiments employing more than one signal source have particular problems. Whether the subject is required to fixate or not, he can to some extent choose which area of the display to observe, and his strategy will affect his detection performance. The effects may be more subtle than a direct alteration in detection rate if subsequent observing behaviour or response criteria are affected by the number or location of signals previously detected.

Sanders (1963) has gathered together evidence on the observing behaviour of subjects in a variety of situations, and identifies three levels in the functional visual field in terms of the mechanisms used: the stationary field, the eyefield, and the headfield. Inspection strategy changes according to the type of field in use, that is whether head or eye movements are allowed, and detection performance also changes. Such work emphasises the active aspect of the detection task, in terms of the observing strategy of the subject. In the stationary field, as in the present experiment, the subject may be sampling areas of the field for observation even though the image falling on the retina changes little. This does not mean, however, that all areas of the visual field are sampled equally often. We are accustomed to using our eyes to obtain an image on the fovea of an object which interests us, and so we are used to 'paying attention to' and observing this area of the retina more than any other. Observing strategy in the eyefield may therefore emphasise central regions at the expense of others and accentuate the mechanical causes of decreasing detection rate with increasing eccentricity of the stimulus.

The type of experiment in which these considerations are important is reported by Hockey (1970). He used a similar experimental arrangement to that of Bursill (op. cit.), requiring the subject to report detection of light stimuli at different locations in the visual field. He used noise as the experimental variable instead of heat as Bursill did. He achieved a similar effect, of reduced efficiency in the periphery of the visual field when the stress was applied, but attributed the effect to the greater subjective probability that the more central lights would be lit, due to past experience. This cannot be a complete explanation, since the previous experience, if biased, must itself result from some kind of bias.

Bulger (1972) points out that Hockey's experiment did not really distinguish between the two explanations, of location and subjective probability. Bulger used random vibration as an experimental variable and required subjects to detect signals from any one of four lamps. The signal probability was biased to one side or the other. He found that the vibration produced a performance decrement, that performance on the two central lamps was better than that on the two outer lamps, that this effect increased over time, and that the direction of the bias had no effect. This shows that signal probability alone was not responsible for the changes induced by the stress. In a subsequent experiment investigating the interaction between noise and vibration, he found no effect of these variables on detection performance. This led him to conclude that:

> ' in a stressful environment, the presence of probabilistically unequal information sources puts an increased demand upon the information processing mechanism; in other words the observed effect is the consequence of a change in sampling strategy in order to compensate for induced psychological stress.'

However, if the sampling strategy is based accurately upon the information provided, this should result in greater efficiency in observing responses and the pattern of detections should reflect the signal probability. This increased efficiency should reduce the psychological stress, once the sampling strategy is being employed. To take an extreme example, if signals only come from one side of the display, the subject will soon learn to ignore the other side and his efficiency should increase, as he now has a smaller area to sample and so can sample each part of it more often (Nicely and Miller 1957). According to Easterbrook's hypothesis, the imposition of a stressful variable should have the effect of reducing the range of the subject's search. Perhaps when the range is already limited by subjective probability bias, the stressful variable can have no further effect.

Observing responses do not necessarily involve eye or head movements. There is evidence that even while the subject is fixating on the fixation point, his attention is not always 'focussed' on this point. It seems that the probability of detection of signals in the visual field varies over time in a manner not connected with movements of the image of the display over the retina.

Engel (1971) measured the 'conspicuity area' around the fixation point within which the test object was detected when the subject had no foreknowledge of its location. He then introduced an 'attention point', a location different from the fixation point at which the test object had a high probability of appearing. By introducing the test object at different 'surprise' locations, he was able to plot the 'attention area' associated with an attention point. The attention areas plotted were found to be similar to the corresponding conspicuity areas, but were stretched in the direction of the attention point, regardless of its distance from the fixation point.

Lie (1969) measured the threshold intensity of a test flash detected by subjects having a foreknowledge of the location of the test flash, in either space or time. He introduced flashes from a new location during the experiment and found a higher threshold intensity for those flashes coming from an unexpected place.

Mackworth (1965) showed subjects displays of letters centred on the fixation point with an exposure time of 100 msec. and asked them to detect whether or not the central letter also appeared on both sides. There were three conditions of 'noise', that is the number of letters present in the display and their arrangement. The disruptive effect of extra letters did not appear to be retinal, since even doubling the viewing distance (and thereby presenting the display nearer to the fovea) did not affect performance. He concluded that whereas scanning normally occurs inwards towards the centre, when there is too much information the field is scanned from the centre outwards and the 'useful field of view', that is the area around the fixation point from which information is being briefly stored, contracts. This produces a temporary 'tunnel vision'.

Further support for the importance of central processes in detection within the stationary field comes from Webster and Haslerud (1964). Subjects responded to lights flashed on an arc perimeter while fixating on a central light. In addition they either counted clicks presented through headphones or counted flashes of the fixation light. Those subjects who performed the counting task gave a worse performance on the peripheral task in terms of both detection rate and reaction time, but there was no difference between subjects performing the two counting tasks, visual and auditory. Pre- and post-experimental measurements of each subject's peripheral limits did not show a significant difference.

Thus the evidence suggests two hypotheses. Firstly, that the probability of detection of a signal presented from one location in the subject's field of view depends on retinal factors and also on a non-retinal factor which may be called 'attention'. Secondly, in any given set of conditions a 'field of attention' exists, that is, an area in the subject's field of view within which a signal will be detected. The conditions determining the location of the attention area include instructions, expectation, the performance of another task, and time.

It would therefore be insufficient to accept an explanation of the present results in terms of retinal factors alone. The retinal factors limit performance in extra-foveal areas, but performance is still further limited by the subject's observing strategy in the following manner.

Assuming that attentional selectivity with good fixation works in a directional mode like ordinary visual selectivity (Engel op. cit.) it would not be good strategy on the subject's part to 'scan' any particular peripheral area too frequently or for too long a time, as he would then run a high risk of missing signals from more central areas. If we take the frequently used metaphor of attention as a spotlight searching the visual field, the observer will give a better performance (taking into account his lower threshold for more central signals due to physiological factors) by shining the spotlight mainly in the centre. He will then rely on the more diffuse glow around the edges, together with the occasional brief sortie, to pick up as many peripheral signals as possible without a great risk of missing central signals.

The observation that signal location affects detectability in a manner similar to other signal parameters such as size and intensity is important for later discussion. The eccentricity of the signal source, measured in terms of visual angle from the fixation point, is analogous to the intensity of the signal, measured in terms of its luminance. In the present experiments for each subject all other parameters except location were held constant, and so location becomes the only variable affecting the detectability of the signal. In this sense it is possible to speak of the 'strength' of a signal in reference to its eccentricity.

2. Prediction from the pilot experiment and detection rate.

The intensities of luminance at which the signal lamps were set for each group in the main experiment were determined by the results of a pilot experiment especially designed for this purpose. The settings were intended to produce a detection rate of approximately 50%. This figure is essentially arbitrary but was simply intended to provide suitable data for analysis. Obviously, if the groups were to differ greatly in overall detection rate, or the rate for all groups were exceptionally high or low, analysis would be limited, especially as it was expected that the most interesting results wold be found in analyses of responses over time, and over the visual field.

In effect, the only group of subjects with a detection rate near the predicted one was that run under 600 cd/m^2. Other groups did better than predicted, and progressively so as the display luminance decreased. Overall detection rate was 49 - 63%.

The most important difference in conditions between the pilot experiment and the main experiment was the size of the visual field tested, increasing from 45^o to 95^o. Graph 2 shows that separation between groups in terms of detection rate begins at 55^o, that is as signals appear from locations added in the new display. This means that predictions from the pilot experiment succeeded in their purpose, that is in equalising the overall detection rate of the groups sufficiently for valid analysis, but were only accurate for the size of visual field tested in the pilot experiment. Actual performance at the two angles concerned in the pilot experiment (25^{o} and 45^{o}) was much better than predicted, with an average rate of 80%. Detections declined below 50% as the angle of the signal increased above 45^{o}, and so it seems that the average detection rate of the groups at 49% - 63%, a convenient one for analytical purposes, was a fortunate coincidence.

Why should the subjects in the main experiment have performed so much better at 25^{o} and 45^{o} than expected? There were differences in the timing of sessions, subjects in the pilot experiment receiving 200 signals in five trials, and in the main experiment 240 signals in four trials. This would not seem to be relevant, especially since main experiment subjects had longer trials and so any difference might be expected to be in the direction of poorer performance rather than better. Subjects in the pilot experiment attended four sessions rather than only one, but the same applies, that a practice effect induced by repeated attendance would produce a better performance in the pilot subjects. Expectations about performance in the pilot subjects were controlled, since each subject acted as his own control, serving under four intensities of display luminance but in an order randomised over subjects. Thus experimental design factors are eliminated.

The remaining explanation is in terms of the display design, the new shape and materials used, and the increase in the size of the visual field tested. The increase in the number of locations from which the signals could appear, and the increased visual angle of some of the signals, would seem to decrease detection rate at any particular angle rather than to increase it. The attentional mechanism would have a far larger field to scan, which would mean less time to be spent 'watching' any one part of the field, and therefore a greater chance of missing signals from that part. But this argument assumes that 'scanning' strategy remains the same in the two situations, which it may not do. For example, in the pilot experiment where there were only eight locations from which signals could be presented, the subject may have been indulging in guessing the location of the next signal, and therefore in a more deliberate observing strategy. This may have reduced his detection rate rather than increasing it. Thus a more natural, and relaxed observing strategy in the main experiment may have improved detection rate.

In addition, consider Engel's (op. cit) work on the 'attention area'. The attention area extends outwards from the fixation point, towards the point at which the signal is expected to appear. If the subject is guessing, or simply directing his attention to different parts of the periphery, the effect in the pilot experiment, with the lamps placed in eight different directions from the fixation point, would be to increase the likelihood of his missing a signal from another direction. In the main experiment, with a much higher concentration of lamps in the same visual area, the subject would have a chance of seeing signals from the area between the fixation point and the chosen 'attention point'.

Another possibility is that the subject tended to consider the display as consisting of several parts, in concentric areas from the fixation point, and scan accordingly. This strategy might result in a concentration on the central areas more than the peripheral ones, since his threshold would be lower for signals nearer the fixation point and he would have a better chance of seeing them. The natural division in the pilot experiment would be between 25^{o} and 45^{o}, especially since the apparent size of the signallamps also decreased from 24' to 18', increasing the difficulty of seeing the 45^{o} signals. In the main experiment, with a larger area to observe, the areas so divided would tend to be larger, the area most frequently observed perhaps being 05^{o} - 45^{o}. This would have the effect of reducing mistakes of strategy, and improving performance within that area.

3. Performance and time.

The present experiments have some features in common with the studies on vigilance summarised in the introduction, and so it is interesting to compare the results with findings from such studies. The signals presented were brief and had been shown in the pilot experiments to have a contrast value insufficient to ensure 100% detection rate. In these circumstances detection rate might be expected to decrease with time (Bakan op. cit), the presence of multiple visual sources to discourage decrement (Loeb and Jeantheau 1958), and peripheral sources to show more decrement than central ones (Baker 1958). Reaction times might increase with time (Buck 1966), showing an inverse relationship with detection rate. On the other hand, the length of each session might not prove sufficient to allow decrement to appear, and the rest periods between trials may have also prevented decrement (Colquhoun 1959).

The results show (6.3) that the main effect of trials on detection rate was not significant, that is detection rate did not show a decrement with time over the session. Such an effect was not expected since it did not appear in the pilot experiments. It may of course appear in sessions longer than thirty minutes.

During each trial, however, detections did decrease from the first half to the second half of each trial, in all groups (6.18). Also, for all groups except 120, the number of gaps increased from the first half to the second half of the trial, explaining the decrease in detections(6.19). In the case of the 120 group, the gaps decreased in number but must have increased in length to produce fewer detections in the second half of the trial.

Reaction times lengthened with trials (6.8), the number of short times decreasing and the number of medium times increasing, and this occurred in all groups.

In summary, the effects of time which might be predicted from vigilance studies did not appear clearly. Instead of an overall decrement with time, a decrement was observed within trials each of which lasted only a few minutes. The explanation may be that the rest periods sufficed to restore performance to its original level by the beginning of each trial, and that the task was sufficiently interesting or difficult to prevent any longer term decrement.

An indication that decrement was in fact present even though it did not appear in terms of detection rate, is provided by the reaction times analysis. Reaction times are more sensitive to factors such as fatigue, which operate over time , than is detection rate. A decrement is therefore indicated, a decrement which increases with display luminance.

4. Performance and personality characteristics.

No correlation was found between scores on either scale (neuroticism or extraversion/introversion) of the Eysenck Personality Inverntory and group (6.25, 6.26). No such correlation was expected, as subjects were allotted to groups at random.

No correlation was found between performance on the task, and extraversion/introversion (6.25). The suggestion that there might be some degree of correspondence is based on data from vigilance experiments, in which extravert subjects appear to become bored and show a performance decrement more quickly than introvert subjects. The present data does not show this trend, possibly because the task was not sufficiently boring, or because the session was too short or the rest periods too frequent to allow a performance decrement to appear.

However, when scores on the neuroticism scale were compared with detection performance, a positive correlation was found (6.26). Eysenck (1973) says that the two dimensions of personality measured by the two scales in his Inventory are independent, and so this result is not anomalous. The correlation seems to show (see also graph 21) that subjects with a low neuroticism score do worst on the task, while a medium score goes with best performance.

This relates to the data in graph 22, in which scores on the neuroticism scale, in terms of three groups of scores, are plotted against gap length. The low neuroticism group has the poorest detection performance, and also shows the longest gaps. Thus gap length may be the link between neuroticism score and detection rate. Whatever factor it is that influences gap length (bearing in mind that the data from all subjects show a similar number of gaps) appears to affect the low neuroticism group more than the other groups.

5. Display luminance and the functional visual field.

i. Display luminance and detection rate.

A simple effect of display luminance on the total number of detections made by each subject was not expected. Luminance of the signal lamps was calculated from the results of the pilot experiment in such a way that subjects operating under the four different intensities of display luminance would show an equivelant detection rate overall.

However, the two statistical tests applied to the data, one parametric and one non-parametric, gave different results, with a significance result of 10% and 0·01% respectively (6.2). This appeared to be because variability between subjects in the same group was high, not allowing the parametric test to achieve a high level of confidence, although the range of scores can be seen to change from one intensity to the next (graph 3).

The validity of this interpretation is supported by the analysis of gap length by group (6.12). While all groups show the same number of gaps, gap length varies with display luminance, and as this effect is statistically significant it means that the number of detections decreases as display luminance increases. The conclusion must be that the non-parametric test mentioned above does show a real difference in total detection scores between groups.

On the assumption that this conclusion is correct, it is now possible to see how the effect of display luminance reveals itself. Two analyses are relevant, of the location of signals detected by each group, and of 'category of detections' or consistency of response.

ii. Display luminance and location of signals detected.

The location of signals detected by each group is illustrated in graph 2. Analysis of the data on which this graph is based does not show an interaction effect of angle of signal with groups. If increasing intensity of display luminance had the effect of diminishing the functional visual field, then this interaction would have achieved statistical significance. The higher intensity groups would show a sharp fall in the proportion of detections at the most eccentric angles, which they do not. They do show a reduced proportion of detections at angles greater than about 35°, but the magnitude of the difference does not increase consistently with angle. This analysis rules out the possibility of a simple 'tunnel vision' effect of increasing display luminance, within the range of luminances studied.

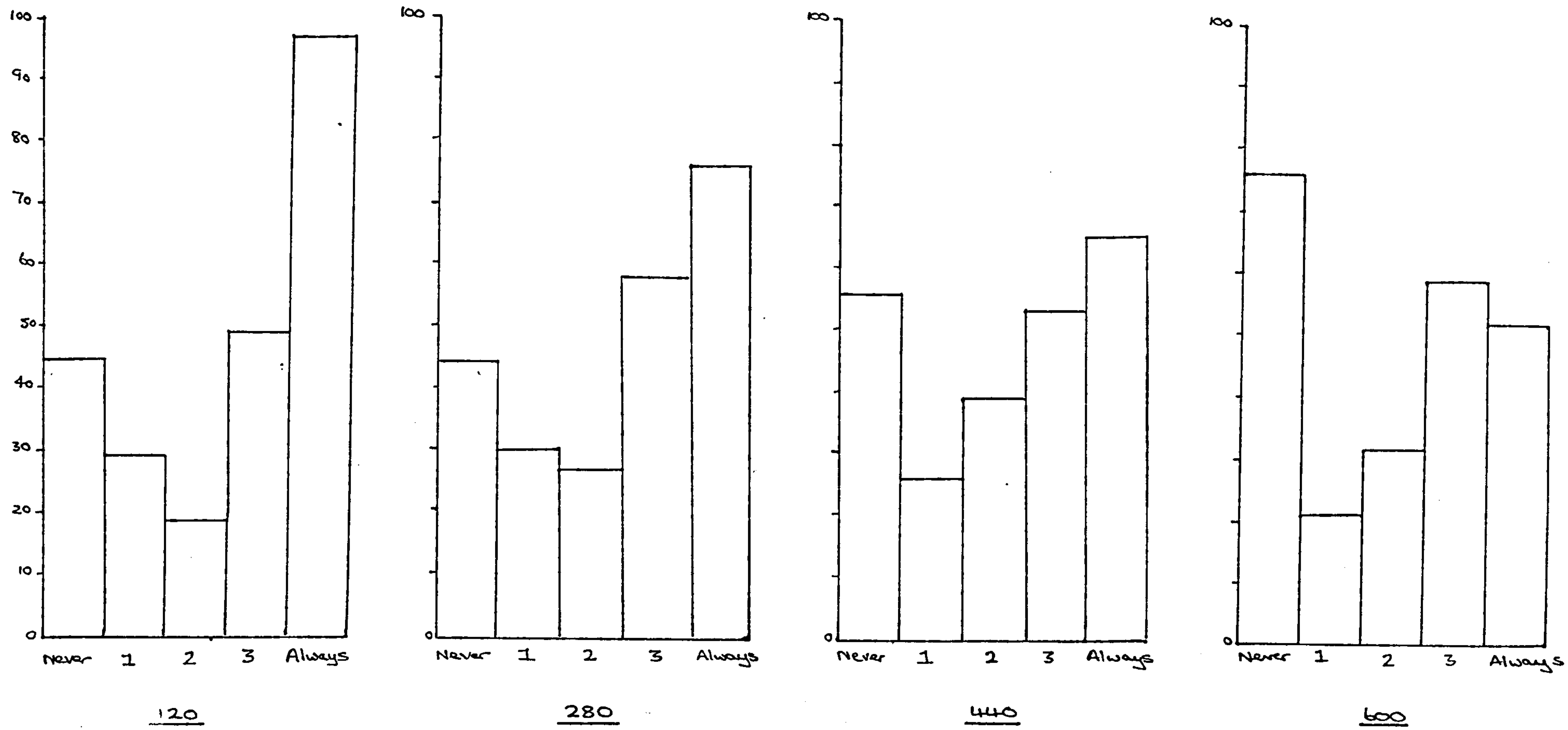
iii. Display luminance and consistency of response.

The analysis on 'category of detections' shows the consistency of response of the subject to signals from any one location(6.9). The 'never' and 'always' categories (0 and 4 detections out of 4 presentations) correspond with perfect

Figure 15.

Category of detections: number of lamps in each category.

(total 240 per group)



consistency, and the other three categories to imperfect consistency.

The main differences between groups lie in the 'never' and 'always' categories. If a tunnel vision effect were present, then the difference would be solely in the 'never' category. An increase in the number of lamps in this category for the higher display luminance groups would represent some lamps in the periphery which these subjects never saw.

Instead, the analysis reveals a decrease in consistency of response with increasing intensity of display luminance. This relates to the finding that higher display luminance groups show longer gaps than the other groups, although the location of the missed signals is similar for all groups. As gaps lengthen, more signals are missed, but except for gaps of length one signal they do not emanate from different locations according to gap length. The result is a lack of consistency in response which is demonstrated by the 'category of detections' analysis.(figure 15).

iv. Display luminance and reaction times.

The higher display luminance groups gave fewer short reaction times and more long times than other groups (graph 7). This effect is more marked than differences between groups in terms of detection rate. The effect is not due to differences in absolute signal luminance between groups, since the groups giving longer reaction times also had higher intensities of signal lamp luminance.

The implication is that as the luminance intensity increased, so did the difficulty of the task. Reaction times are a sensitive index of time taken to reach a decision about a signal, all other things being equal. They also tend to be a more sensitive indication of difficulty than detection rate, if performance is being maintained at some extra cost to the subject (Buck 1966).

Graph 6 shows mean reaction time for each group plotted by angle. The interaction effect, groups by angle, is significant and it can be seen from the graph that this is due to comparatively short times from the 120 group at 05 - 25°, and long times from the 600 group at 65 - 85°. There is little difference between the groups from 35 - 55° (where 42% of signals were located) and this area corresponds to the medium reaction times seen in graph 7.

Graph 2 shows that after about 55°, the groups begin to separate in terms of the number of signals detected at each angle. This supports the view that the long reaction times given by the high luminance groups to more peripheral signals are indicative of increasing difficulty in signal detection. However the correspondence is not perfect, as only the 600 group shows these long reaction times consistently and yet the disparity in detection rate covers all four groups. In addition, all groups have a similar detection rate at small angles, while the 120 group shows shorter reaction times in this area. If longer reaction times do indicate greater difficulty in performing the task, it may be that the higher luminance groups are pursuing a different observing strategy to the other groups, in the way described above ('The detection task and observing behaviour'). These groups may be observing more actively, in an attempt to compensate for greater difficulty in detecting the more peripheral signals, and therefore taking longer to respond to more central ('easier') signals, because their locus of attention is further towards the periphery than that of the other groups.

6. Runs and gaps - the problem of variability over time.

Analysis 6.10 shows that detection responses are bunched over time, and that the length but not the number of the gaps so formed varies directly with display luminance (6.12). This would appear to be directly related to display luminance rather than signal luminance or signal/background contrast (6.15). The number of gaps increases in the second half of the trial for the higher luminance groups (6.19). The first signal detected after a gap is likely to be more central, that is nearer the fixation point, than other signals detected (6.20).

The information obtained about gaps may be summarised as follows. All subjects display them, in approximately equal numbers per trial, and per session. However the length of the gaps does vary, in terms of signals missed from one to twelve, and in terms of real time an average of eight seconds per signal missed. Subjects observed under the higher intensities of display luminance show more long gaps. This effect relates solely to the intensity of display luminance. Those subjects showing longer gaps also show an increase in the number of gaps in the second half of the trial, but this effect is not cumulative from trial to trial.

'Blocking' and 'gaps'.

The phenomenon here presented seems to be related to the 'blocking' first named by Bills (1931). He defined a block as a response time more than twice as long as the average response time for the subject. This type of definition is necessarily arbitrary but has not been improved upon, because the concept has been so little used except in connection with Broadbent's filter theory. A problem with using response blocksas a measure of performance is that they are only obvious in two experimental situations: when the signal appears at a time of which the subject has foreknowledge (as in self-paced tasks), and when the stimulus continues to be presented until the subject has responded to it. If the stimulus appears for a fixed duration, the experimenter must use some criterion to decide which responses are correct and which are false, or errors of commission. This is done by setting an arbitrary upper limit on reaction time before the data is analysed and counting all other responses as false. The tendency is then for the experimenter to simply record the number of extra-long response times without recording their timing.

Bills' definition has been used as a measure of performance by Baker and Theologus (1972). Administration of caffeine was the experimental variable in a three-hour task simulating some aspects of night driving, the subject watching two red lights (simulating the rear lights of a vehicle ahead) and responding when he saw them separate. The dominant feature of the analysis proved not to be variation of response time as such, but the random (in time) appearance of extra long reaction times. A response block was defined as any response more than twice as long as the mean value of the ten shortest times recorded during the first hour, when no subjects received the drug. Caffeine (which is supposed to reduce the effects of fatigue) had the effect of reducing the number of respnse blocks recorded. The authors compare the response blocks to momentary lapses of attention which can occur during long, monotonous periods of driving.

A similar definition was again used, by Theologus, Wheaton and Fleishman (1974) in testing the effects of two types of noise, random and patterned, on three tasks in two half-hour sessions. The tasks were simple reaction to light, a tracking task, and a time-sharing task which meant performing the first two simultaneously. Frequency of response blocks was only found to change in the time-sharing task, decreasing from the first session to the second for the 'quiet' group, and from random to patterned noise for the 'noise' group.

Bertelson and Joffe (1963) have criticised such experiments. Firstly, the criterion used in the definition of a block needs to be carefully explained. Response times during serial responding do not show a normal distribution but are skewed towards the long times (Conrad and Hille 1954). Therefore, a definition of a response block as, say, a response time more than twice as long as the average time, has a particular meaning depending on the type of average employed and from what part of the session the average is taken.

Secondly, the hypothesis that the blocks allow dissipation of a build-up of fatigue, allowing a recovery of performance or compensatory behaviour in unpaced tasks, cannot be supported until response times and error rates before and after the block, have been analysed. Thirdly, it is often assumed that blocks are a symptom of long-term fatigue even though their incidence can increase very early in the session, perhaps after the first five minutes.

Bertelson and Joffe set out to do further analysis on data from an experiment which had already been completed (Bertelson and Joffe 1962), with the aim of eliminating these faults. The primary purpose of the experiment had been to study the effects of two drugs on prolonged performance of a serial responding task. The session lasted thirty minutes and the task was to press one of four keys in response to one of four numbers. The next signal appeared as soon as the previous response had been completed, so the task was self-paced.

Ten reaction times were taken from the beginning and end of the task, and were found to lengthen with time on task. Distributions of short and median times remained constant, while the proportion of long ones increased. The constancy of short and median times was found to operate throughout the session, and so Bill's criterion of a block could be adopted. The frequency of blocks was found to rise sharply during the first five minutes and then stay practically constant. They point out:

"If blocks are a symptom of fatigue, it is of a very short-term fatigue."

They went on to analyse reaction times and errors before and after a block, and the results support the hypothesis that blocking dissipates some kind of fatigue. Reaction times for the four or five respnses preceding a block rise sharply, and times fall abruptly immediately afterwards. The changes in the percentages of wrong responses closely parallel those in reaction time. However, an unexpected finding was that the decrement cancelled by blocking is a very short-term one. Performance does not begin to deteriorate immediately after a block, but stays stable for some time before the next block, an average of 50 responses, and is brought back to normal after four or five steps. In other words, the blocking comes into action quickly and is very effective.

The type of response blocks discussed above seem to be of short duration, a matter of seconds. On a quite different time-scale, Murrell (1962) has studied efficiency cycles in work. He defines an actile period as;

> " a period of time during which there is a state of preparedness to respond optimally to stimulation either discretely or continuously."

The cycle envisaged for the actile period appears to be quite long, and to refer to changes in performance of prolonged tasks which might be described in vigilance terms as practice effects, decrements, or end-spurts. The actile period concept is an attempt to replace the negative concept of fatigue with a positive concept.

The time scale of the gaps appearing in the present data, from several seconds to well over a minute, does not seem to appear in the literature. This is because the type of task in which it will be measurable is strictly limited. The signals must be of fixed duration, not too far above 50% threshold, and presented regularly at intervals of several seconds. Even so, it is surprising that experimenters using such tasks have apparently not employed the kind of fine-grained analysis which would reveal similar variations over time. In addition, performance on tasks such as object-sorting, when the objects are regularly presented at pre-determined intervals, should be susceptible to analysis of this type if each element of performance is separately timed.

Most experiments are designed to eliminate the effect of time, for example by rotating the different experimental conditions around performance sessions so that the main effects are not confounded. In the type of experiment where time is of primary interest, the vigilance study, the session is likely to be as long as possible and a large amount of data will be analysed in equal segments so that vigilance decrement can be detected; there is apparently no purpose in a more detailed analysis of the distribution of respnses over time. It is likely that such analyses would prove fruitful. There is a low probability that the subjects' responses in such an experiment will be randomly distributed over time. Even if long-term changes such as vigilance decrement are present, short-term cycles in performance may still be detectable, and the decrement may even be due to a change in their nature.

'Gaps' and response variability.

Variability is an essential feature of life. Studies on system noise (discussed below) have shown that random variation is an intrinsic feature of the nervous system. Apart from this micro-variation, the responses of living systems are also influenced by other factors, much studied by psychologists, which limit the predictability of responses to a series of identical stimuli.

What kind of variability do gaps represent? The data can be examined for its fit to two different interpretations of the effect of display luminance on the subject's responses.

Tunnel vision of an intermittent type would be predicted on the basis of the cue utilisation studies discussed above. During the period that the (high luminance) subject was experiencing tunnel vision, he would be able to perceive only centrally located signals, and so when more peripheral signals were being presented, his pattern of responses would show long gaps. However, we should also expect a different number of gaps between experimental groups, and this does not occur. More importantly, we should also expect a sharp fall in detections of peripheral signals by groups observed under the higher luminance conditions compared to the other groups, and this does not occur. The fall is gradual; and examination of the signal contents of the longer gaps shown by the higher luminance groups shows that they do not differ from the contents of other gaps, as would be expected if the increased length were due to some other factor, like tunnel vision, connected with signal location.

A response threshold interpretation fits more neatly with the data. During the gap the subject has a raised threshold for all signals, so that a borderline signal which normally elicits a response a proportion of the time, now fails to do so. The conditions of the experiment, including signals of equal size, luminance and distance from the subject, were such that location of signal was the only signal parameter affecting detectability. In this sense the signal becomes 'weaker' as its location moves further away from the fixation point. During the gaps, therefore, the subject's raised threshold tends to reduce response to the weaker (more peripheral) signals, but perhaps not in a sufficiently clear-cut fashion with respect to location, to produce an interaction effect between display luminance and signal location. The raised threshold interpretation applies to the gaps seen in the data from all display luminance groups; increased intensity of display luminance increases the length of the periods of raised threshold and thereby the length of the gaps.

The signal content of gaps is similar for all gaps of length more than one signal, and consists of a selection of signals from more difficult locations. The effect of the increased period of raised response threshold in the high luminance groups is to diminish response to more peripheral signals in general. Since the effect of raised threshold is not to completely inhibit perception of signals in peripheral areas, but to decrease the probability that a more 'difficult' signal will be detected, occasional detection of peripheral signals will still be possible, ending the gap. This means that the signal content of the gaps is not particular to any one area of the display. The effect is of greater inconsistency in the subject's responses to more peripheral signals, rather than intermittent lack of any response at all.

In summary, gaps are symptomatic of a periodical reduction of efficiency in response, caused by some factor which is cyclical in its effect. This factor does not completely regulate the length of the gaps, but rather interacts with the signal schedule to produce an effect which is seen in the data as gaps. The mechanics by which the factor operates to produce the gaps are to diminish response to all signals, preventing detection of any but the strongest, that is the most central in the display. When a section of the signal schedule, containing peripheral signals, and a diminution of response coincide, no response will be elicited from the subject until either a strong signal occurs or the response threshold returns to its former level.

The general problem of variability in response.

The response variability revealed by analysis of the present data can now be compared with other types of variability described in the literature of psychology. The work of Bills and others on response 'blocking' has already been examined but the phenomenon can now be approached in a wider context which includes other studies on variations in response, over time, to a series of similar stimuli.

1. Theories of attention seek to explain the way in which the subject selects important stimuli from those impingeing on his senses. This process is a prior condition for response.
2. Studies on response to constant visual stimulation examine the changing sensations of the subject when presented with an absolutely constant display. These studies reveal the nature of selectivity in perception and are also an important consideration in such experiments as the present one in which the stimuli represent the only changes in the display.
3. Studies on system noise and its relationship to threshold discriminations examine a physiological variable which may relate to experimental variables such as display luminance. System noise provides a partial explanation of variability in response to a series of identical threshold stimuli.

1. Theories of attention.

The problem of variability of response has occupied psychologists for some time. Absolute regularity and reliability are a feature of machines, not people. If a perceiving machine were to behave like a human subject it would be considered faulty, for given exactly the same conditions and stimulus, the machine would be expected to produce an identical response. The human subject does not behave in this way, and the reasons for his variability of response are the subject of the study of attention.

Work on vigilance situations has promoted attempts at a theoretical understanding of attentional processes, aided by technical developments such as E.E.G. recordings which for the first time enable a link to be established between inferences about attentional processes made from experimental data, and physiological responses. However, most models of attention are still cognitive rather than physiological and serve less as realistic explanations than as sources of new experimentation. Since one of the best ways to investigate a process is to disturb it, experiments have very often been concerned with the introduction of noise (in any modality) to observe the effect on performance and make deductions about the underlying processes.

Broadbent (1958) has proposed a model which is now out of favour as a complete explanation, but is still useful in its basic ideas. The filter theory proposes that the nervous system acts as a single communication channel of limited capacity. A selective operation is performed on sensory input on the basis of such gross physical features as the intensity, pitch and spatial localisation of sounds. Various factors determine whether the stimuli pass the limited capacity channel, for example instructions about the 'wanted' signal. There is also a temporary store prior to the filter at which information may be held for a matter of seconds. In particular, the attention switches among channels when necessary and has a bias for those channels least recently selected. Information from the unselected channels can be held for a little while in the short-term store. Triesman puts forward the criticism that the filter must have such complex selective properties that it is almost as complicated as the mechanism it serves.

Triesman postulates successive tests of increasing complexity on incoming stimuli, but flexible ones, so that analysis is much simpler for expected messages. This helps to explain how messages differing only in comparatively fine detail can be discriminated one from another. However, this model implies the analysis of all input at some stage, and while it fits some data from experiments on selective attention better than Broadbent's original model, it is still not very selective.

Deutsch and Deutsch have proposed an alternative model in which signals analysed according to physical properties are selected for pertinence to previous signals. This involves the excitation of stored representations both of the incoming signal and of the class of pertinent events. The item most highly excited by the combination of sensory and pertinence inputs is selected for further analysis.

The decision theory of vigilance of Jerison and Pickett (1963) postulates that the observer is continually making decisions about whether or not to observe, on the basis of the temporal predictability of the signal and the payoffs associated with signal detection. The higher the event rate, the more important is signal probability.

Bakan emphasises the importance of the detection of signals as a reinforcement for attentive behaviour. If observation is not sufficiently reinforced, the display becomes de-differentiated, increasing the monotony of the situation. To keep himself awake the subject fidgets and day-dreams and misses even more signals. From subjective reports of subjects who have performed Bakan's tasks (which consist of detecting a certain sequence of numbers in a continuous display) it seems that observing responses are based on the subject's judgements of when the signal is 'due'.

Reese also emphasises this aspect of the subject's behaviour. He says that feedback from the task, that is, the subject's knowledge of the signal frequency, determines his observing responses as he averages previous inter-signal intervals to predict the time of the next stimulus. Baker has a slightly different expectancy theory, in that expectancy falls gradually after the mean inter-signal interval has passed. Experiments suggest that apparently undetected signals may play a part in these calculations, and also that individuals with good judgement of time intervals can perform better in a vigilance task. However, the expectancy hypothesis can be criticised for failing to explain decrements in later sessions with the same subjects, as presumably they will be learning the temporal sequence of the signals more and more accurately. It seems likely that expectancy has only a partial influence on observing responses in this sense and then mainly in monotonous situations.

The foregoing theories seek to explain the selection of stimuli from the environment (for further discussion and review see Mostofsky 1970). Theories of arousal on the other hand, seek to explain not selective attention and particular responses, but rather a general level of sensitisation, a background against which stimuli have their effect.

The reticular formation is part of both a diffuse projection system relaying quantity rather than quality of excitation from receptors to cerebral cortex, and of a specific projection system which preserves detailed information. The upper or thalamic part is evidently able to excite areas of the cortex separately and also possibly inhibit others at the same time. A sleeping animal continues to receive excitation from the sensory pathways in the cortex, but unless the stimulus is sufficiently intense or significant to cause the R.A.S. (reticular activating system) to activate the cortex, there is no overt reaction. Berlyne (1960) points out that emotional states are intimately connected with arousal level, and that an arousal dimension appears in attempts to classify emotional states; for Wundt the 'excitement-quiescence dimension', for Schlosberg 'level of activation' and for Osgood 'activity'.

Lindsley's activation theory states that the arousal continuum is very largely a function of cortical bombardment by the ascending R.A.S., such that the greater the bombardment, the greater the activation. The relation between activation and behavioural efficiency is described by an inverted U-curve (c.f. the descriptions of subjects exposed to stressful stimulation in cue utilisation experiments above). Neural impulses in a closed chain of neurons (Hebb's cell assembly) are facilitated by impulses arriving from outside the chain, but through over-stimulation a neuron may acquire a high threshold and fail to transmit the circulating impulses. Activity in the cell assembly will cease (Malmo 1959).

This indicates that there is an optimum range of stimulation in terms of both quantity and quality beyond which the stimulation (or lack of it) will prove harmful. The quality of stimulation is important in terms of its meaningfulness; that is the number of 'bits' of information presented as well as their emotional import. This of course will vary with the individual.

The level of arousal varies in the normal individual in a regular cyclic fashion. In humans the peak is usually around midday and the trough in the early hours of the morning. The natural circadian rhythm, the alternation of light and darkness every 24 hours, has an all-pervasive influence on life. Photoperiodism occurs in a wide variety of plants and animals. Little is known about man's response to the natural 24-hour cycle. It is difficult to conduct the kind of experiment on man that has provided answers about other animals. Such studies as have been conducted have concentrated either upon adapting the subjects to an artificial daylength, or on removing cues associated with the passage of time and observing the rhythms adopted. It is much easier to study such effects in an animal with a polyphasic sleep pattern than in man, especially as it is so difficult to isolate man's activity cycle from social influences.

It seems likely that in man as in other forms of life, light is closely allied to activity cycles, whether through some biological mechanism or social conditioning, and that the important parameter is the presence or absence of light, rather than its intensity. However the intensity may determine the degree of activation. If the relationship between activation and light intensity is linear, then according to Malmo the relationship between light intensity and performance will be described by an inverted U-curve, producing a deterioration in performance with very low and high intensities.

Theories of attention and theories of arousal do not compete as explanations of variability in response. Together they seek to explain processes of attention ranging from sensitivity to stimulation in general, to selection of wanted inputs. Responses to a series of stimuli will be affected by variation in the subject's level of arousal during the time the stimuli are being presented, the modality from which signals are presented (Broadbent op. cit.) and the mechanics of the detailed analysis and selection of inputs.

The attention theories considered above do not all give explanations suitable for the present data. To be suitable, a theory must explain a cyclical fluctuation in response which varies in period with display luminance. The theories of Triesman and Deutsch and Deutsch relate to the mechanics of selection of the wanted signal from a large number of stimuli, and so do not apply in a situation where all signals are 'wanted' signals, except to explain attention to the display in general. Bakan and Deese concentrate on the effect of feedback from previous responses and serve to explain decrement during performance, but not differences in performance between subjects run under different conditions where such performance does not show a decrement. In addition, none of these theories explains a cyclic fluctuation in attention appearing from the outset of the experimental session.

Broadbent's filter theory describes intermittent interruptions, or blinks, at some point between the sensory perception of a stimulus and its analysis. Performance is noticeably affected only when the task is paced, and compensation between blinks is not possible. Distracting stimuli may cause performance to deteriorate still further by increasing the scanning of irrelevant channels. Blocking is not absolute, so that a particularly intense stimulus will still elicit a response.

This description fits the present data very well, in some respects. Gaps are regular, like blinks, but relate to the signal schedule, in the same way as blinks have an effect related to the paced or unpaced nature of the task. Particularly intense stimuli will end a gap, or prevent a blink. High intensity of display luminance may be compared to some extent with distracting stimuli, in that they both produce a deterioration in observing behaviour. In fact, gaps could be considered to be the evidence of an intermittent disturbance of behaviour caused by long-term blinks.

There are two objections to this view. Firstly, there would seem to be a fundamental difference in nature between a brief blocking, perhaps caused by the scanning of another channel, and the relatively long diminution of response of a gap which lasts for several seconds at least. Secondly, probably most people have experienced a brief blocking of the type Broadbent describes, when trying to perform a task which exceeds channel capacity. Had the subjects in the present experiments experienced this type of blocking it would have been reported during the course of the interviews, at least once. The types of disturbance reported were all of a visual nature, difficulties in focussing, maintaining a clear image, and so on. Broadbent's blinks occur after the process of perception, in the sense of registration of the stimulus by the sense organs, and affect the analysis of the stimulus rather than its perception.

However, if the gaps are evidence of a phenomenon like blinks but on a longer time-scale, the subjective sensation may not be the same as that associated with a blink. Signals may be perceived normally at the periphery of the nervous system, giving the subject the impression that he is observing the display normally, but if analysis is blocked then no response is made to the signal. The effect of increased intensity of display luminance is then to increase the length of these periods of reduced response but the subjective sensations connected with the gaps may not be reported.

The arousal model predicts that intensity of stimulation will determine the level of activation of the organism, in a general sense. These two factors also interrelate, in that stimulation follows a 24-hour cycle and some animals including man deliberately influence the stimuli impingeing on them or their receptivity to the stimuli, in a 24-hour cycle. For example, people intentionally create a situation of partial sensory deprivation when they want to sleep.

The relationship between light intensity and performance, then, is described by an inverted U-curve. The mechanism by which this might be effected is described by Miller (1961) in terms of information input ('bits' per second) but parallels may be drawn in terms of intensity of stimulation as the over-loading factor.

As input is increased:

1) The rate of output follows it exactly in a linear fashion, for a period of time.
2) Output begins to level off until it reaches the channel capacity. This rate is maintained for a time even while input rate increases.
3) Output falls drastically, sometimes even to zero. The system is overloaded.

The role of the reticular system appears to be to react to the total quantity (number of bits) of information coming in through all sensory pathways. When the channel capacity of the decision-making mechanism of the nervous system is exceeded, the reticular system limits the total amount of information over all the modalities by filtering out excess inputs.

The fundamental mechanisms of defence to a situation of sensory overloading are as follows;

1) omission - simply not processing the information.
2) error - processing incorrectly and then not making the necessary adjustment.
3) queuing - delaying responses during peak periods and then catching up during lulls.
4) approximation - a less accurate response is given because there is no time to be precise.

5) filtering - systematic omission of certain categories of information according to some sort of priority scheme.
6) multiple channels - parallel transmission systems.
7) decentralisation - a special case of (6)
8) escape - leaving the situation entirely or taking other steps to effectively cut off the flow of information.

One strategy may be more useful, or more dangerous, than others depending on the situation.

To apply this model to the present results, the basic assumption is made that the high intensities of illumination employed represent an overload of stimulation, since this is the only environmental variable operating between groups of subjects.

Some of the defence mechanisms described are not applicable to the situation; error (except in terms of false responses), queuing (the task was paced), approximation (the reaction required was a simple, not a choice reaction), multiple channels, or decentralisation.

The queuing defence, incidentally, sounds exactly like Broadbent's blinks, but presented here as a deliberate strategy rather than as a block and subsequent compensation.

The omission defence does not fit the facts because if gaps were a complete hiatus in the processing of information, the signal content would be random and it is not (6.16). The only escape defence which would not be observable would be if the subject had closed his eyes during the gap. Apart from the fact that no such behaviour was reported by the subjects (no direct controls were enforced) the same objection applies as to the omission defence.

This leaves the filtering defence, and here two possibilities present themselves. Firstly, the criterion for response might be raised, so that the subject was filtering out weak stimuli and only making decisions on those which were sufficiently strong to satisfy the new criterion. This process allows response to strong signals to end the gap. This would not prevent overloading of primary channel capacity, however, since all signals (or rather, events) would have to be processed intially before being rejected or processed further. Secondly, certain features of the design (for example, the peripheral region) might be ignored for the purposes of signal analysis during the gap, allowing processing only of central signals.

An objection to this model as an explanation of the present results is that it fails to account for a cyclical variation in response. This objection can be accomodated however if it is supposed that the operation of a defence mechanism serves to ameliorate the effects of sensory overload for a time, after which the defence is again invoked. A further assumption must be made, in view of the fact that all groups show the same number of gaps, that increasing degrees of overload do not increase the frequency with which the defence is used, but increase the length of time for which the defence operates. The periods inbetween gaps are then associated with a level of performance common to all groups.

Another problem in the application of this model is that of defining the way in which the subject monitors and guages the degree of overload (or stimulation) provided by the display luminance. This problem is fundamental to all theories of attention and arousal which seek to explain the effect of intensity of stimulation on behaviour.

Physiological studies have shown that if there is any response to steady background illumination, it is in the form of a diminution of response by the nervous system rather than of an increase.

Ditchburn (1973):-

> " Any signal at cortical level must depend on the small differences between the pattern of spikes in the resting discharge of retinal ganglion cells and a pattern which represents steady, uniform illuminance ... At retinal ganglion level, the effect of uniform illumination may be to reduce the resting discharge. "

Burns (1968):-

> " ... all of the many investigations of cortical response to retinal excitation have employed either flashing or moving light as a stimulus because no response to stationary, continuous illumination could be detected."
> " That part of the central nervous system essential to normal perception appears to respond only to local change of retinal illumination."

Continuous information about absolute level of illumination is transmitted, but apparently used at a lower level in the system, for example for the control of the pupillary aperture.

Some response to steady illumination must exist if the results of the present experiments and others like it are to have any meaning. If intensity of illumination, divorced from other factors such as contrast and glare, can be used as an experimental variable and produce significant differences in performance, then there must exist some way in which the subject obtains an absolute measure of intensity even after adaptation has taken place.

The implication is that there are two types of monitor for visual information, using the same basic information in the form of discharge from retinal ganglion cells. One monitors pattern, and the other absolute intensity. It is likely that the two monitors take their information from two different sets of cell fibres, rather than encoding a complex combination of two sets of signals. The system of analysis of discharge appears to depend upon the rate of spiking, measured by the time taken for a group of spikes to occur, rather than upon time intervals between individual spikes (Brindley 1970). This system does not allow minute differentiation between two superimposed patterns. In addition, the specialised receptive fields which respond to onset and cessation of stimulation show little or no response when neighbouring zones are illuminated together.

The intensity monitor, then, controls not only pupillary activity but also arousal mechanisms. The pupillary mechanism is known to have a degree of sophistication demonstrated for example by Fechner's Paradox. The eye is presented with a small, fairly bright source, and the pupil closes to a certain size. When a second, dimmer light is added, at a sufficient distance from the first to stimulate a completely different set of retinal receptors, the pupil does not close further in response to the increased total intensity of light; it opens, to correspond to an intensity which is the average of the two lights. This implies a collection and comparison of information from at least the major part of the retina, surely a relatively high-level process.

The arousal model, then, provides for a cyclical fluctuation in sensitivity to stimulation which is influenced by absolute level of stimulation as well as the information content of perceived stimuli. It does not pretend to offer a complete explanation for attentional phenomena and may be considered in conjunction with a suitable model of attention to encompass both relatively long-term fluctuations in performance, and the mechanism by which individual stimuli are detected or not detected.

2. Response to constant visual stimulation.

In most visual detection experiments the subject is presented with a display in which changes occur only at threshold level. Even assuming that the subject is highly motivated and conscientious, he is unlikely to be able to maintain a constant vigil in all parts of his visual field. It is in the nature of sensory systems that they respond principally to change, and lack of change in input may not only fail to produce a response but may also positively militate against efficient observation.

Troxler reported a disruption of vision with an unchanging visual display in 1804. 'Troxler's effect' does not require perfect fixation to appear; a display with a central fixation point and a small eccentrically placed stimulus is viewed monocularly and the disappearance of the stimulus can be noted. There is an almost linear, positive relationship between visual angle of the stimulus and cumulative duration of disappearance, and an increase in frequency of disappearances with time, but no difference between the nasal and temporal parts of the visual field (Poe and Crovitz 1968).

Clarke and Belcher (1962) carried out experiments to localise Troxler's effect in the visual pathway. They used dark-adapted subjects and a very dim stimulus light at 20^{o} to the line of fixation. Calculations showed that when fade-out occurred, less than one-tenth of the rods in the receptive area were receiving quanta of light and the response caused by fresh rods was clearly being blocked higher up the visual pathway. The area affected by the blocking must be larger than the boundaries of the optical image since otherwise saccades would present the image to non-adapted receptors and disappearance would not occur. Other experiments suggest the lateral geniculate body as the seat of the phenomenon.

Marks (1949) obtained reports from subjects fixating a display of a cross surrounded by a circle. He classified the reported phenomena into four types; movements of the fixation point or changes in its shape, a periodic variation in light intensity or different spatial intensities, partial or complete 'blotting out' of the field, and changes in the shape of the circle.

Cohen (1958) presented subjects with a completely enclosed uniform field in scotopic or photopic conditions, viewed monocularly or binocularly, and with or without a small circle in the centre of the field. He was interested in the occurrence of 'white-out' reported by subjects in a previous experiment, an unusual experience like the cessation of vision. Seven out of thirteen subjects reported the phenomenon in the new experiment. He found that it was more likely to be reported with monocular vision, scotopic intensity of illumination, and in the second half of the experimental session. It occurred less often when the presence of the circular spot reduced the uniformity of the field. Subjects sometimes reported that the field only reappeared after extensive blinking and movements of the eyes. Inhibiting factors were the visibility of parts of the subject's own face and an attitude of search accompanied by considerable eye-movement.

The results of these experiments demonstrate that change over time in the image falling on the receptors is a necessary constituent of normal vision. Even more rigorous conditions are provided by the technique of retinal stabilisation, which is employed to ensure perfect fixation of the presented image on the receptors. The image is transmitted to the eye via a contact lens which when well fixed removes the effects of any eye movement including saccades.

Ditchburn (1973) has summarised the type of experience reported in experiments with stabilised retinal images. Clear vision of the target disappears in 2 - 10 seconds and is only restored by a sudden change in illumination or the position of the target. Loss of pattern perception follows though the resulting grey field may be tinged with the colour of the target. The image may also fluctuate in clearness, and some structures such as curved lines may be more resistant to disappearance than others. Finally a total lack of perception may occur and a very strong stimulus is needed to restore vision. This last type of experience, unlike the others, always occurs in both eyes, suggesting a central cause. Ditchburn proposes a tentative theory to account for this type. The hazy field preceding the effect produces only feeble signals. This leads to a reduction in those signals controlling visual attention, possibly via the reticular formation. This leads to a further loss of intelligible information and so on; a vicious circle is set up. The whole visual perception system becomes inoperative, possibly including repression of resting discharges, since subjects describe what they 'see' as 'blacker than black', perhaps because the weak retinal light caused by noise is no longer perceived.

Experiments using imperfectly stabilised images show similarities with those on stabilised images, though the effects are lessened, except that objects in the extreme periphery disappear almost as quickly. Ditchburn:

> " The low resolving power of the peripheral retina makes the residual eye-movements of fixation insufficient to maintain full visual performance."

A vicious circle may be set up similar to the one postulated for retinal stabilisation conditions. The subjective experience, however, is different, since the 'black field' appearance is not obtained. Ditchburn suggests that the decrease in illumination towards the periphery found in most experimental conditions, and also fluctuations in pupillary diameter causing changes in retinal illuminance, may be sufficient to prevent it. The pupil reflex may still occur because it depends on the chemical state of the receptors rather than on signals received from boundaries of the image, and so is not affected by absence of contrast.

Photo-chemical adaptation appears to continue for several minutes after a stabilised image has become hazy or disappeared, so that the hazy field must be due to a more rapid process. In a stabilised image the signals from the receptors are probably already feeble after 0·1 sec., due to habituation of signals in response to background illumination, and lateral inhibition occurring between ganglion cells receiving signals from the boundaries of the image. Cortical activity probably takes 2 - 3 seconds to decay. Fluctuations in the clarity of the image may be due to fluctuations in the resting discharge of cells at cortical level which respond to specific pattern stimuli.

The idea of central involvement in disappearances is supported by work done on E.E.G. records and stabilised images. In most people, alpha rhythm is found in the dark or when viewing a ganzfeld (unpatterned display). It is partially or completely suppressed when viewing a pattern in normal vision (Adrian and Matthews 1934). The alpha rhythm is correlated with disappearances of the stabilised image and fluctuations of an after-image. Tepaz (1962) found that 'perceptual blanks' experienced when viewing a ganzfeld coincided with increased alpha rhythm, and fluctuations in perception of a target near the threshold of visibility have also been correlated with strong alpha rhythm. This is consistent with two hypotheses: fluctuating signals sent by the retina to the cortex control alpha activity, or fluctuating activity at a central level causes variations in perception even when constant input is received from the retina.

Results do not support one hypothesis exclusively. Cohen found alpha rhythm in only half his subjects even in darkness, but these subjects experienced more white-out, the others rarely reporting it. The oonditions favouring alpha rhythm during the experiment were the same as those favouring white-out, and alpha appeared with fogginess of the field or white-out with a high correlation. Strong alpha activity usually followed the onset of white-out with a latency of about one second, though it did not always persist during the entire white-out, and it then disappeared after the offset of white-out.

On the other hand, Lehmann et al (1956) and Keesey and Nichols (1967) found that the alpha rhythm appeared before disappearance of the stabilised image and ceased before reappearance of the image. This implies central rather than peripheral control of disappearances. This view is supported by other elements in the stabilisation situation. Barlow and Sparrock (1964) measured the apparent luminance of an after-image in relation to that of a stabilised image on an adjacent part of the retina. Both apparent luminances increase and decrease together, supporting the hypothesis of central control of fluctuations. The discrepancy between findings from stabilised image, and ganzfeld situations may result from the difficulties of correlating a physiological measure with verbal reports of experience.

The 'vicious circle' theory does not preclude both central and peripheral involvement, starting with local habituation and building up to complete repression of visual function by central processes if conditions are right. One thing is clear, that in the absence of changing stimulation, visual processes cease to function with full efficiency. This stimulation need not be visual; noise can restore vision of the image in conditions of retinal stabilisation, and this too points to central involvement. Habituation and a more active form of suppression combine to reduce response to uniform stimulation.

In summary, reports of subjects presented with an unchanging visual display show cyclical fluctuations in visual clarity. Since the display used in the present experiments was relatively unstructured, it is possible that the subjects were undergoing similar experiences which caused a regular impairment in efficiency.

Most subjects, however, seemed satisfied that they had been observing the display throughout the session, when interviewed at its conclusion. The most common complaint was of increasing difficulty in maintaining adequate fixation during the course of each trial, and of maintaining sharp focus. The rest periods appear to have restored these functions to normal at the beginning of each trial. The rest periods, and the presence of the fixation point (c.f. Cohen op. cit.) as well as the active performance of a task, probably sufficed to prevent the appearance of the more severe disturbances of function reported in the retinal stabilisation and ganzfeld experiments. Those disturbances which were reported did not appear to have lasted for more than a few seconds at the most and were reported in all groups, so that they are not thought to have affected the results of comparisons between groups.

Whatever caused the gaps in responses by the subjects, it does not seem to have been apparent to them. Answers to questions about the clarity of the display and criteria of response bear a random relationship to detection rate or false responses.

Fluctuations in visual clarity of the type described in this section would explain the regularity of gaps, but not differences in gap length between subjects observed under different conditions of display luminance. Increasing intensity of background illumination does not seem from the literature to increase the frequency or duration of visual disturbance, rather the reverse. Cohen (op. cit.) found white-out more likely to occur with scotopic than with photopic vision, and this suggests at least that the relationship between white-out and display luminance is not a linear one. However, such work does show that central control of visual functioning is possible, and probable, and that gaps could prove to be the evidence of such control.

3. System noise and threshold discriminations.

In any detection task in which signals are presented at an intensity such that the subject's performance shows an efficiency inbetween 0% and 100%, system noise can be considered as a source of variability in response. System noise, a concept first developed in the field of electrical communications, is activity intrinsic to the system which is in a similar form to the signal and reduces its detectability. Detection of a signal depends on discrimination between changes in the background stimulation caused by noise, and those caused by a signal.

Variations in the performance of an hypothetical peffect and noiseless detector will occur only as a result of variance in emission of photons from the signal source, which follow a Poisson distribution. In a living visual system, variations in the detection of a signal image falling on the retina also occur according to the exact momentary state of the receptors upon which it falls, and of the neural components transmitting information about changes, as well as the criteria within which the subject is operating.

Research on visual noise in living systems has proceeded from the observation that there is never a complete absence of activity in the visual system, so that a 'dark light' is always present to reduce efficiency. This phenomenon has already been mentioned in connection with the subjective reports of subjects making observations under conditions of retinal stabilisation. One line of research (Barlow 1958) considers photopigments in the retina as the starting point. Barlow used light stimuli of various sizes, durations and intensities to plot thresholds of detection against a background of varied intensities of luminance within the range of human scotopic vision. From the assumption of an intrinsic retinal noise which has the effect of an even illumination of the retina at all times, he was able to make specific predictions about the mathematical relation between increment thresholds and background intensity. These predictions were upheld experimentally within the range of scotopic vision. He suggested that a thermal breakdown of rhodopsin (resulting from normal body heat) might cause the intrinsic noise and have the effect of a dim illumination on the retina upon which the predictions were based.

Muntz and Northmore(1968) tested this theory of thermal influence by investigating the effect of temperature on the visual thresholds of fresh water turtles. The animals were trained to detect the presence of a spot of light for a food reward. The luminance of the light was held constant but the background luminance and so the contrast, varied. Visual noise would make this discrimination more difficult. The turtles showed a rise in visual threshold as the temperature of the water in which they were immersed was raised, but this occurred only at a very low background luminance. Visual noise was thus shown to be related to temperature, supporting Barlow's theory.

Hubbard (1958) points out that Barlow's theory rests on the assumption that the mechanics of breakdown of rhodopsin in thermal and photic bleaching are the same, causing the same reaction in the rod cell. However, bleaching by light produces all-trans retinene and native opsin, while thermal bleaching produces be-b retinene and denatured opsin, so there is no evidence that bleaching by heat can result in nervous excitation.

Whatever the mechanics of the rhodopsin bleaching, Rushton (1965) has suggested a way in which it might work. When receptors contain some bleached molecules, certain ganglion cells continually receive signals from these receptors. This is not perceived as light normally, because it is constant like a stabilised image. The number of spikes in one of these signals is subject to random fluctuation, and a fresh signal due to an additional stimulus is certain to be perceived only if it produces signals in the ganglion cells much larger than the average, or even momentary, value of the noise. When the signal is about equal, it will sometimes be seen and a frequency-of-seeing curve can be plotted. In this way a very small fraction of bleached molecules can alter the sensitivity by a very large factor.

A possible explanation of Muntz and Northmore's results which takes account of Hubbard's objection and has the advantage of being applicable to the nervous system in general, may be based on the work of Fatt and Katz (1952). They found miniature end-plate potentials in ennervated muscle fibre at the nerve-muscle junction. This spontaneous, random discharge is thought to be due to a slow, continuous leakage of acetylcholine from the nerve terminal. Fatt and Katz state that the discharges are affected by temperature, osmotic pressure, damage to the nerve-ending and stretching of the muscle; all increase the frequency of the discharge.

Li (1959,1961) has directly observed similar events in the cells of the somato-sensory cortex of lightly anaesthetised cats, a kind of 'synaptic noise' which may be due to leakage of humoral transmitters in a similar manner to the leakage at the nerve-muscle junction. The results are more noticeable, however, since most central neurones respond to spatial summation and therefore may respond to 'leakage summation', while the leakage in the motorneurone is well below the level normally necessary for excitation.

Kuffler, Fitzhugh and Barlow (1957) recorded a steady discharge in single ganglion cells in the retina of a decerebrate cat and found that while the resting discharge was constant in mean frequency, precise firing times were random, so that when a change in illumination produced responses superimposed on this background noise, no two responses were alike.

If Barlow's theory is rejected as an explanation of Muntz and Northmore's results, they can still be explained by saying that the turtles experienced more noise not because of thermal decomposition of photopigments, but because the increased temperature increased the frequency of discharge in nerve synapses just as temperature affected discharge in the work of Fatt and Katz. However, this does not explain the fact that the rise in visual threshold occurred only at the lowest intensity of background illumination, unless it is assumed that the discharge does not affect discrimination to such an extent at higher absolute levels of background luminance.

A visible form of visual noise is phosphenes, tiny flashes of light usually seen as moving across the visual field. They are probably what is meant by 'seeing stars' after receiving a blow on the hedd. They are sufficiently stable to be currently considered as a means of providing visual information for the blind and can be produced in man by electrical stimulation of the visual pathways, the occipital cortex and the midbrain, and by pressure on the eyeball.

Gebhard (1953) reports the work of Motokawa. Electrical current was passed through the eye by externally applied electrodes and the voltage increased or decreased until a threshold phosphene was reported. Stimulation was subliminal and intermittent, as excitation occurs only on the make or break of the circuit. Motokawa found that either photic or electrical stimulation lowers the threshold for the other in the production of phopphenes. When electrical stimulation was the sensitising agent, threshold sensitivity to light was measured during forty minutes of dark adaptation. Electrical stimulation was found to lower the threshold for light, during both the rod and the cone portions of the dark-adaptation curve. In the reverse experiment, the thresholds for phosphenes produced by electrical stimulation were found to be lower in the presence of threshold photic stimulation.

Motokawa proposes the ganglion cells of the retina as the probable lucus of the electrical effect. The times observed for the decay of the sensitisation effect are very different for photic sensitisation (10 sec. or more) and electrical sensitisation (about 200 msec.) and he attributes this to the slow rate of photochemical reactions. He argues that if the optic pathways or higher centres were responsible for the process, light and electricity, as sensitising agents, should work in the same way. In addition, if only one eye is illuminated, but electrical phoephene thresholds are measured in both eyes, the threshold lowers only in the illuminated eye.

Motokawa's work is the only indication that visual noise may operate to reduce efficiency in detecting signals at high levels of background illumination. His results reveal the possibility that intensity of illimination may affect the spontaneous production of phosphenes at high intensities of illumination and thus reduce efficiency.

In a signal detection task visual noise might reduce efficiency in one of two ways. If it acts as 'retinal light' as Barlow suggests, increasing the effective luminance of the display above its real level, then presumably it does so over the whole visual field. In Muntz and Northmore's experiment, for example, signals from the area of the retina on which the target spot of light falls, will also be augmented. The ratio of contrast between signal and background luminance is thus reduced, making detection more difficult.

Alternatively, random noise activity may occur only in those receptor systems which are receiving stimulation from the background, the effects of noise in those receptor systems receiving stimulation from the signals being overridden by response to the signal stimuli. The effect however would be identical to the mechanism described above, of reducing the detectability of the signal by decreasing the signal/background ratio.

If Rushton's theory is correct, and if visual noise increases as the number of bleached molecules increases, then visual noise should vary positively with display luminance. This conclusion may also be drawn from Motokawa's work if his results mean that spontaneous production of phosphenes increases with intensity of display luminance. The effect of the increased visual noise will then be to increase variability of response or at least raise threshold, since signal/noise discrimination becomes more difficult.

These predictions are not borne out by the experimental evidence. Muntz and Northmore found a rise in threshold with temperature only under the lower intensity of background illumination. Barlow's work applies only to scotopic vision. Most importantly, data on contrast thresholds as related to the absolute intensity of background illumination (e.g. Blackwell, and the present results) contradict such a view. If visual noise did increase with background illumination sufficiently to reduce detectability of the signal, then the contrast threshold would rise with background illumination. In fact the opposite happens. Presumably the level of intrinsic noise is so low (or the visual system is able in some way to compensate for it) that it is swamped by the response of the visual mechanism to the display and does not represent a sufficiently large proportion of total activity to impair efficiency.

Apart from these considerations, the explanation of visual noise applied to the present results is unsuitable because the difference in response from the subjects in the four groups is in terms of the spacing of responses over time. Whatever causes the gaps, or controls their length, is acting in a fluctuating manner with a period of many seconds. It is difficult to see why interference from system noise, if the level of the latter is controlled by display luminance, should fluctuate in conditions where intensity of display luminance is kept constant throughout the session.

The problem of variability in response: conclusions.

To repeat the findings on gaps once more:

1. They are symptomatic of a cyclical fluctuation in attention which is common to all subjects.
2. They appear an equal number of times in the response patterns of all subjects, irrespective of the display luminance under which the subjects were observed.
3. The groups vary only in the length of gaps shown in their responses.
4. The signal content of gaps of all lengths except gaps of length one signal, is similar.
5. The location of signals detected immediately after a gap is significantly likely to be nearer the fixation point than other signals detected at other times.
6. The frequency of gaps increases within each trial, differentially between groups.
7. Gaps do not represent a complete cessation of activity, since signals from locations near the fixation point rarely appear in the signal content of gaps. Nor do they represent a lack of response exclusively to signals from the periphery of the visual field.

Gaps bear a similarity to the blocking of Broadbent and others, but represent an event on a different time scale. They are also measured in a different way to these other studies, not as a pause in a sequence of responses in a self-paced task, but as the result of an analysis of the patterning of responses in a paced task, over time. The additional dimension of 'easy' and 'difficult' (central and peripheral) signals is also introduced into the analysis, allowing detailed inferences to be drawn about the nature of the process underlying gaps.

The cyclical fluctuation in attention which reveals itself as gaps, is a partial and selective failure to complete the process of perception, filtering and analysis of the signals presented, at regular intervals during the course of performance. The time-period of the cycle is of the order of many seconds. In terms of subjective experience, the sensation may be indistinguishable from that of normal observing behaviour, or it may be so much part of normal experience that it does not seem to the subjects to call for comment.

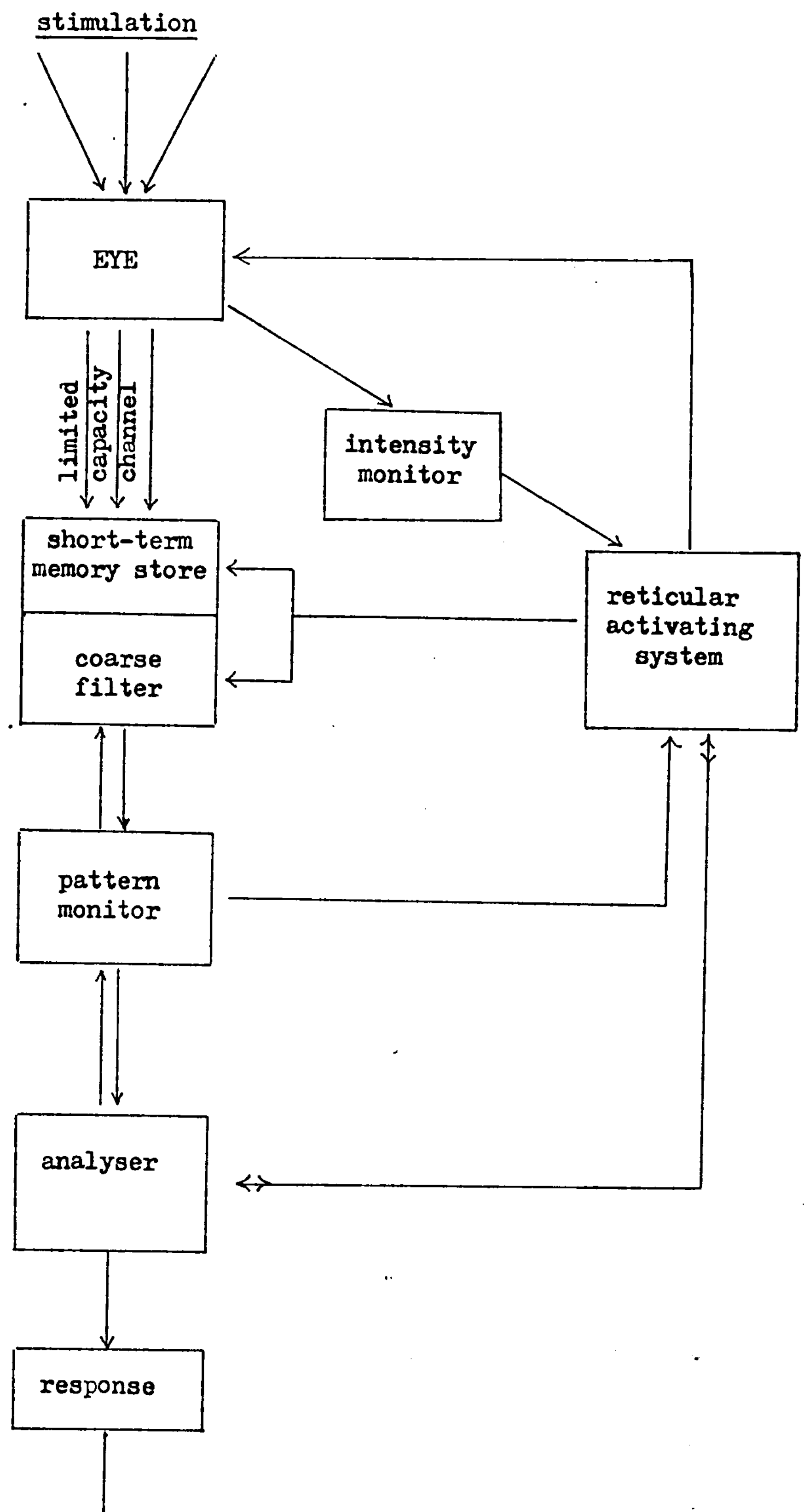
Several explanations for this phenomenon have been considered, and nearly all rejected in their original form because they do not involve a cyclical fluctuation, or because they bear no apparent relationship to intensity of display luminance, or because they would predict an all-or-none type of fluctuation which is inappropriate here.

A general model may however be tentatively proposed which encompasses two complementary explanations, Malmo's arousal model and a version of Broadbent's filter theory, with Miller's account of the defences to sensory overloading as the intermediary mechanism. (Figure 16.)

When stimuli impinge upon the retina they are encoded into electrical signals, which are stored in a short-term memory store in some form. The information then passes through the first filter where an initial selective operation is performed according to gross physical characteristics, selected for either meaning

Figure 16.

Model.



or novelty value. The selectinn for meaning is pre-set, either temporarily (the 'wanted' signal for example) or permanently (the sight of one's own name or a particularly important object or person). The selection for novelty value may also be permanent or temporary. Permanent selections would include sudden changes in stimulation, an important requirement for survival. The temporary selection would be prompted by a search for novelty for its own sake, initiated by higher centres, as we shall see.

The information selected by this coarse filter then passes through the pattern monitor on its way to higher centres. The pattern monitor judges the degree of patterning of the information as a whole. It might seem that the pattern monitor could come before the coarse filter in the chain, but this is not the case. The coarse filter first decides on the degree of patterning relevant to the situation. What would seem like very little patterning of stimulation to a person going about their ordinary business would seem like a great deal to the subject of a sensory deprivation experiment, for example.

Information passes from the pattern monitor to the reticular activating system to help determine the level of arousal, but not completely, as the intensity monitor and auto-arousal both also play a part. Information is then fully analysed and a decision made whether or not to respond to the stimulus. This process also serves to stimulate the R.A.S.

Returning to the eye again, information about absolute intensity of stimulation is passed to the intensity monitor and thence to the R.A.S. At the same time, messages in the reverse direction, and possibly from a higher source, control the pupillary reflex.

The mechanics of sensory overloading and possibly to some extent of normal perception, are as follows. The R.A.S., bombarded with an excess of stimulation from the intensity monitor, the pattern monitor, or both, brings defensive mechanisms into play, their nature depending on the severity of the situation. Efferent fibres from the higher centres to the periphery of the nervous system are known to exist, and may even help the R.A.S. to shut down the initial processing of information if necessary, as in retinal stabilisation and ganzfeld experiments. In less extreme situations, the R.A.S. can cut down activity in the different components of the chain, perhaps starting with higher functions. Thus analysis may be curtailed or stopped. It is interesting to speculate on the subjective sensation associated with the curtailment of analysis; the subject may be unaware of the event. With partial curtailment the effect will be an increased selectivity of response, when only some classes of stimulus will produce a response ('filtering') or else 'error' when selection becomes indiscriminate.

At a lower level the R.A.S. decreases the time for which information is held in the short-term memory store, allowing a fast turnover but a loss of information causing error or omission. Some information may simply be lost altogether. Queuing may be effected by increasing the time information is held in store, but for short periods only as the store has a limited capacity.

The system may reach a state of long-term equilibrium. As the R.A.S. cuts down the amount of information being processed, the pressure eases until the defence is no longer needed. The controls are relaxed, the pressure builds up again, the defence is operated, and so on, in a regular cycle.

Low levels of stimulation (the first part of the arousal 'inverted U-curve') will also find an explanation in the model. As stimulation decreases (this time conveyed solely by the pattern monitor) the filter and analyser are set to accept all information and the level of stimulation required from the pattern monitor to maintain arousal is decreased. Selectivity becomes marginal. It is known that subjects in sensory deprivation experiments will sleep a lot at first (Vernon 1963), this mechanism having failed to maintain wakefulness because controls have not been sufficiently reset to meet the demands of the new situation, but then cannot sleep. The R.A.S. presumably prevents too much sleep as it may be harmful to the organism; if self-arousal is not achieved in the absence of external stimulation, the organism could fail to carry out its normal functions. The subject will eventually provide his own stimulation in the form of colourful dreams when he does sleep, daydreams, talking aloud and in extremes, hallucinations. The balance of arousal having been disturbed, the subject could develop the same psychotic personality as he would after a long period of sleep deprivation. Under more normal circumstances the system will find its own equilibrium in the same way as when it is over-stimulated.

The mechanism of gaps specifically can be explained as follows. As the R.A.S. receives strong stimulation from the intensity monitor, periodically one part of the system, probably the analyser since the subject appears to be unaware of the change, is reset to process fully only selected signals. The instructions may relate to the peripheral area of the display, or more probably the 'strength' of the signal. Some selectivity does continue to function, since strong signals still produce a response which ends the gap. This reduction in analysis eases the load on the system (reducing stimulation to the R.A.S.) and instructions are then reversed. This may even be a normal process, when continual top capacity processing of information constitutes a strain on the system. In addition (to accomodate scanning) the coarse filter may be reset in respect of novel stimuli, irrelevant stimuli which would normally be disregarded being processed and the novelty in some way providing relief from strain perhaps because slightly different functions are being carried out.

The more intense the stimulation (in this case display luminance) and therefore the more intense the bombardment from the intensity monitor, the longer the R.A.S. operates the defence mechanism before equilibrium is temporarily restored.

The mechanism by which personality variables have their effect may be that they influence the range of stimulation the R.A.S. will accept before bringing defence mechanisms into force.

The implications of response variability.

1. Experimental design and analysis.

The type of response variability which analysis of gaps reveals may occur in many different experimental situations, and be susceptible to various experimental variables. Design requirements for its interpretation may be specified exactly. Signals should be brief and near 50% threshold value, so that fluctuations in response threshold will become apparent in terms of detection rate. They should also be presented as regularly as possible without inducing the subject to indulge in too much 'guessing' about the time of the next signal, and sufficiently frequently for the subject to remain motivated to perform the task.

The recording of responses must be in chronological form, so that gaps can be counted and their length analysed. Analysis is simple, commencing with an assessment of the subject's responses over time to see how they deviate from the norm associated with his detection rate. If the detection rate of all subjects is comparable, gap frequency and length can then be correlated with experimental variables. Analysis of the signal content of the gaps will reveal the kind of variability that is presented.

2. Tasks performed under high intensities of illumination.

The consequence of response variability in many industrial situations will be harmful to task performance. Where the stimulus to be detected is weak, brief, or in the periphery of vision, performance will be impaired by high intensities of display illumination. Examples of such tasks are the inspection of small objects (sometimes at such speed that the stimulus is both brief and partly in the periphery of vision) and the monitoring of displays.The operator will suffer regular periods of raised threshold to important signals. Even where the signal remains present until detected, a delay will be caused during the period of raised threshold. In other circumstances a decreased consistency of threshold will result. These effects may increase in severity during a period of prolonged monitoring. If distractions are present, they may prove more effective under conditions of high intensities of illumination than they would otherwise do. The conclusion to be drawn is that where optimum intensities of illumination have been established, they should not be exceeded, even where no complaints have been voiced by the operator. The present evidence suggests that the deleterious effect of high intensities of illumination may not be noticed by the operator, who may think his performance is being maintained at an optimum level.

Conclusions

Conclusions

The starting point for the present study was a general enquiry into the effect of high intensities of luminance on task performance. The task chosen was the detection of transient light signals in an illuminated display encompassing the whole of the subject's visual field.

Experimental conditions were designed to test one particular prediction from previous work, that high intensities of environmental stimulation tend to reduce the range of cues utilised from the environment in performance of a task. In the case of high intensities of luminance the prediction would be of a reduction in the size of the visual field.

The data produced did not bear out this prediction. Although subjects observed under comparatively higher intensities of display luminance did show decreased response to peripheral signals, the effect was not that of a reduction in the size of the visual field. Instead, these subjects showed a decreased consistency of response so that their detection rate for peripheral signals was lower than that of subjects observed under comparatively lower intensities of display luminance, but not in a sufficiently clear-cut fashion with respect to location to be 'tunnel vision' as predicted.

This decreased consistency of response was found to be due to a difference in the temporal pattern of response. All subjects showed a regular cyclic fluctuation in responsiveness to all signals. While the frequency of the fluctuation was the same for all subjects, in the case of the higher luminance subjects the periods of reduced responsiveness lasted for a longer time. This caused a greater inconsistency in response.

The difference in temporal patterning of responses between groups was demonstrated to be due solely to intensity of background luminance, and not to other factors such as signal/background contrast ratio. However, there was also a correlation between patterning of responses and score on the neuroticism scale of the Eysenck Personality Inventory, which suggests that the effects of the environmental variable of display luminance may be mediated by personality characteristics.

No effect of time on detection rate over the experimental session was found. However, during each trial the periods of reduced responsiveness did increase for most groups, reducing the number of detections made.

Analysis of reaction time data was able to discriminate between display luminances, and trials. As display luminance increased, subjects gave fewer short reaction times and more long ones. During the course of a session of four trials, subjects gave fewer short times and more medium times. There was no difference between groups in this respect.

The effect of display luminance appears mainly in changes in the temporal patterning of responses and in the length of reaction times. There was no definite tunnel-vision effect.

Increasing intensity of display luminance appears to have accentuated a phenomenon occurring in the results of all subjects, namely the cyclic fluctuation in response threshold. This effect may also be mediated by the personality variable of neuroticism.

It is not possible to say from the present data whether or not these fluctuations would appear in the results of subjects observed over a very wide range of display luminances. The type of analysis presented here does not appear to have been used before in conjunction with this type of data, and so comparisons cannot be made. However, it would seem from studies of response thresholds in general, very likely that such fluctuations would be found. It also seems likely that analysis of fluctuations would reveal a sensitivity to variations in display luminance over a wide range, and to other environmental variables as well. It is essential though that the groups of subjects so compared should be comparable in terms of detection rate, so that the frequency of the fluctuation be preserved. The length of time for which the periods of reduced sensitivity last can then be measured as an indicant of the effect of the environmental variable.

Variability is known to be an essential feature of the nervous system, and knowledge is accumulating about different types and frequencies of variation. This thesis demonstrates a method of analysis revealing a frequency of variation apparently not previously described. The analysis may be applied to data from experiments in all sensory modalities.

The effect of decreased consistency of response demonstrated would seem to have a deleterious effect on performance on many tasks, reducing the amount of time for which the operator is performing at an optimum level, or even causing him to miss important signals. The intensities of display luminance employed in the experiments are equivelant to the illumination levels in many offices, and the higher ranges to illumination on specialised tasks involving fine detail such as inspection and assembly work on small objects such as electrical components. In other circumstances, the illumination levels for which facilities have been designed may be temporarily exceeded by daylight illumination through windows; and luminanee values depend on the reflectivity of the surface viewed as well as illumination intensity. Out of doors, the luminance value of the sky can easily exceed the values used in the experiments, even on an overcast day. This could be especially important for drivers viewing a high proportion of sky through their windscreens or for those working out of doors.

Several areas of research have been considered in a search for an explanation of the cyclic fluctuations found in the present data. Most have been rejected because they predict an inappropriate type of fluctuation, or bear no apparent relationship to intensity of display luminance. A tentative model has been constructed from elements of arousal theory, a model of attention and an account of the effects of sensory overloading. The model is based on the assumption that some mechanism exists which monitors absolute intensity of stimulation, an assumption made in many experimental hypotheses but as yet only tenuously supported by physiological evidence. The model includes provisions for auto-arousal, important in that personality variables play a part in detection performance, as does motivation.

Bibliography

Bibliography.

Adrian, E.D. and Matthews, B.H.C. (1934) The Berger rhythm: potential changes from the occipital lobes in man. Brain, 57, 355-385.

Bahrick, H.P., Fitts, P.M. and Rankin, R.E. (1952) Effect of incentives upon reactions to peripheral stimuli. J. Exp. Psych. 44, 400-406.

Bakan, P. (1955) Discrimination decrement as a function of time in a prolonged vigil. J. Exp. Psychol., 50, 387-390.

Bakan, P. (1959) Extraversion-introversion and improvement in an auditory vigilance task. Brit. J. Psychol., 50, 325-332.

Baker, C.H. (1958) Attention to visual displays during a vigilance task. Brit. J. Psychol., 49, 279-288.

Baker, W.J. and Theologus, G.C. (1972) Effects of caffeine on visual monitoring. J. Appl. Psychol., 56, 422-427.

Barlow, H.B. (1958) Temporal and spatial summation in human vision at different background intensities. J. Physiol., 141, 337-350.

Barlow, H.B. and Sparrock, J.M.B. (1964) The role of after-images in dark adaptation. Science, 144, 1309-1314.

Berkun, M.M. (1964) Performance decrement under psychological stress. Human Factors, 6, 21-30.

Berlyne, D.E. (1960) Conflict, arousal and curiosity. New York, McGraw Hill.

Bertelson, P. and Joffe, R. (1963) Blockings in prolonged serial responding. Ergonomics, 6, 109-116.

Bills, A.G. (1931) Blocking: a new principle in mental fatigue. Amer. J. Psychol., 43, 230-245.

Blackwell, R. (1959) Development and use of a quantitative method for specification of interior illumination levels on the basis of performance data. Illum. Eng., June.

Bodmann, H.W. (1967) Quality of interior lighting based on luminance. Trans. Illum. Eng. Soc., 32, 22-40.

Boyce, P.R. (1970) The influence of illumination level on prolonged work performance. Lighting Res. and Tech., ii, 74.

Boyce, P.R. (1973) Age, illuminance, visual performance and preference. Lighting Res. and Tech., 5, 3, 125-144.

Boynton, R.M. and Boss, D.E. (1971) The effect of background luminance and contrast upon visual search performance. Illum. Eng., 1, 173-186.

Brindley, G.S. (1970) Physiology of the retina and visual pathway. 2nd. Edn. London, Edward Arnold.

Broadbent, D.E. (1953) Noise, paced performance and vigilance tasks. Brit. J. Psychol., 44, 295-303.

Broadbent, D.E. (1958) Perception and communication. London, Pergamon Press.

Bruner, J.S., Matter,J. and Papanek, M.L. (1955) Breadth of learning as a function of drive level and mechanisation. Psychol. Rev., 62, 1-10.

Buck, L. (1966) Reaction time as a measure of perceptual vigilance. Psychol. Bull., 65, 291-308.

Bulger, P.M.J. (1972) The effects of random vibration on the 'tunnel vision' phenomenon. Human Response to Vibration: Conference. Spt. 1972, Sheffield.

Burns, B.D. (1968) The uncertain nervous system. London, Edward Arnold.

Bursill, A.E. (1958) The restriction of peripheral vision during exposure to hot and humid conditions. Quart. J. Exp. Psychol., 10, 113-129.

Callaway, E. and Dembo, D. (1958) Narrowed attention. Arch. Neurol. Psychiat., 79, 74-90.

Claridge, G.S. (1967) Personality and arousal: a psycho-physiological study of psychiatric disorder. London, Pergamon Press.

Clarke, F.J.J. and Belcher, S.J. (1962) On the localisation of Troxler's effect in the visual pathway. Vision Res., 2, 53-68.

Cohen, W. (1958) Some perceptual and physiological aspects of uniform visual stimulation. Office of the Surgeon-General, Dept. of the Army, Progress Report no. 1, Res. and Dev. Div., Ref. ACSIL/60/1771.

Colquhoun, W.P. (1959) The effects of a short rest pause on inspection efficiency. Ergonomics, 2, 367-372.

Conrad, R. and Hille, B.A. (1954) Comparison of paced and unpaced performance at a packing task. Occup. Psychol., 29, 15-28.

Cornsweet, D.M. (1969) Use of cues in the visual periphery under conditions of arousal. J. Exp. Psych., 80, 14-18.

Davies, D.R. and Tune, G.S. (1970) Human vigilance performance. London, Staples Press.

Ditchburn, R.W. (1973) Eye movements and visual perception. Oxford, Clarendon Press.

Easterbrook, J.A. (1959) The effect of emotion on cue utilisation and the organisation of behaviour. Psychol. Review, 66.

Engel, F.L. (1971) Visual conspicuity, directed attention and retinal locus. Vision Research, 11, 6, 563-575.

Eysenck, H.J. (1973) Eysenck on extraversion. London, Crosby Lockwood Staples.

Eysenck, H.J. and Willett, R.A. (1964) Cue utilisation as a function of drive: an experimental study. Percept. Mot. Skills, 15, 229-230.

Fatt, P. and Katz, B. (1952) Spontaneous threshold activity at motor nerve endings. J. Physiol., 117, 109-128.

Gebhard, J.W. (1953) Motokawa's studies in electric excitation of the human eye. Psych. Bull., 50, 73-111.

Hammerton, M. and Tickner A.H. (1969) An investigation into the effects of stress upon skilled performance. Ergonomics, 12, 851-855.

Hockey, G.R.J. (1970) Signal probability and spatial location as possible bases for increased selectivity in noise. Quart. J. Psych., 22, 37-42.

Hubbard, R. (1958) The thermal stability of rhodopsin and opsin. J. Gen. Physiol., 42, 259-280.

Jerison, H.J. and Pickett, R.M. (1963) Vigilance: a review and re-evaluation. Human Factors, 5, 211- 238.

Keesey, U.T. and Nichols, D.J. (1967) Fluctuations in target visibility as related to the occurrence of the alpha component of the electroencephalogram. Vision Research, 7, 859-879.

Kuffler, S.W., Fitzhugh, R. and Barlow H.B. (1957) Maintained activity in the cat's retina in light and darkness. J. Gen. Physiol., 40, 683-702.

Lehmann, D., Beeler, G.W. Junior, and Fender D.H. (1965) Changes in patterns of the human electroencephalogram during fluctuations of perception of stabilised retinal images. Electroenceph. Clin. Neurophysiol., 19, 336-343.

Li, C-L. (1959) Cortical intracellular potentials and their responses to strychnine. J. Neurophysiol., 22, 4, 436-450.

Li, C-L. (1961) Cortical intracellular synaptic potentials. J. Cell and Comp. Physiol., 58, 2, 153-168.

Lie, I. (1969) The momentary sensitivity curve of the retina: an approach to the study of attention. Studia Psychologica, xi, 2, 157-160.

Liebowitz, H.W. and Appelle S. (1969) The effect of a central task on luminance thresholds for peripherally presented stimuli. Human Factors, 11, 387-392.

Lion, J.S. (1964) The performance of manipulative and inspection tasks under tungsten and fluorescent lighting. Ergonomics, 7, 51-62.

Loeb, M. and Jeantheau, G. (1958) The influence of noxious environmental stimuli on vigilance. J. Appl. Psychol., 42, 47-49.

Mackworth, N.H. (1965) Visual noise causes tunnel vision. Psychonomic Science, 3, 67-68.

Malmo, R.B. (1959) Activation: a neurophysiological dimension. Psychol. Review, 66, 367.

Marks, M.R. (1949) Some phenomena attandant on long fixation. Am. J. Psych., 62, 392-398.

Marsden, A.M. (1964) Factors affecting fine visual discrimination. E.R.S. Industrial Section Meeting, June 1964.

Miller, J.G. (1961) Sensory overloading. In: Flaherty (Ed.) Psycho-physiological aspects of space flight. Columbia Univ. Press.

Mostofsky, D.I. (1970) Attention: contemporary theory and analysis. Appleton Century-Crofts.

Muntz, W.R.A. and Northmore, D.P.M. (1968) Background light, temperature and visual noise in the turtle. Vision Res., 8, 787-800.

Murrell, K.F.H. (1962) Operator variability and its industrial consequences. Int. J. Prod. Res., 1(3), 39.

Nicely, P.E. and Miller, G.A. (1957) Some effects of unequal spatial distribution on the detectability of radar targets. J. Exp, Psych., 53, 195-198.

Osterberg, G. (1935) Topography of the layer of rods and cones in the human retina. Acta. Opthal., Supplement 6.

Poe, D. and Crovitz, H.F. (1968) Measurements of Troxler's effect. Psychonomic Science, 11, 123-124.

Postman, L. and Bruner, J.S. (1948) Perception under stress. Psychol. Review, 55, 314-323.

Rushton, W.A.H. (1965) Bleached rhodopsin and visual adaptation. J. Physiol., 181, 645-655.

Sanders, A.F. (1963) The selecetive process in the functional visual field. Institute for Perception RVO-TNO. Nat. Def. Res. Org., Soesterberg, the Netherlands.

Saunders, J.E. (1969) The role of the level and diversity of horizontal illumination in an appraisal of a simple office task. Ligthing Res. and Technol., 1, i, 37.

Schmidt, H-E. (1964) Relation of the narrowing of the visual field with an increase in distance to manifest anxiety. J. Exp. Psychol., 68, 334-336.

Solso, R.L., Johnson, J.E. and Schatz, G.C. (1968) Perceptual perimeters and generalised drive. Psychonom. Sci., 13, 71-72.

Spicer, P. Research into factors affecting the detection of aircraft through optical sights. Study note no. 4: Evaluation of the importance of illumination, background type and contrast on the measurement of visual acuity. B.A.C. Bristol, L50/20/PHY/186/1067.

Tepas, D.J. (1962) In: Visual problems of the armed forces, NAS-NRC Publication 21-25 Washington D.C., U.S.A. Cited by Ditchburn (1973).

Theologus, G.C., Wheaton, G.R. and Fleishman, E.A. (1974) Effects of intemittent, moderate intensity noise stress on human performance. J. Appl. Psychol., 59, 5, 539-547.

Tinker, M.A. (1952) The effect of intensity of illumination upon speed of recognition of reading six-point italic print. Amer. J. Psychol., 65, 600.

Tolman, E.C. (1948) Cognitive maps in mice and men. Psychol. Review, 55, 314-323.

Vernon, J. (1963) Inside the black room. London, Pelican Books.

Webster, R.G. and Haslerud, G.M. (1964) Influence on extreme peripheral vision of attention to a visual or auditory task. J. Exp. Psychol., 68, 269-272.

Weltman, G. and Egstrom, G.H. (1966) Perceptual narrowing in novice divers. Human Factors, 8, 499-506.

General and statistical references not cited in the text.

Adler, F.H. and Fliegelman, M. (1934) Influence of fixation on the visual activity. Arch. Upthal., 12, 475-483.

Beck, S.D. (1963) Animal Photoperiodism. New York, Rinehart and Winston.

Buckner, D.N. and McGrath, J.J. (Eds.) (1963) Vigilance: a symposium. New York, McGraw-Hill.

Burg, A. (1968) Lateral visual field as related to age and sex. J. Appl. Psychol., 52, 10-15.

Davson, H. (1962) The Eye. Oxford, Pergamon Press.

Duke-Elder, (1968) System of Upthalmology Vol. IV. The physiology of the eye and of vision. London, Henry Kimpton.

Edwards, A.L. and Horst, P. (1950) The calculation of sums of squares for interactions in the analysis of variance. Psychometrika, 15, 1, 17-24.

Fry, G.A. (1970) Definition of the limits of the field of view. Illum. Eng., 65, 559-560.

Galan, F. (1968) Normal fields of vision with Goldmann perimetry. Mod. Probl. Opthal., 6, 52-61.

Hopkinson, R.G. and Collins J.B. (1970) The ergonomics of lighting. London, MacDonald.

Johnston, D.M. (1965) A preliminary report on the effect of smoking on the size of visual fields. Life Sciences, 4, 2215-2221.

Yves Le Grand, (1970) An introduction to photobiology: the influence of light on life. London, Faber and Faber.

Luce G.G. and Segal J. (1967) Sleep. London, Heinemann.

McNemar, Q. (1962) Psychological statistics. New York, John Wiley.

Motokawa, K. (1970) Physiology of colour and pattern vision. Tokyo, Igaku-Shoin.

Nashold, B.S. (1970) Phosphenes resulting from stimulation of the midbrain in man. Arch. Opthal., 84, 433-435.

Norman, D. (1969) Memory and attention. New York, John Wiley.

Orme, G.E. (1969) Time, experience and behaviour. London, Iliffe.

Philpott, S.J.F. (1933) A theoretical curve of fluctuation of attention. Brit, J. Psychol., 25, 221.

Siegel, S. (1956) Nonparametric statistics for the behavioural sciences. New York, McGraw-Hill.

Stone P.T. and Groves S.D.P. (1968) Discomfort glare and visual performance. Trans. Illum. Eng. Soc. (London) 33, 9-15.

Winer, B.J. (1971) Statistical principles in experimental design. 2nd. edn., New York, McGraw-Hill.

Woodworth R.S. and Schlosberg, H. (1966) Experimental Psychology. London, Methuen.

Appendix A

◇ 120 cd/m^2

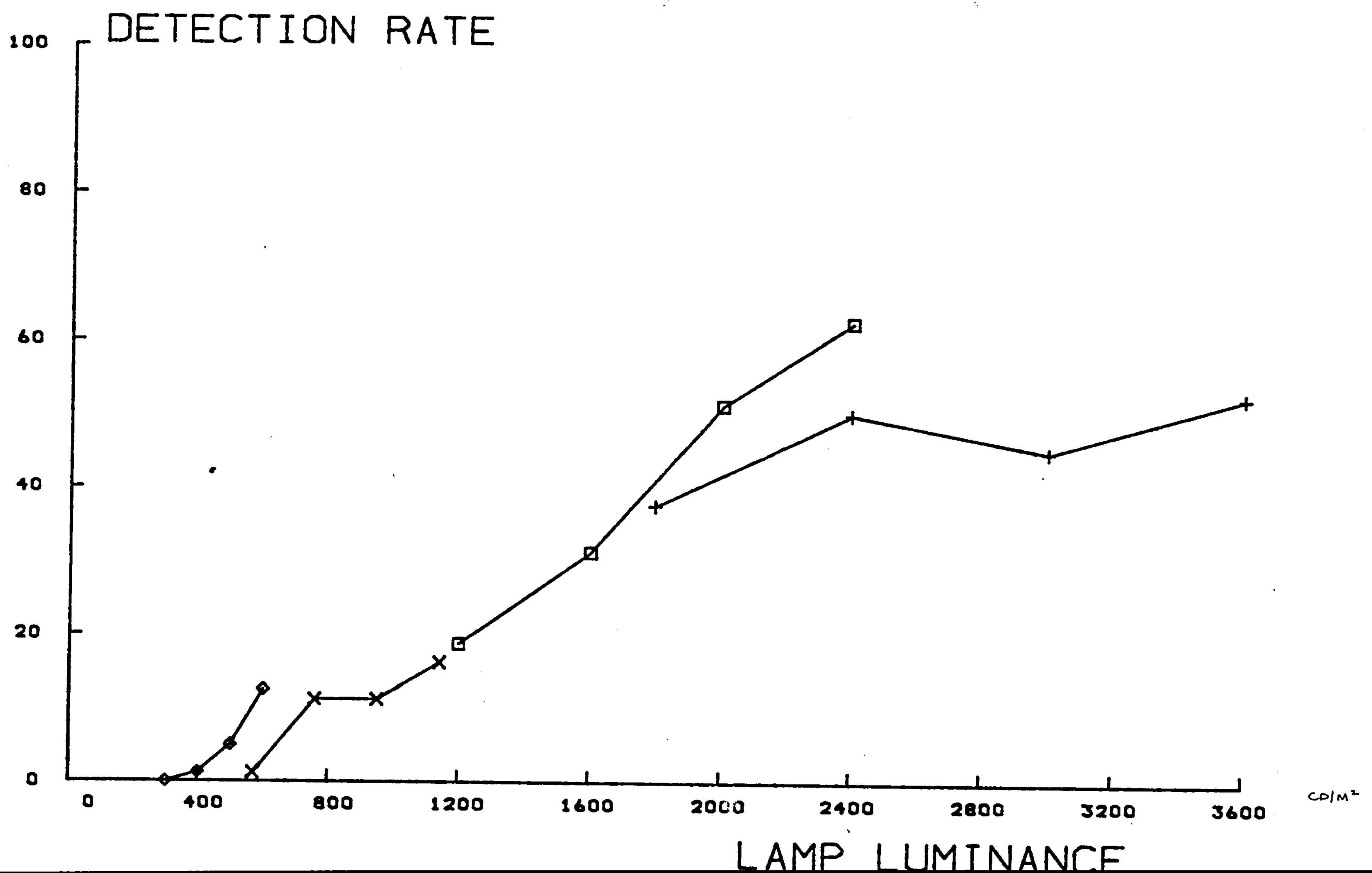
× 280

□ 440

+ 600

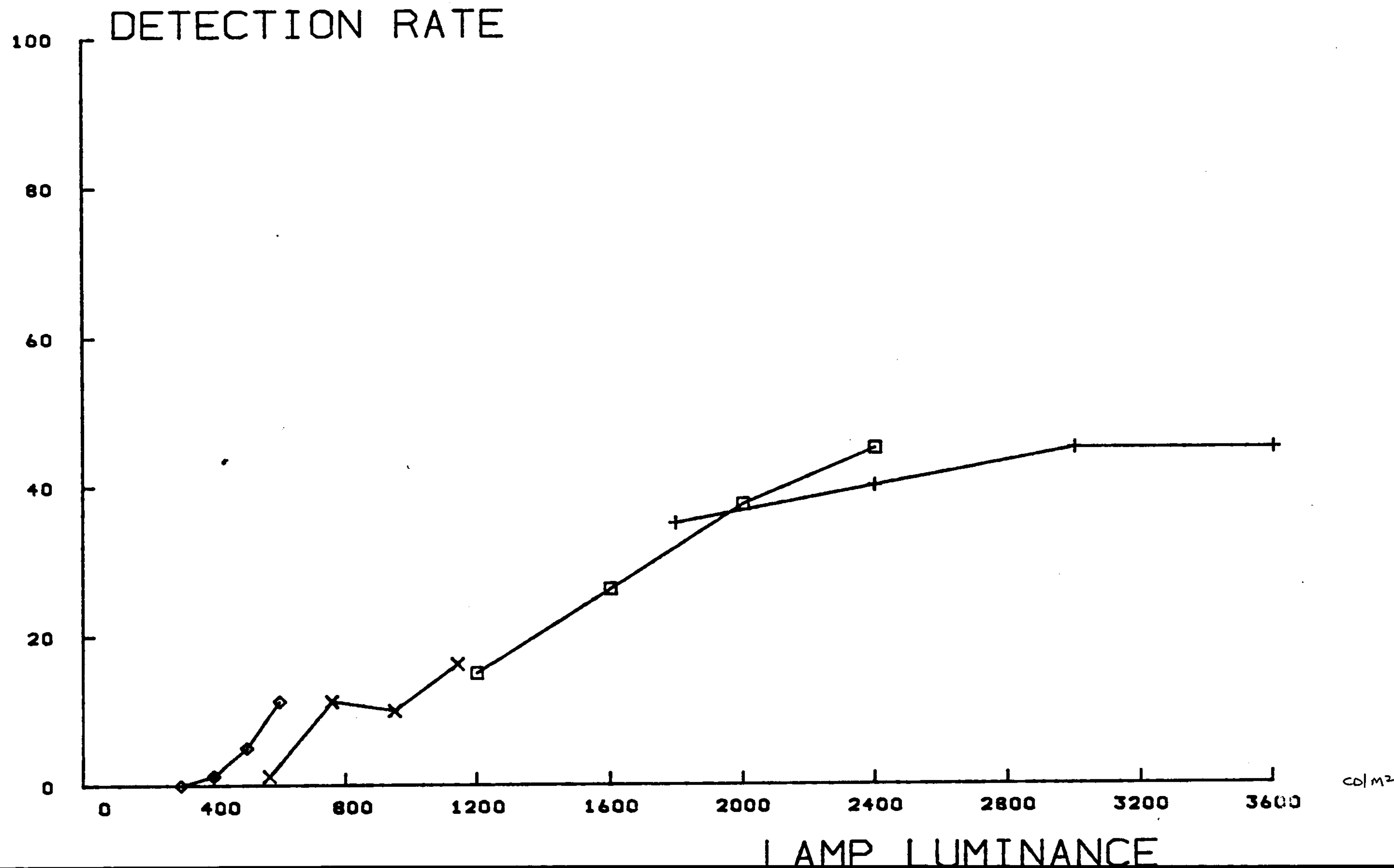
Appendix A - graph 1.

Detection and lamp luminance - all signals



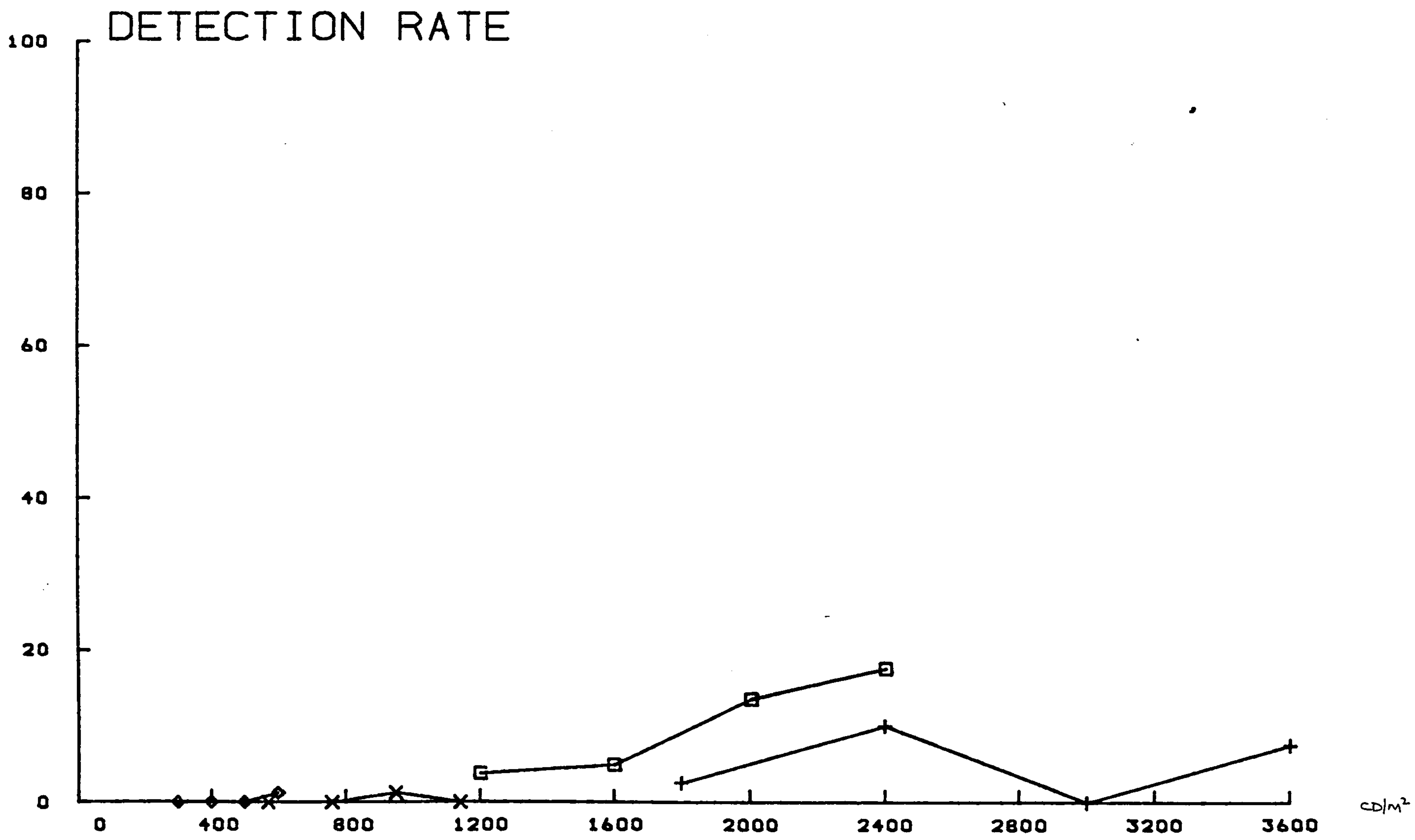
Appendix A - graph 2.

Detection and lamp luminance - central



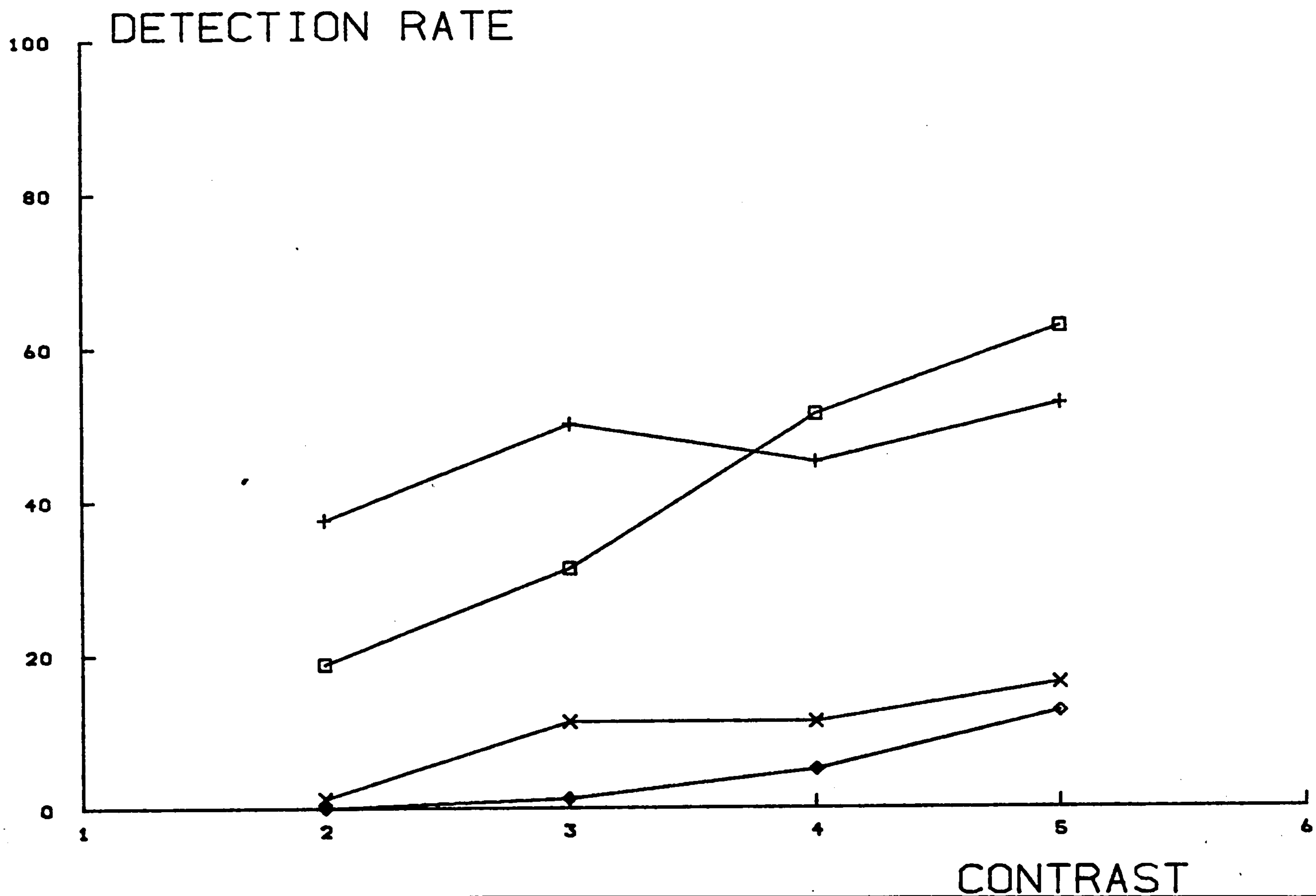
Appendix A - graph 3.

Detection and lamp luminance - peripheral



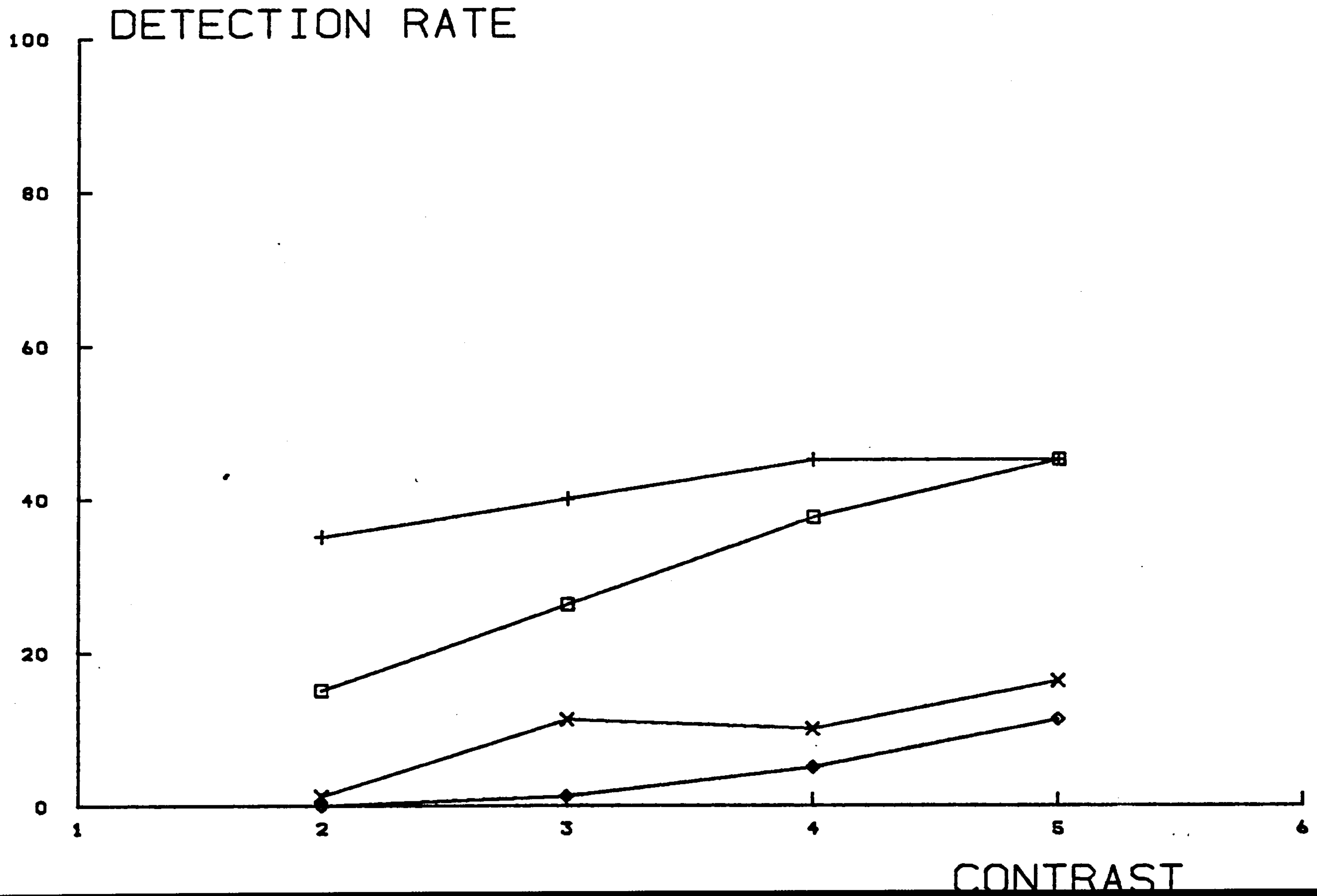
Appendix A - graph 4.

Detection and contrast - all signals.



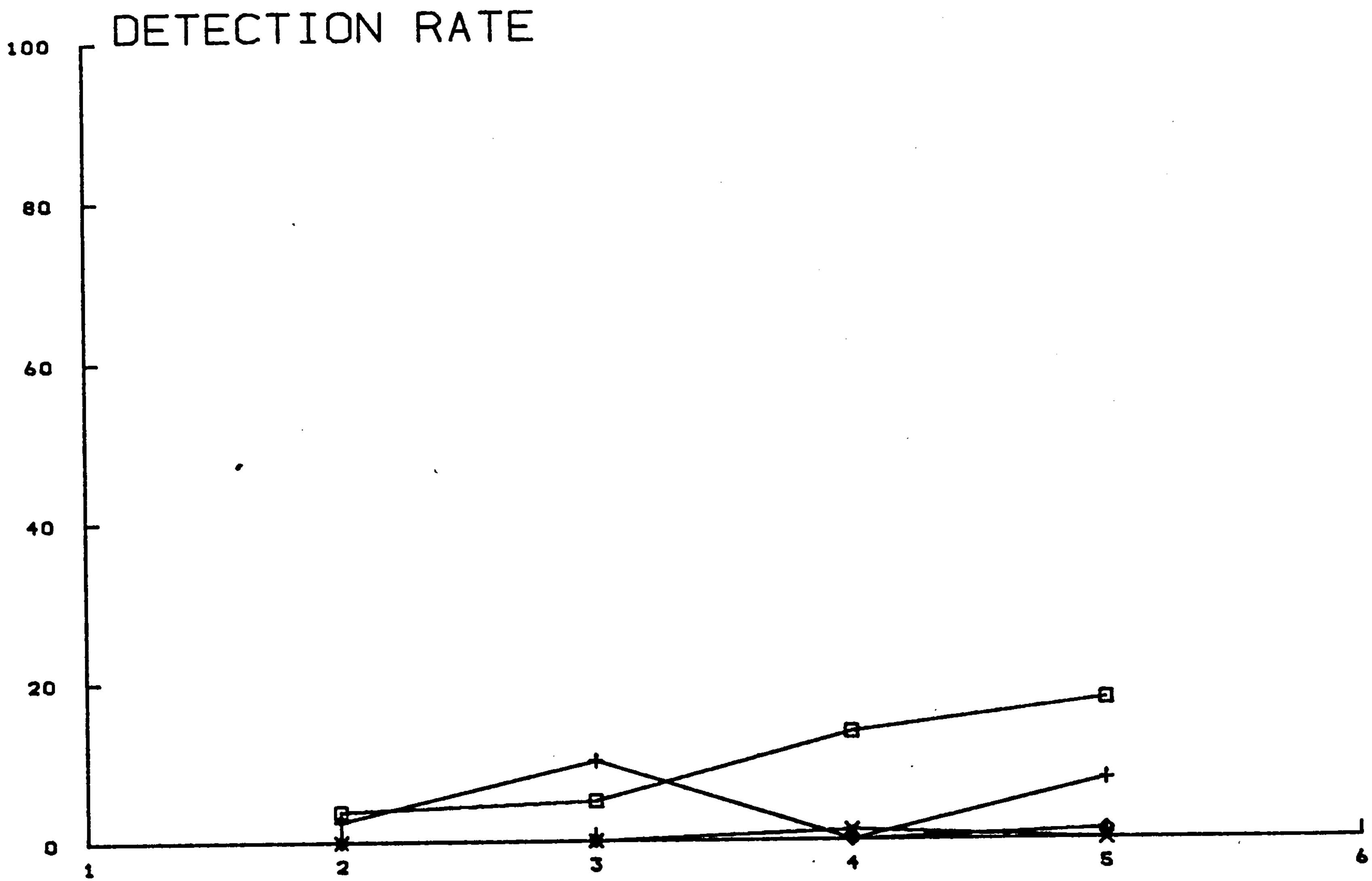
Appendix A - graph 5.

Detection and contrast - central.



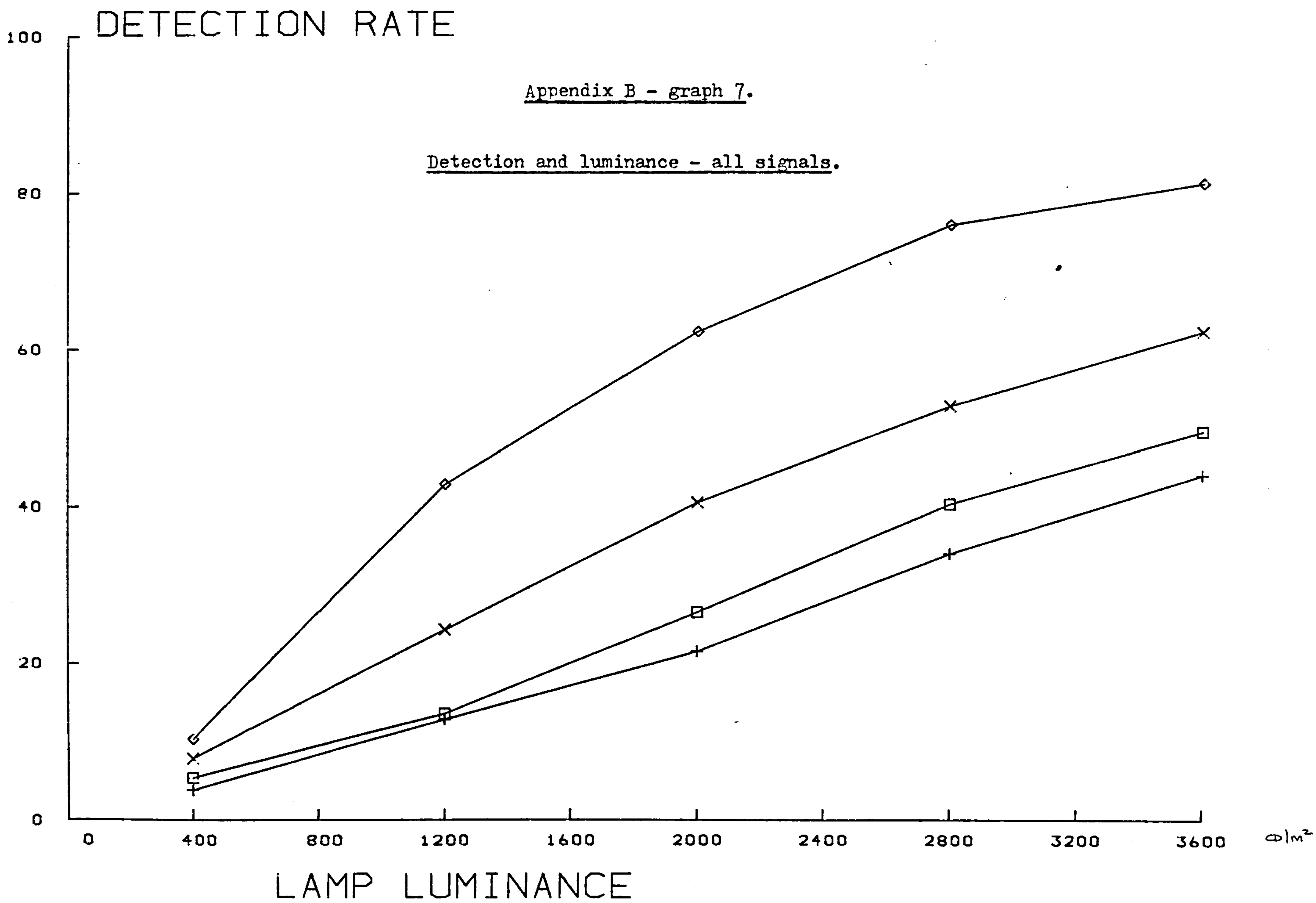
Appendix A - graph 6.

Detection and contrast - peripheral

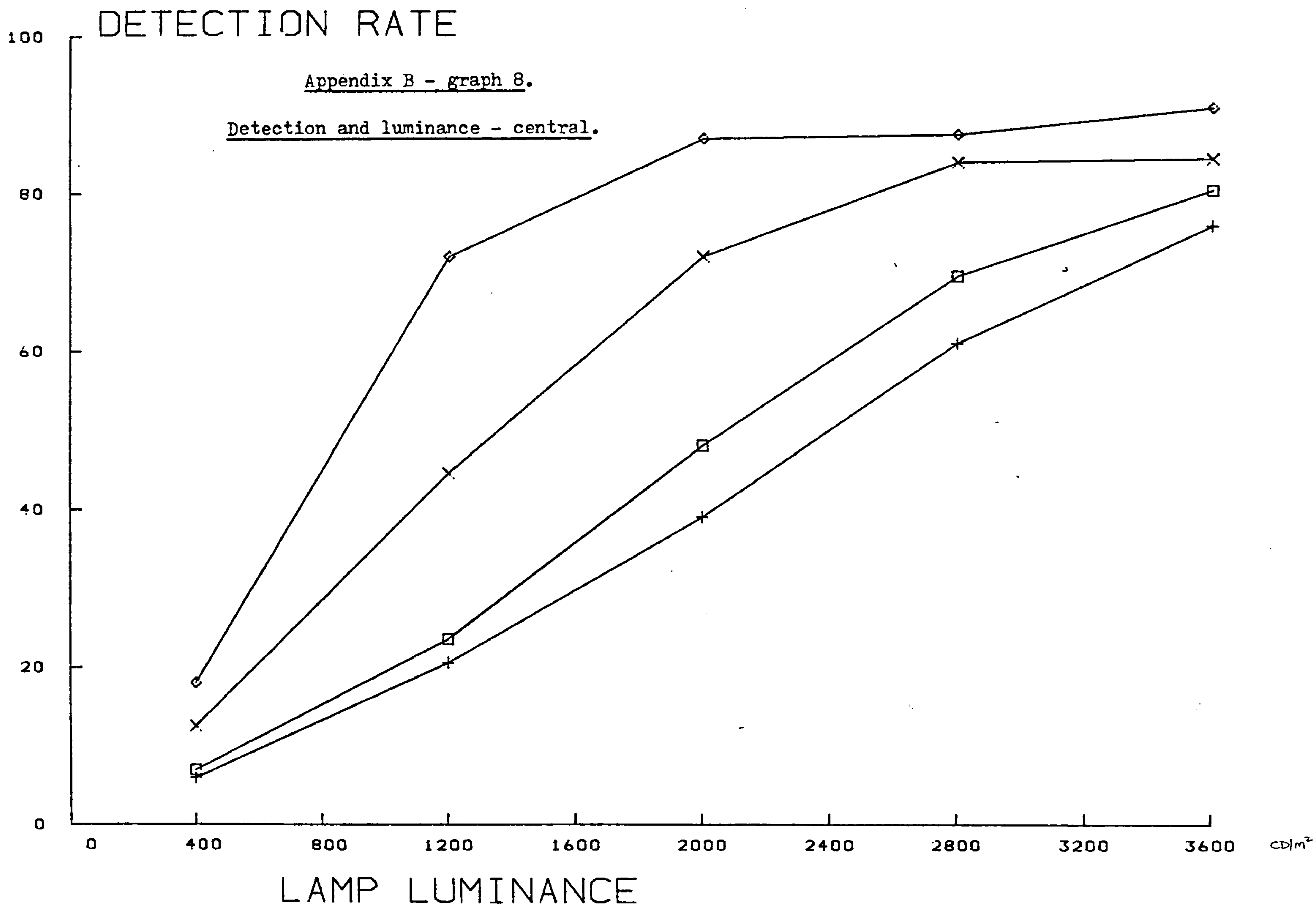


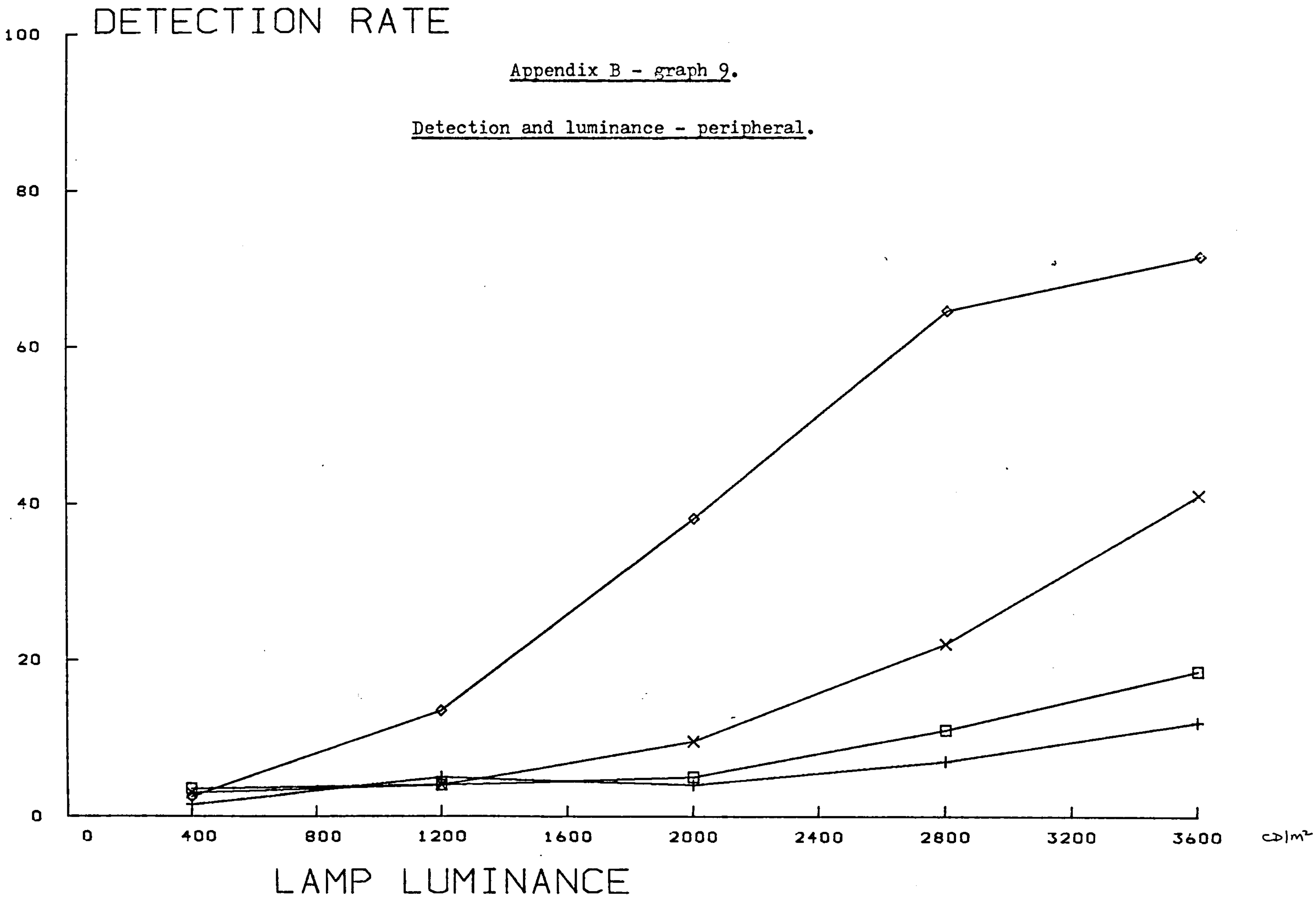
Appendix B

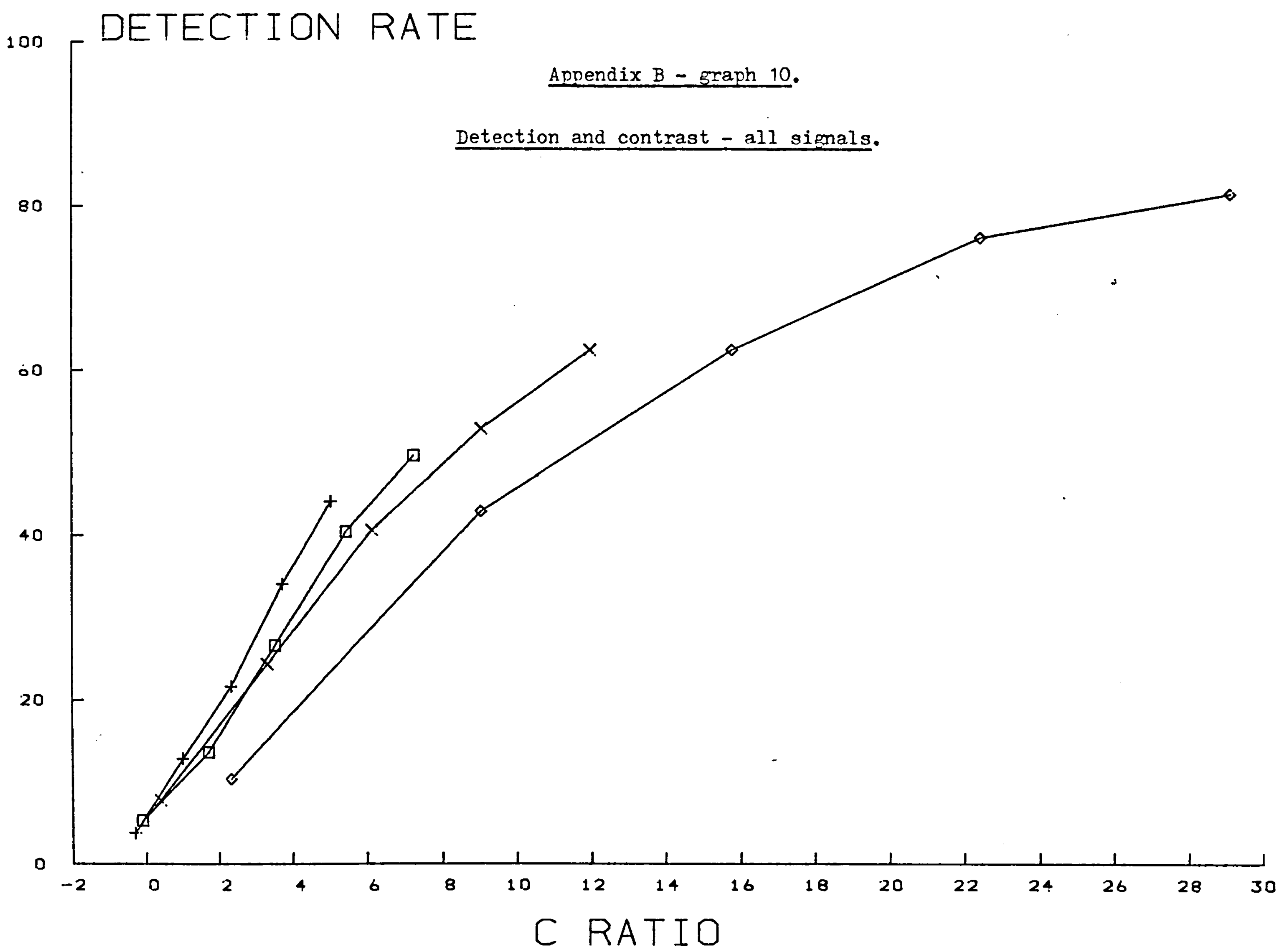
◇	120 cd/m^2
×	280
□	440
+	600

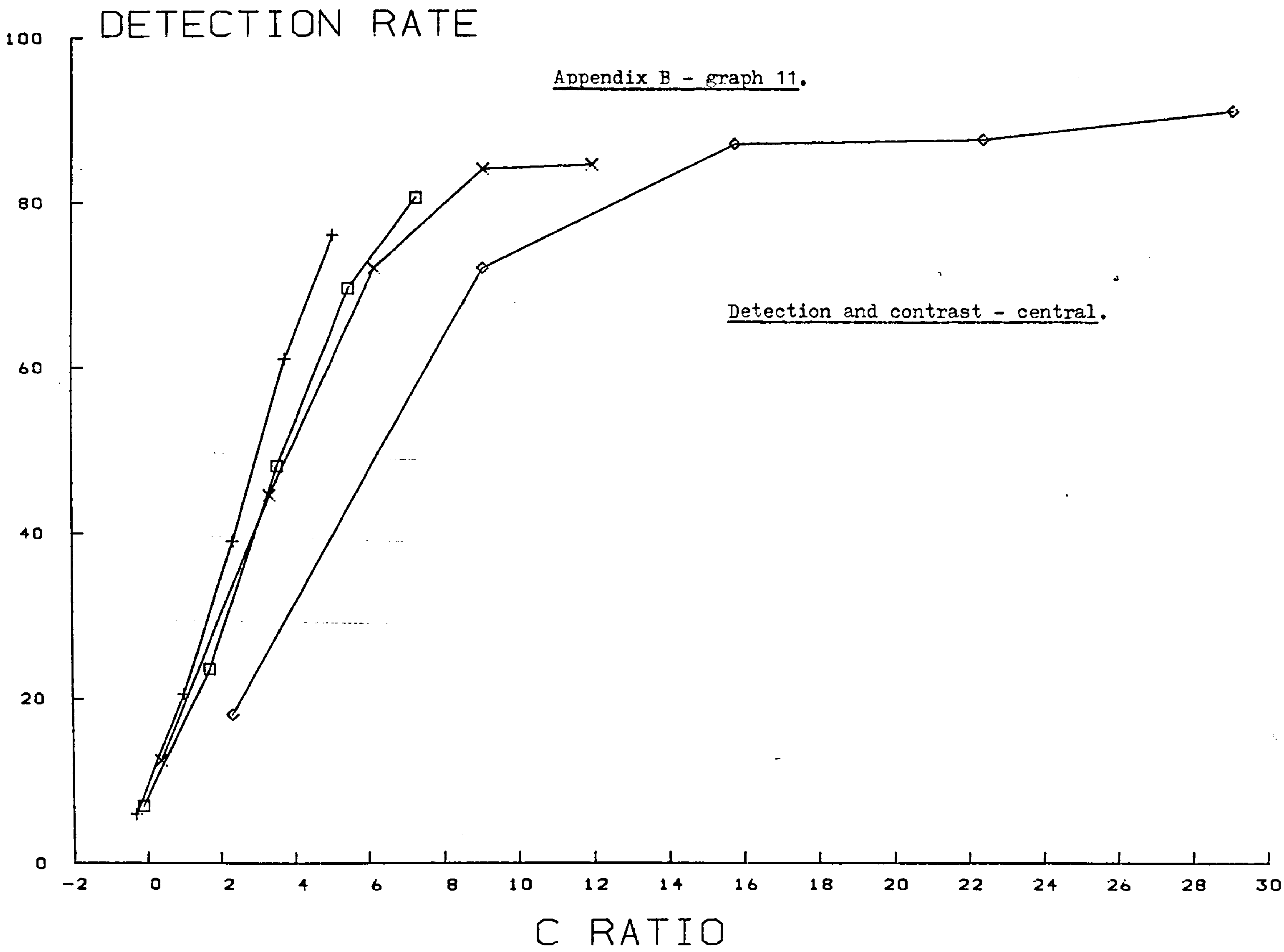


DETECTION RATE
Appendix B - graph 7.
Detection and luminance - all signals.
100
80
60
40
20
0
0
400
800
1200
1600
2000
2400
2800
3200
3600
cd/m²
LAMP LUMINANCE


DETECTION RATE
Appendix B - graph 8.
Detection and luminance - central.
100
80
60
40
20
0
0
400
800
1200
1600
2000
2400
2800
3200
3600
CD/m²
LAMP LUMINANCE


DETECTION RATE
Appendix B - graph 9.
Detection and luminance - peripheral.
100
80
60
40
20
0
0
400
800
1200
1600
2000
2400
2800
3200
3600
cd/m²
LAMP LUMINANCE


DETECTION RATE
Appendix B - graph 10.
Detection and contrast - all signals.
100
80
60
40
20
0
-2
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
C RATIO

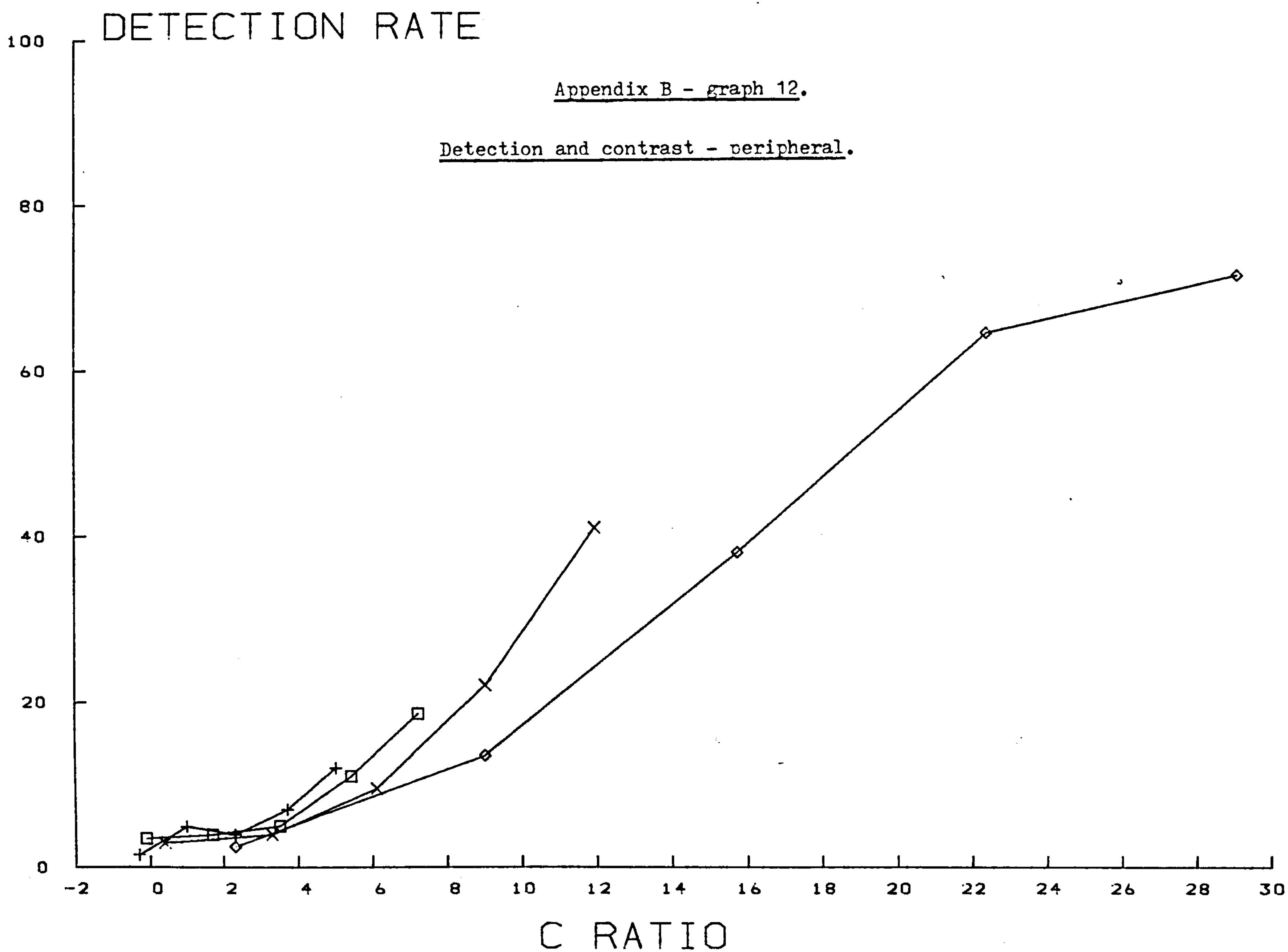


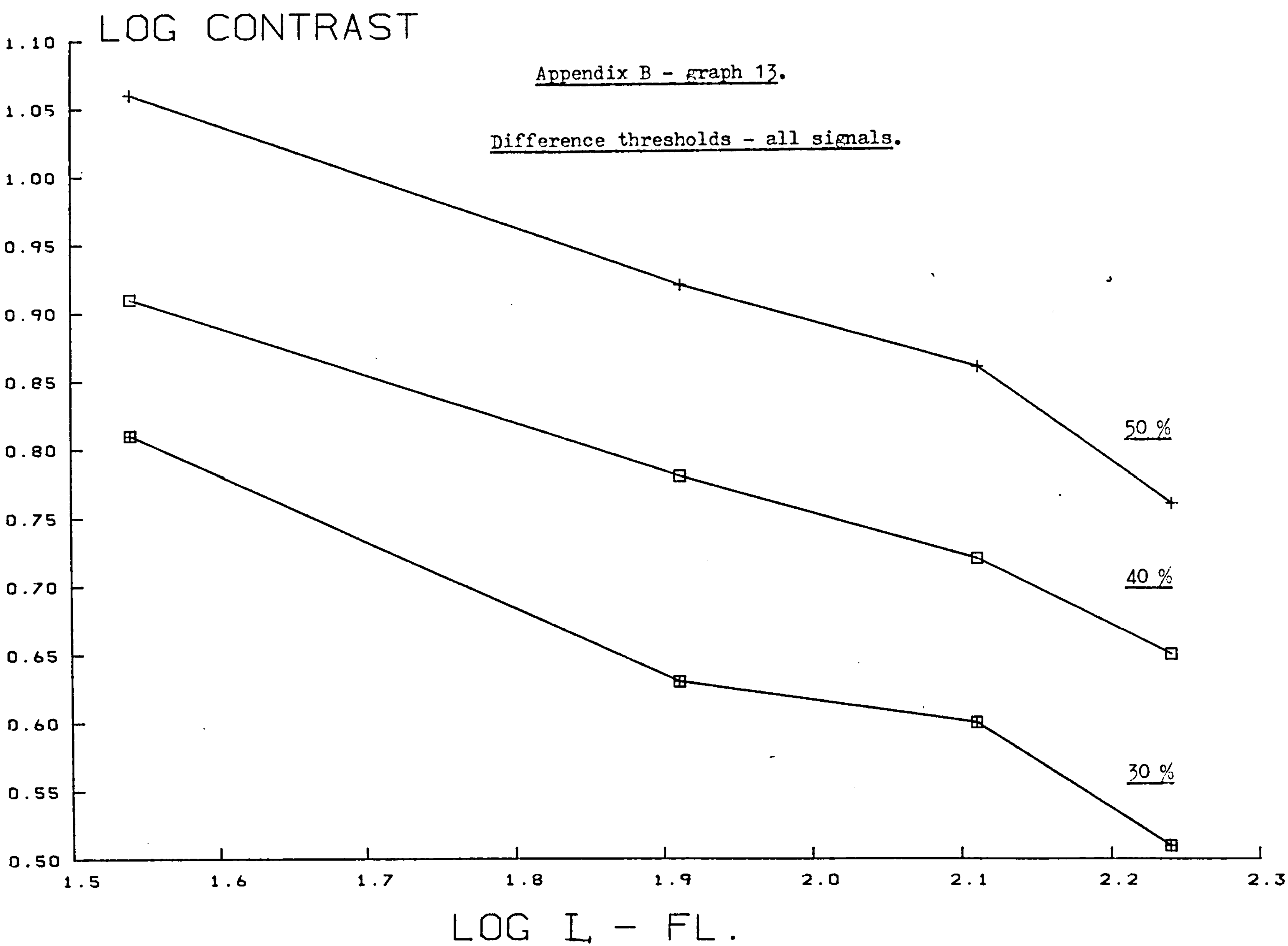
Appendix B - graph 11.

Detection and contrast - central.

Appendix B - graph 12.

Detection and contrast - peripheral.





LOG CONTRAST
Appendix B - graph 13.
Difference thresholds - all signals.
50 %
40 %
30 %
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
LOG L - FL.

Appendix C

Subject interviews

Subject Interviews

Interviews with five subjects were recorded in full. Questions were substantially the same for each interview, although one might not be asked if it had already in effect been answered, and points of interest were pursued.

Details of the five subjects are given below, together with their total correct, and false responses. This total is represented by T, the number of false responses by F. Average number of correct responses per subject over the whole experiment was 284.5. The total number of signals was 800.

Subject 1.	Middle aged male.	T = 283, F = 178
Subject 2.	Middle aged male.	T = 433, F = 260
Subject 3.	Young female.	T = 229, F = 6
Subject 4.	Young female.	T = 326, F = 231
Subject 5.	Young male.	T = 364, F = 35

The experimenter first explained what she meant by trial, session, etc.

Question 1. How many lights do you think there were during each trial?

S1. About 50

S2. The subject misunderstood this question at first, and took it to mean the number of lamps flashed at any one time. "On some occasions there was one, on some occasions there were two, and on some occasions there was, I believe, a flash over the whole ... system". The question was further explained. "Very roughly, I would say about 20 times". (In fact, in eleven out of the 20 trials, this subject responded correctly at least 20 times, not taking numerous false responses into account).

S3. I think it varied. (This subject would not attempt an estimate).

S4. About a hundred.

S5. They varied. 40 odd.

Question 2. Of these, how many do you think you responded to?

S1. About half.

S2. Well, I only pressed the ones that I was sure that I saw, but I feel on many occasions there were times when you set off a series of lights, so that I wasn't 100% sure and didn't press the button. I would say around 75%.

S3. 90%.

S5. About 80%.

Question 3. How many false responses do you think you made, if any?

S1. I wouldn't think many. I tend to be the other way. I've got to see it definitely before I press.

S2. Maybe about 5-10%, because I've got a very quick response on my finger, and I thought, and my finger thought at the same time, and there was no way of cancelling it out.

S3. Earlier on I pressed some that weren't there - I should think about half a dozen over the whole time.

S4. About half the responses. After, when you see a light you realise you've done something wrong.

S5. About 20%.

Question 4. On the occasions when you did make a false response, what do you think accounted for them?

S1. I don't know really, unless it's possibly you've been looking for dots, you know, and then you just suddenly think you see one. Q:- You think it's something you imagine? A:- Yes, it is.

S2. By your own lights in your eyes: sometimes more than others. Sometimes your vision is completely clear, and sometimes if you blink, you produce your own lights .... you might have pressed the lights just as I was blinking, so you pressed them again, which then created the feeling that you might have been having illusions, or not. Q:- You say that sometimes this occurred and not at other times - was there any kind of logic behind this, that you can discern? A:- Not really, because sometimes just the fact that your eyes are more tired than at other times seems to produce this.

S4. Perhaps it's a sort of back flash (S. means after-image) of the light which you've already seen previously. I usually found this when either I'd been staring for a long period of time and there seemed to have been no lights, and you sort of visualised there being a light there, or other times I thought it was a sort of back flash of the light I'd already seen, there was a sort of faint flickering and I thought it was another light.

S5. Usually, images on the retina. (After images). Or flicking the eyes to one side.

Question 5. Do you think that each trial was the same length?

All subjects answered "yes" to this question.

Question 6. And how long do you estimate that would be?

All subjects said "about 5 minutes" except S3, who after some difficulty said "About 4 minutes".

Question 7. Were you able to see the display clearly the whole time? That is, the interior of the box.

S1. Most of the time, but occasionally it seemed to go out of focus, you know, ... it would mean giving a blink, otherwise you didn't seem to be able to see the full width of the box.

S2. I could always see the whole of the box, and the whole of the black patches, but when you altered the light frequency, in other words when you flashed them quicker - I'm assuming I'm right in this - then I felt your brain didn't quite accept when it was a light and when it was your own personal thoughts. But I could always see all the dots and everything. And this was also in spite of the fact that I gradually moved my head very slowly. I never moved my eyes from the centre, but just a slight amount gave you quite an amount of help in vision. When you are staring at one particular spot, you are tending to focus your concentration on to one point, but with moving your head, you are just slightly breaking up that concentration. (Note: the author has had this same experience, but would attribute the relief obtained to retinal factors).

S3. Yes .... what I couldn't see very well at all were the outside dots. This is where I think I might have missed some flashes.

S4. No. I cut out the top half - I couldn't keep focus on the whole thing - or the grey dots would disappear altogether. The dots seemed as though they were tilting - this was sometimes when I thought I saw a light - a slight movement.

S5. Occasionally. I wasn't able to see all the black lamps when they were off, but when they were lit I was able to see the change.

Question 8. Did you find it easy to fixate on the red spot?

S1. Yes, too much, sometimes - you wouldn't see anything else other than the spot. Q:- That's when you say it would go out of focus?

A:- Yes.

S2. Yes.

S3. See Q. 14.

S5. No. I focussed just above it. If I focussed on it, it seemed to blank out everything else.

Question 9. Did your performance vary, do you think, from trial to trial?

S1. I don't know, really, unless the brightness of the lights that flashed varied .... I don't know.

S2. Yes. The first time that I came, I was probably not sure of myself. I tried too hard, for one thing. For me it was a challenge to see every light. But eventually, you relaxed, and you realised that the important thing is to only do what comes naturally to you. Trying too hard made you concentrate too hard on the dot, and that then made it more difficult - you were concentrating into the dot too hard, and shutting off your outer range of vision.

S3. Yes, I seemed to have slowed up the last two sessions, actually. The lighting seemed to alter - sometimes it seemed to be brighter than other times. I noticed it first of all between sessions, but then I think it might have varied between trials. You might get used to the lighting - when you first go in you think it's brighter.

S4. Yes.

S5. Yes.

<u>Question 10.</u> What do you think accounted for this variation in performance?

S2. In my own case, eye fatigue, and possibly tension from work as well. Whether you try to build up this tension by your own light system in there, and the noise of the fan as well, I don't know, but I think this was probably one of your aims, to find out what a person can put up with. I think in a way you were trying to kid me on - if I didn't respond, you would give me a brighter light, just to sharpen up my senses possibly, and then you would also try to break up the intervals of when you presented a light to me. Then, if you didn't give me a light, then I assume that you might think that I would visualise my own lights, and press for them in any case, not being your eyes, but your brain that would do this.
Q:- You mentioned before that you thought that the lights varied in length. A:- Yes. I noticed a difference between sessions, but also between trials. Q:- Did you notice any variation in brightness? A:- Within a trial. I think that you gave me a bright light to put me on my toes a little bit, ... and then in between the bright lights, you gave me lights than were quicker, and not so bright, just to see if they created hallucinations.

S3. See Q.9. Q:- Did the small lights vary? A:- Not that I could say.

S4. I thought probably the flashes were different strengths.

S5. Getting used to it - knowing where to look. I probably improved during the session. (cf. Q.11).

Question 11. Did you notice that the lighting in the box varied from session to session?

S1. No, I thought it was the same.

S2. It seemed just a little bit brighter on one occasion. I think it was today. (The level on this day was in fact 280 cd/m^2).

S4. No.

S5. Yes. It went brighter and then went dimmer for the last one. The small lights varied in brightness during the session.

Question 12. Do you think the rest periods were long enough?

S1. I think it was satisfactory.

S2. They were all right.

S3. Yes. I found the rest periods tended to make you lose concentration.

S4 and S5. Yes.

Question 13. And did you enjoy doing the experiment?

S1-S4 replied enthusiastically that they had.

S5 said: "Well, it was a challenge".

Question 14. Is there anything else you would like to say about your experiences?

S1. Sometimes, you see a movement, especially in the corners of the board, which you think might be a light, but you don't feel confident enough to press it .... It seemed as though sometimes, shortly after I'd seen a light, the same one would flash again, within a matter of two or three seconds, but you knew very well it wasn't the light proper.

S2. To me it's a question of a decision of the brain, of what you're actually seeing, and what you think you're seeing.

S3. You tend to sit there thinking; did I see any light, or didn't I? I numbered all the trials - there were five - I tried to think what I'd seen in each one when I came out. I occasionally thought that the lights varied in the length of time they were on. I thought today that there were little flashes - I put this down to staring at that red dot - if you stare at anything for long enough you see flashes around it. The flashing seemed to build up towards the end of each trial. If you stared at it long enough, there seemed to be a ring of light around the red dot. I found it difficult to concentrate on it (the red dot) because I kept thinking the lights on the outside might be flashing, and I'm not seeing them. It seemed to be very few times that I saw any lights in the outside four.

Appendix D

Appendix 1.

Display: number of lamps at each angle.

Angle	No. of lamps	No. of presentations to each subject
05	2	8
15	2	8
25	5	20
35	7	28
45	7	28
55	11	44
65	3	12
75	13	52
85	6	24
95	4	16
	60	240

Classification of lamps into three groups.

Angle	No. of lamps	Total	Lamp group
05	2		
15	2		
25	5		
35	7		
45	4	20	1
45	3		
55	11		
65	3		
75	3	20	2
75	10		
85	6		
95	4	20	3

Appendix 2.

Raw data - detections by subject, trial and visual angle. Group 120.

Subject	Trial	Angle° 05	15	25	35	45	55	65	75	85	95	Totals	
S1	1	2	2	5	7	6	10	2	2	1	1	38	
	2	2	2	4	6	5	11	2	4	1	1	38	
	3	2	1	4	6	6	8	2	3	3	0	35	
	4	2	1	4	5	5	11	2	6	1	1	38	149
S8	1	2	2	5	7	7	10	1	8	3	2	47	
	2	2	1	4	6	6	10	2	4	2	2	39	
	3	2	2	5	7	6	10	2	5	3	2	44	
	4	2	2	4	6	4	10	2	6	2	1	39	169
S12	1	2	1	5	5	5	6	1	3	0	2	30	
	2	2	2	5	6	6	5	0	3	1	2	32	
	3	2	2	5	7	5	8	2	2	2	1	36	
	4	2	2	5	6	3	6	1	4	1	2	32	130
S16	1	2	2	5	5	7	7	0	4	1	3	36	
	2	2	2	5	7	7	9	2	6	1	2	43	
	3	2	2	5	5	5	8	1	6	1	1	36	
	4	2	2	5	7	7	8	1	6	2	2	42	157

Appendix 3.

Raw data - detections by subject, trial and visual angle. Group 280.

Subject	Trial	Angle° 05	15	25	35	45	55	65	75	85	95	Totals	
S2	1	2	1	5	6	4	8	1	7	3	1	38	
	2	2	1	5	7	4	7	2	5	2	4	39	
	3	2	1	4	6	7	8	2	7	3	3	43	
	4	2	1	3	7	3	8	2	3	2	4	35	155
S5	1	2	2	5	6	4	6	1	2	1	0	29	
	2	2	2	5	7	6	8	1	3	4	3	41	
	3	2	2	5	6	5	6	1	5	1	1	34	
	4	2	1	3	7	6	2	1	3	3	1	29	133
S9	1	2	2	5	6	6	9	2	2	0	0	34	
	2	2	1	5	3	5	9	2	1	2	1	31	
	3	2	2	5	5	6	9	1	3	0	1	34	
	4	2	1	4	5	3	7	1	2	0	2	27	126
S13	1	2	1	4	5	6	10	2	6	3	2	41	
	2	2	2	5	6	4	8	2	5	2	2	38	
	3	2	2	4	6	7	9	1	5	3	3	42	
	4	2	2	4	5	7	7	2	4	2	2	37	158

Appendix 4.

Raw data - detections by subject, trial and visual angle. Group 440.

Subject	Trial	Angle° 05	15	25	35	45	55	65	75	85	95	Totals	
S3	1	2	2	5	6	4	6	1	1	0	0	27	
	2	2	2	4	6	5	8	2	2	1	0	32	
	3	2	2	5	7	7	6	1	1	2	1	34	
	4	2	2	4	5	5	7	1	1	0	1	28	121
S6	1	2	2	4	7	7	6	1	3	1	2	35	
	2	2	2	4	3	5	8	1	3	1	1	30	
	3	2	2	4	5	5	4	1	2	0	1	26	
	4	2	1	4	4	7	6	2	3	2	0	31	122
S10	1	2	1	5	7	6	9	1	8	3	4	46	
	2	2	1	5	7	7	8	2	4	3	3	42	
	3	2	2	4	6	5	9	2	4	1	4	39	
	4	2	1	5	6	6	10	2	1	2	2	37	164
S14	1	2	1	4	6	4	6	1	2	1	2	29	
	2	2	1	5	7	5	7	2	2	1	2	34	
	3	2	2	5	7	5	6	2	2	1	1	33	
	4	2	2	3	4	3	5	0	3	2	0	24	120

Appendix 5.

Raw data - detections by subject, trial and visual angle. Group 600.

Subject	Trial	Angle° 05	15	25	35	45	55	65	75	85	95	Totals	
S4	1	2	2	4	6	4	7	2	1	1	0	29	
	2	2	2	3	3	3	5	2	2	1	1	24	
	3	2	2	5	6	4	6	1	2	1	1	30	
	4	2	1	5	4	4	4	1	1	1	0	23	106
S7	1	2	2	3	6	6	5	1	1	0	1	27	
	2	2	2	5	6	4	6	0	0	1	0	26	
	3	2	1	4	6	7	5	0	4	0	1	30	
	4	2	2	5	4	4	5	0	0	1	1	24	107
S11	1	2	0	4	4	4	8	0	3	1	0	26	
	2	2	2	5	6	6	8	1	1	1	0	32	
	3	2	1	4	5	3	6	1	2	1	1	26	
	4	2	2	4	6	7	6	1	0	1	0	29	113
S15	1	2	2	5	5	3	7	1	4	3	2	34	
	2	2	2	4	7	5	8	2	3	1	3	37	
	3	2	2	4	7	4	7	2	4	2	3	37	
	4	2	1	4	6	5	8	1	4	2	3	36	144

Appendix 6.

Detections by trial, subject and visual angle (grouped).

Group	Subject	Trial 1 Angle 1	Trial 1 Angle 2	Trial 1 Angle 3	Trial 2 Angle 1	Trial 2 Angle 2	Trial 2 Angle 3	Trial 3 Angle 1	Trial 3 Angle 2	Trial 3 Angle 3	Trial 4 Angle 1	Trial 4 Angle 2	Trial 4 Angle 3
120	S1	20	14	4	17	6	5	17	13	5	15	16	7
	S8	20	16	11	16	15	8	19	17	8	16	16	7
	S12	17	9	4	18	10	4	19	13	4	16	11	5
	S16	18	11	7	20	17	6	17	14	5	20	14	8
280	S2	17	13	8	18	12	9	17	16	10	15	11	9
	S5	18	10	1	19	14	8	19	10	5	17	7	5
	S9	19	13	2	15	12	4	18	14	2	12	11	4
	S13	16	16	9	18	14	6	18	15	9	17	12	8
440	S3	17	9	1	17	13	2	20	11	3	16	11	1
	S6	19	12	4	13	13	4	16	7	3	15	12	4
	S10	18	16	12	19	14	9	17	15	7	18	14	5
	S14	16	9	4	19	10	5	19	11	3	13	7	4
600	S4	17	11	1	13	7	4	18	8	4	15	1	1
	S7	16	9	2	17	8	1	17	9	4	17	5	2
	S11	13	11	2	19	12	1	14	10	1	18	10	1
	S15	16	10	8	17	14	6	18	11	8	17	12	7

Data: detections per angle, per trial
(out of 20 signals)

n = 16

Visual angles: group 1 - 0 - 45°
group 2 - 45 - 75°
group 3 - 75 - 95°

Appendix 7.

Detection scores by group: Kruskal-Wallis analysis of variance.

Group			
120	280	440	600
38	27	38	29
38	32	39	24
35	34	43	30
38	28	35	23
47	35	29	27
39	30	41	26
44	26	34	30
39	31	29	24
30	46	34	26
32	42	31	32
36	39	34	26
32	37	27	29
36	29	41	34
43	34	38	37
36	33	42	37
42	24	37	36

Data: scores for each subject for each trial.

Null hypothesis: that all the samples are from the same or identical populations.

$$H = \frac{12}{N(N+1)} \sum \frac{R^2}{n} - 3(N+1)$$

H = 19·428 (corrected for tied ranks)

d.f. = 3

p = 0.001

Null hypothesis not upheld.

Appendix 8.

The number of signals detected by subject and trial.

Group	Subject	Trial 1	2	3	4	Total
120	S1	38	38	35	38	149
	S8	47	39	44	39	169
	S12	30	32	36	32	130
	S16	36	43	36	42	157
280	S2	38	39	43	35	155
	S5	29	41	34	29	133
	S9	34	31	34	27	126
	S13	41	38	42	37	158
440	S3	27	32	34	28	121
	S6	35	30	26	31	122
	S10	46	42	39	37	164
	S14	29	34	33	24	120
600	S4	29	24	30	23	106
	S7	27	26	30	24	107
	S11	26	32	26	29	113
	S15	34	37	37	36	144
Totals		546	558	559	511	2174

Kruskal-Wallis analysis of variance:

$$H = \frac{12}{N(N+1)} \sum \frac{R^2}{n} - 3(N+1)$$

H = 2·538

d.f. = 3

p = 0·5 (not significant)

Null hypothesis: that all the samples are from the same or identical populations.

Hypothesis upheld.

Appendix 9.

Reaction time by subject and angle of signal.

Group	Subject	Angle° 05	15	25	35	45	55	65	75	85	95	arithmetic mean
120	S1	609	577	617	717	772	775	711	871	848	883	742
	S8	523	514	623	680	647	707	780	782	764	693	685
	S12	503	524	566	577	617	676	730	753	650	664	621
	S16	540	659	539	587	663	675	713	743	706	744	651
280	S2	635	618	711	675	724	702	721	740	743	775	710
	S9	556	758	625	676	700	796	698	826	930	723	717
	S13	656	653	681	644	694	789	783	838	866	834	743
440	S10	744	756	822	834	820	850	840	907	916	911	846
	S14	436	455	527	575	559	648	680	614	702	540	576
600	S7	547	540	693	645	715	747	1050	754	910	786	690
	S11	623	600	671	671	724	750	843	968	920	710	723
	S15	709	821	762	800	817	843	822	1004	948	859	837

Data: reaction time in milleseconds (arithmetical average) for all trials.

N = 12.

Appendix 10.

Mean reaction time by angle of signal - summary by group.

Angle	Group 120	280	440	600
05	543•75	615•67	590•00	626•33
15	568•50	676•33	605•50	653•67
25	586•25	672•33	674•50	708•67
35	640•25	665•00	704•50	705•33
45	674•75	706•00	689•50	752•00
55	708•25	762•33	749•00	780•00
65	733•50	734•00	760•00	905•00
75	787•25	801•33	760•50	908•67
85	742•00	846•33	809•00	926•00
95	746•00	777•33	725•50	785•00

Appendix 11.

Reaction time and group - Chi-squared.

Reaction time (milleseconds)	Group 120	280	440	600	Totals
500	36	12	42	11	101
500 - 599	178	77	39	70	364
600 - 699	164	121	35	72	392
700 - 799	111	106	53	62	332
800 - 899	57	72	65	63	257
900 - 999	35	29	31	49	144
1000 +	24	22	19	37	102
Totals	605	439	284	364	1692

Data: reaction times (milleseconds) of twelve subjects, for all trials.

$X^2 = 170 \cdot 04$

d.f. = 18

p = 0·001

Null hypothesis: the proportion of response times falling into each category is the same for all groups.

Not upheld.

Appendix 12.

Reaction time and trial - Chi-squared.

Reaction time (milleseconds)	Trial 1	2	3	4	Totals
500	35	33	16	17	101
500 - 599	89	92	100	83	364
600 - 699	112	84	101	95	392
700 - 799	80	72	86	94	332
800 - 899	54	73	71	59	257
900 - 999	26	47	43	28	144
1000 +	30	30	18	24	102
Totals	426	431	435	400	1692

Data: reaction times (milleseconds) of twelve subjects.

$X^2 = 36 \cdot 57$

d.f. = 18

p = 0·01

Null hypothesis: the proportion of response times falling into each category is the same for all trials.

Not upheld.

Appendix 13.

Category of detections by subject and group.

Group	Subject	Category 0	1	2	3	4
120	S1	10	8	8	11	23
	S8	9	3	6	14	28
	S12	17	8	4	10	21
	S16	9	10	1	15	25
280	S2	8	9	5	16	22
	S5	15	6	8	13	18
	S9	13	10	9	14	14
	S13	9	6	6	16	23
440	S3	19	7	6	10	18
	S6	12	12	10	14	12
	S10	7	3	12	15	23
	S14	18	4	11	14	13
600	S4	23	3	9	15	10
	S7	20	7	10	12	11
	S11	19	8	7	13	13
	S15	14	3	6	19	18
Totals		222	107	118	221	292

960

Data: the total number of lamps falling into each category, for each subject.

Appendix 14.

Category of detections by groups : Chi-squared.

No. of detections out of four presentations	Group 120	280	440	600	Totals
0	45	45	56	76	222
1	29	31	26	21	107
2	19	28	39	32	118
3	50	59	53	59	221
4	97	77	66	52	292
Totals	240	240	240	240	960

Data: total number of detections falling into each category, for each group of four subjects, and four presentations each of sixty signals.

$X^2 = 36{\cdot}68$

d.f. = 12

$p = 0{\cdot}001$

Null hypothesis: the proportion of detections falling into each category is the same for all groups.

Not upheld.

Appendix 15.

Z-scores for runs during each trial.

Group	Subject	Trial 1	Trial 2	Trial 3	Trial 4
120	S1	+0·318	-2·208	+0·491	+0·599
	S8	-2·462	+0·201	-0·491	-0·373
	S12	-0·781	+0·032	-1·031	-2·580
	S16	+1.954	+0·526	-0·760	+0·560
280	S2	-1·085	-0·659	+1·813	-1·384
	S5	-0·260	+0·001	+0·672	+1·565
	S9	+0·672	+0·783	-0·124	+0·079
	S13	-1·800	+1·160	-0·373	-0·653
440	S3	+0·868	-1·534	-2·245	+0·558
	S6	-0·849	-3·645	-1·185	-0·260
	S10	+0·195	+1·493	+1·347	-0·010
	S14	-1·041	-0·654	+0·605	-1·574
600	S4	+0·001	-0·760	+0·781	-0·377
	S7	-1·236	-1·450	-0·781	-0·489
	S11	-0·665	+0·035	-0·389	-0·521
	S15	-1·715	+1·002	+0·175	+0·587

Data: z-scores for each subject's responses, for each trial.

Appendix 16.

Gaps: total number by subject by trial.

Group	Subject	Trials 1	2	3	4	Totals	
120	S1	15	10	16	15	56	
	S8	7	14	11	14	46	
	S12	14	16	13	10	53	
	S16	18	13	13	14	58	213
280	S2	12	13	15	12	52	
	S5	15	14	16	18	63	
	S9	16	17	15	16	64	
	S13	10	16	12	13	51	230
440	S3	17	12	11	17	57	
	S6	14	8	13	15	50	
	S10	11	15	16	14	56	
	S14	14	14	16	12	56	219
600	S4	15	13	17	14	59	
	S7	13	12	14	14	53	
	S11	14	16	14	15	59	
	S15	12	17	15	16	60	231
Totals		217	220	227	229		893

Data: the number of gaps in each trial for each subject.

Appendix 17.

Gaps: length by subject.

Group	Subject	Gap length 1	2	3	4	5+	Totals
120	S1	34	15	3	2	2	56
	S8	29	10	6	1	0	46
	S12	30	9	4	5	5	53
	S16	41	14	1	1	1	58
280	S2	32	11	6	2	1	52
	S5	37	16	7	0	3	63
	S9	37	12	10	3	2	64
	S13	35	9	4	1	2	51
440	S3	26	16	9	2	4	57
	S6	23	12	9	3	3	50
	S10	39	14	3	0	0	56
	S14	25	19	4	3	5	56
600	S4	25	14	7	8	5	59
	S7	21	12	10	4	6	53
	S11	30	9	13	2	5	59
	S15	42	10	4	1	3	60
Totals		506	202	100	38	47	893

Data: the number of gaps of each length (number of signals missed) for each subject.

Appendix 18.

Gaps: length by group - Chi-squared.

Gap length	Group				Totals
	120	280	440	600	
1	134	141	113	118	506
2	48	48	61	45	202
3	14	27	25	24	100
4	9	6	8	15	38
5+	8	8	12	19	47
Totals	213	230	219	231	893

Data: the number of gaps of each length (number of signals missed) for each group, all trials.

$X^2 = 26{\cdot}072$

d.f. = 12

p = 0•02

Null hypothesis: that the proportion of gaps of each length is the same for all groups.

Not upheld.

Gaps: gap length and group - pilot experiment.

Chi-squared.

Gap length	Group 120	280	440	600	Totals
1	224	249	141	96	710
2	100	97	70	70	337
3	51	55	41	20	167
4	13	12	24	22	71
5	11	14	9	7	41
6+	10	14	14	5	43
Totals	409	441	299	220	1369

Data: total number of gaps of each length (number of signals missed) for each group, from 150 selected trials.

$X^2 = 41{\cdot}451$

d.f. = 15

p = 0·001

Null hypothesis: that the proportion of gaps of each length is the same for all groups.

Not upheld.

Appendix 20.

Gap length and performance - Chi-squared.

gap length	Ranked groups: top 16	next best 16	next worst 16	worst 16	Totals
1	144	143	117	102	506
2	43	52	32	55	202
3	15	18	32	35	100
4	4	7	13	14	38
5+	1	9	12	25	47
Totals	207	229	226	231	893

Data: the number of gaps of each length (number of signals missed) for each group*.

* group: 16 trials in each group, chosen according to ranking of detection rate, and drawn from results of all subjects.

$X^2 = 54{\cdot}08$
d.f. = 12
p = 0·001

Null hypothesis: that the proportion of gaps of each length is the same for all groups of trials.

Hypothesis not upheld.

Appendix 21.

Gaps: gap length and contrast - pilot experiment.

Chi-squared. Group 120.

Gap length	Trials 1	2	3	4	Totals
1	35	43	86	60	224
2	12	24	30	34	100
3	11	8	15	17	51
4+	6	5	8	15	34
Totals	64	80	139	126	409

Data: number of gaps of each length (number of signals missed) in trials of four different signal contrast values.

Data has been collapsed to improve validity.

$X^2 = 15 \cdot 38$

d.f. = 9

p = 0·1

Null hypothesis: that the proportion of gaps of each length is the same for all trials (contrast values).

Hypothesis upheld.

Appendix 22.

Gaps: gap length and contrast - pilot experiment.

Chi-squared. Group 280.

Gap length	Trials 1	2	3	4	Totals
1	75	98	57	19	249
2	32	29	29	7	97
3,4	19	23	16	9	67
5+	4	9	11	4	28
Totals	130	159	113	39	441

Data: number of gaps of each length (number of signals missed) in trials of four different signal contrast values.

Data has been collapsed to improve validity.

$X^2 = 11{\cdot}384$

d.f. = 9

n.s.

Null hypothesis: that the proportion of gaps of each length is the same for all trials (contrast values).

Hypothesis upheld.

Gaps: gap length and contrast - pilot experiment.

Chi-squared. Group 440.

Gap length	Trials			Totals
	1	2	3,4,5	
1	66	53	22	141
2	35	24	22	70
3,4	30	28	7	65
5+	8	10	5	23
Totals	139	115	45	299

Data: number of gaps of each length (number of signals missed) in trials of four different signal contrast values.

Data has been collapsed to improve validity.

$X^2 = 3 \cdot 251$

d.f. = 6

n.s.

Null hypothesis: that the proportion of gaps of each length is the same for all trials (contrast values).

Hypothesis upheld.

Appendix 24.

Gaps: gap length and contrast - pilot experiment.

Chi-squared. Group 600.

Gap length	Trials 1	2	3,4	Totals
1	61	30	5	96
2	45	19	6	70
3+	28	20	6	54
Totals	134	69	17	220

Data: number of gaps of each length (number of signals missed) in trials of four different signal contrast values.

Data has been collapsed to improve validity.

$X^2 = 3{\cdot}572$

d.f. = 4

n.s.

Null hypothesis: that the proportion of gaps of each length is the same for all trials (contrast values).

Hypothesis upheld.

Appendix 25.

Gaps: gap contents and gap length - pilot experiment.
Chi-squared.

	1	2	3	4	5	6+	Totals
'central'	109	109	90	49	36	68	461
'peripheral'	598	567	411	227	174	284	2261
Totals	707	676	501	276	210	352	2722

Data: the number of central, and peripheral signals missed in gaps of different lengths.

$X^2 = 3.402$
d.f. = 5
n.s.

Null hypothesis: the proportion of signals missed of the two categories, is the same for all lengths of gap.

Hypothesis upheld.

Appendix 26.

Gaps: location of signals missed in gaps of different lengths.

Angle of signal°	gap length 1	2	3	4	5+	Totals
05 - 25	20	18	6	5	11	60
35	16	22	15	8	16	77
45	36	25	13	15	27	116
55	58	56	42	24	54	234
65	28	30	20	8	21	107
75	231	139	115	47	91	623
85	76	72	60	26	55	289
95	40	40	32	19	29	160
Totals	505	402	303	152	304	1666

Data: signals missed during gaps of different lengths, classified by visual angle. n = 16

Data has been collapsed to improve validity.

$X^2 = 43{\cdot}45$
d.f. = 28
p = 0·05

Null hypothesis: that the proportion of signals missed from each location is the same for gaps of all lengths.

Not upheld.

This result is largely due to gaps of length one signal. When the analysis is repeated, omitting this data, the results are: -

$X^2 = 26{\cdot}35$
d.f. = 21
n.s.

Null hypothesis (as above) is upheld.

Appendix 27.

Detections by half - trials.

Group	Subject	Trial 1		Trial 2		Trial 3		Trial 4		
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	
120	S1	16	22	17	21	19	16	18	20	
	S8	21	26	21	18	23	21	17	22	
	S12	17	13	17	15	16	20	17	15	
	S16	17	19	22	21	21	15	22	20	
280	S2	21	17	19	20	22	21	18	17	
	S5	16	13	18	23	19	15	14	15	
	S9	21	13	15	16	17	17	13	14	
	S13	22	19	20	18	23	19	21	16	
440	S3	12	15	16	16	18	16	15	13	
	S6	19	16	17	13	12	14	15	16	
	S10	25	21	20	22	17	22	18	19	
	S14	15	14	16	18	19	14	17	7	
600	S4	18	11	11	13	13	17	13	10	
	S7	16	11	18	8	16	14	13	11	
	S11	13	13	14	18	15	11	16	13	
	S15	19	15	19	18	18	19	21	15	
Totals		288	258	280	278	288	271	268	243	2174

Data: the number of detections made in each half-trial of thirty signals. n = 16.

Appendix 28.

Gaps: by half - trial.

Group	Subject	Trial 1		Trial 2		Trial 3		Trial 4	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
120	S1	8	7	6	4	8	8	8	7
	S8	4·5	2·5	6	8	6	5	8	6
	S12	5·5	8·5	9	7	7	6	5	5
	S16	11	7	6·5	6·5	6	7	6	8
280	S2	5·5	6·5	7	6	6	9	6	6
	S5	7·5	7·5	7	7	6	10	8·5	9·5
	S9	8	8	7·5	9·5	7	8	8	8
	S13	5·5	4·5	6	10	4	8	6	7
440	S3	7·5	9·5	5·5	6·5	7	4	9	8
	S6	8	6	3	5	5·5	7·5	7	8
	S10	3	8	10	5	9	7	6·5	7·5
	S14	6·5	7·5	7	7	7·5	8·5	6	6
600	S4	7	8	6·5	6·5	8	9	7·5	6·5
	S7	7·5	5·5	5	7	6·5	7·5	6·5	7·5
	S11	6·5	7·5	9	7	4·5	9·5	8·5	6·5
	S15	4·5	7·5	7	10	9	6	7	9

Data: Gaps were counted for each trial of thirty signals. If a gap overlapped the division into two half-trials, it was counted as half a gap in each half-trial.

Appendix 29.

Gaps: location of first signal detected after a gap.

Gap length	Group	Angle° 05	15	25	35	45	55	65	75	85	95	Totals
1	120	12	5	15	28	14	23	0	18	7	9	131
	280	11	6	22	17	17	28	4	10	10	12	137
	440	7	3	16	25	14	25	2	8	4	7	111
	600	9	2	12	27	14	19	3	11	8	7	112
2	120	1	4	16	10	5	6	2	4	0	0	48
	280	2	5	7	5	7	11	4	2	4	1	48
	440	2	5	13	10	5	11	5	6	3	0	60
	600	1	3	14	5	4	8	3	2	3	0	43
3	120	0	0	2	1	2	6	0	2	0	0	13
	280	0	1	2	4	1	9	4	3	3	0	27
	440	2	1	3	5	3	4	2	3	0	0	23
	600	1	5	9	4	4	8	1	1	0	0	33
4	120	0	3	1	1	0	4	0	0	0	0	9
	280	0	0	1	0	1	2	0	0	0	0	4
	440	0	3	2	2	0	0	0	0	1	0	8
	600	2	2	0	2	1	5	0	2	1	0	15
5+	120	0	1	2	0	2	1	0	1	1	0	8
	280	1	0	3	0	1	0	0	2	0	1	8
	440	0	0	2	1	4	4	0	0	0	1	12
	600	2	1	4	2	4	3	1	1	0	1	19

Data: location of the first signal detected after a gap, analysed by gap length.

Appendix 30.

Gaps: location of first signal detected after a gap compared with location of all other detections - Chi-squared.

angle of signal°	after gaps	others	Totals
05	53	75	128
15	50	54	104
25	146	141	287
35	149	199	348
45	103	249	352
55	177	292	469
65	31	54	85
75	76	135	211
85	45	48	93
95	39	58	97
Totals	869	1305	2174

Data: location of the first signal detected after a gap, compared with all other detections, all subjects.

$X^2 = 40 \cdot 699$
d.f. = 9
p = 0·001

Null hypothesis: the proportion of responses to signals from different locations is the same for those occurring immediately after a gap as for all other detections.

Not upheld.

Appendix 31.

Gaps: location of first signal detected after a gap by group - Chi-squared.

Angle°	Group				Totals
	120	280	440	600	
05	13	14	11	15	53
15	13	12	12	13	50
25	36	35	36	39	146
35	40	26	43	40	149
45	23	27	26	27	103
55	40	50	44	43	177
65	2	12	9	8	31
75	25	17	17	17	76
85	8	17	8	12	45
95	9	14	8	8	39
Totals	209	224	214	222	869

Data: location of the first signal detected after a gap, all subjects, classified by group.

$X^2 = 23 \cdot 673$

d.f. = 27

n.s.

Null hypothesis: the proportion of signals detected from each different location is the same for all groups.

Hypothesis upheld.

Appendix 32.

Gaps: location of first signal detected after a gap - Chi-squared.

Angle°	gap length 1	2	3	4+	Totals
05,15	55	23	10	15	103
25	65	50	16	15	146
35	97	30	14	8	149
45	59	21	10	13	103
55	95	36	27	19	177
65,75	56	28	16	7	107
85,95	64	11	3	6	84
Totals	491	199	96	83	869

Data: location of first signal detected after a gap, all subjects, classified by length of gap after which the signal appears. The total is less than the number of gaps (893) because a gap appearing at the end of a trial will not then have an immediately following signal.

$X^2 = 46{\cdot}75$
d.f. = 18
p = 0·001

Null hypothesis: that the proportion of detections from different locations is the same for all gap lengths.

Not upheld.

Chi-squared as above, omitting gaps of length one signal:

$X^2 = 14{\cdot}889$
d.f. = 12
n.s.

Null hypothesis as above.
Hypothesis upheld.

Appendix 33.

Gaps: reaction times after gaps compared to all other reaction times - Chi-squared.

Reaction time	after gaps	others	Totals
500	39	62	101
500 - 599	144	220	364
600 - 699	135	257	392
700 - 799	128	204	332
800 - 899	101	156	257
900 - 999	60	94	154
1000+	40	52	92
Totals	647	1045	1692

Data: reaction times to the first signal detected after a gap, and all other reaction times. n = 12.

$X^2 = 3{\cdot}913$
d.f. = 6
n.s.

Null hypothesis: there is no difference in the proportion of reaction times of different durations occurring immediately after a gap, and at other times.

Hypothesis upheld.

Appendix 34.

Scores on the E.P.I. Scale.

Group	Subject	Score: Ext/Int	Score: Neurot.	Score: Lie Scale
120	S8	15	12	4
	S12	14	20	2
	S16	4	11	2
280	S5	14	15	3
	S9	16	15	3
	S13	11	12	3
440	S3	11	16	3
	S6	17	5	0
	S10	17	17	1
	S14	16	2	1
600	S4	14	10	2
	S7	11	5	0
	S11	15	6	1
	S15	10	17	3

Extraversion/introversion: arithmetic mean = 13·214
standard deviation = 3·406

Neuroticism: arithmetic mean = 11·643
standard deviation = 5·246

Appendix 35.

Extraversion/introversion scale: Kruskal-Wallis analysis of variance.

Ranks.

Group 120	280	440	600
9·5	7·0	4·0	7·0
7·0	11·5	13·5	4·0
1·0	4·0	13·5	9·5
		11·5	2·0

Null hypothesis: that all the samples are from the same or identical populations.

$$H = \frac{12}{N(N+1)} \sum \frac{R^2}{n} - 3(N+1)$$

H = 3·391 (d.f. = 3)

p = 0·3 (not significant)

The null hypothesis is upheld.

Extraversion/introversion scale: Spearman rank correlation coefficient with detection scores.

Group	Subject	Rank (total detections)	Rank (extra/int. scale)	d
120	S8	14	9·5	4·5
	S12	8	7·0	1·0
	S16	10	1·0	9·0
280	S5	9	7·0	2·0
	S9	7	11·5	4·5
	S13	11	4·0	7·0
440	S3	5	4·0	1·0
	S6	6	13·5	2·0
	S10	13	13·5	6·5
	S14	4	11·5	10·0
600	S4	1	7·0	6·0
	S7	2	4·0	2·0
	S11	3	9·5	6·5
	S15	12	2·0	10·0

$$r_s = 1 - \frac{6 \sum d^2}{N^3 - N}$$

$r_s = -0{\cdot}0341$ (not significant)

Neuroticism scale: Kruskal-Wallis analysis of variance.

Ranks.

Group 120	280	440	600
7·5	9·5	11·0	5·0
14·0	9·5	2·5	2·5
6·0	7·5	12·5	4·0
		1·0	12·5

Null hypothesis: that all the samples are from the same or identical populations.

$$H = \frac{12}{N(N+1)} \sum \frac{R^2}{n} - 3(N+1)$$

H = 1·307 (d.f. = 3)

p = 0·8 (not significant)

The null hypothesis is upheld.

Appendix 38.

Neuroticism scale : Spearman rank correlation coefficient with detection scores.

Group	Subject	Rank (total detections)	Rank (extra/int. scale)	d
120	S8	14	7·5	6·5
	S12	8	14·0	6·0
	S16	10	6·0	4·0
280	S5	9	9·5	0·5
	S9	7	9·5	2·5
	S13	11	7·5	3·5
440	S3	5	11·0	6·0
	S6	6	2·5	3·5
	S10	13	12·5	0·5
	S14	4	1·0	3·0
600	S4	1	5·0	4·0
	S7	2	2·5	0·5
	S11	3	4·0	1·0
	S15	12	12·5	0·5

$$r_s = \frac{\Sigma x^2 = \Sigma y^2 - \Sigma d^2}{2\sqrt{\Sigma x^2 \text{ x } \Sigma y^2}}$$ (formula correcting for tied scores).

$r_s = +0{\cdot}585$ (n = 14)

This is significant at the 0·025 level (one-tailed test).

Appendix 39.

Neuroticism scale and gap length: Chi-squared.

Group	gap length 1	2	3	4+	Totals
1	137	49	20	20	226
2	179	61	28	14	282
3	124	66	43	44	277
Totals	440	176	91	78	785

Data: distribution of gap lengths in data from 14 subjects, classified in three groups according to score on the neuroticism scale.

Group 1: Ss. 12,10,15,3
2: Ss. 5,9,8,13,16
3: Ss. 14,6,7,11,4.

$X^2 = 33{\cdot}274$
d.f. = 6
p = 0·001

Null hypothesis: that the proportion of gaps of different lengths is the same for all groups.

Not upheld.

Appendix E

----- 120 cd/m^2

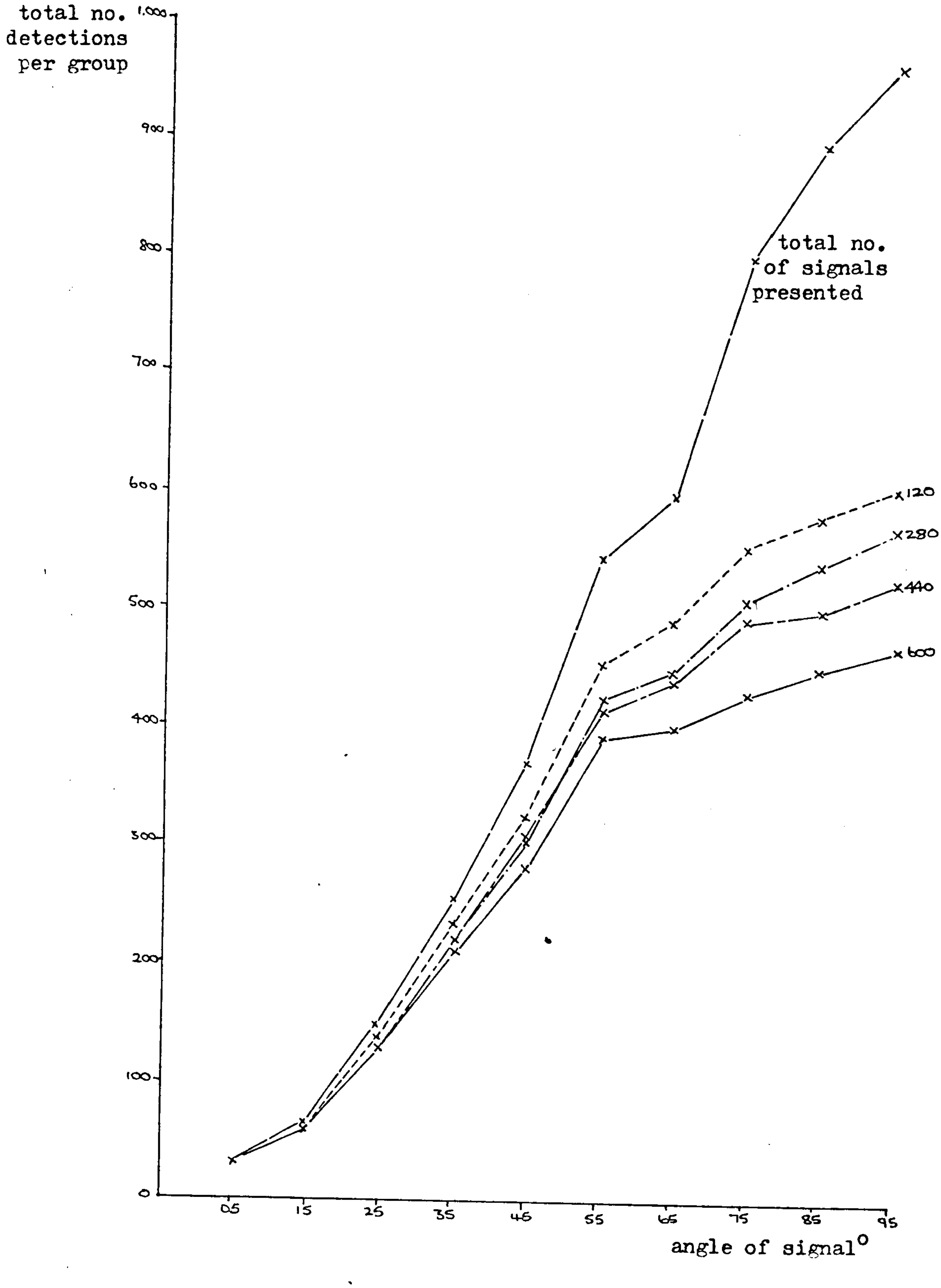
—·—·— 280

—··—·— 440

——— 600

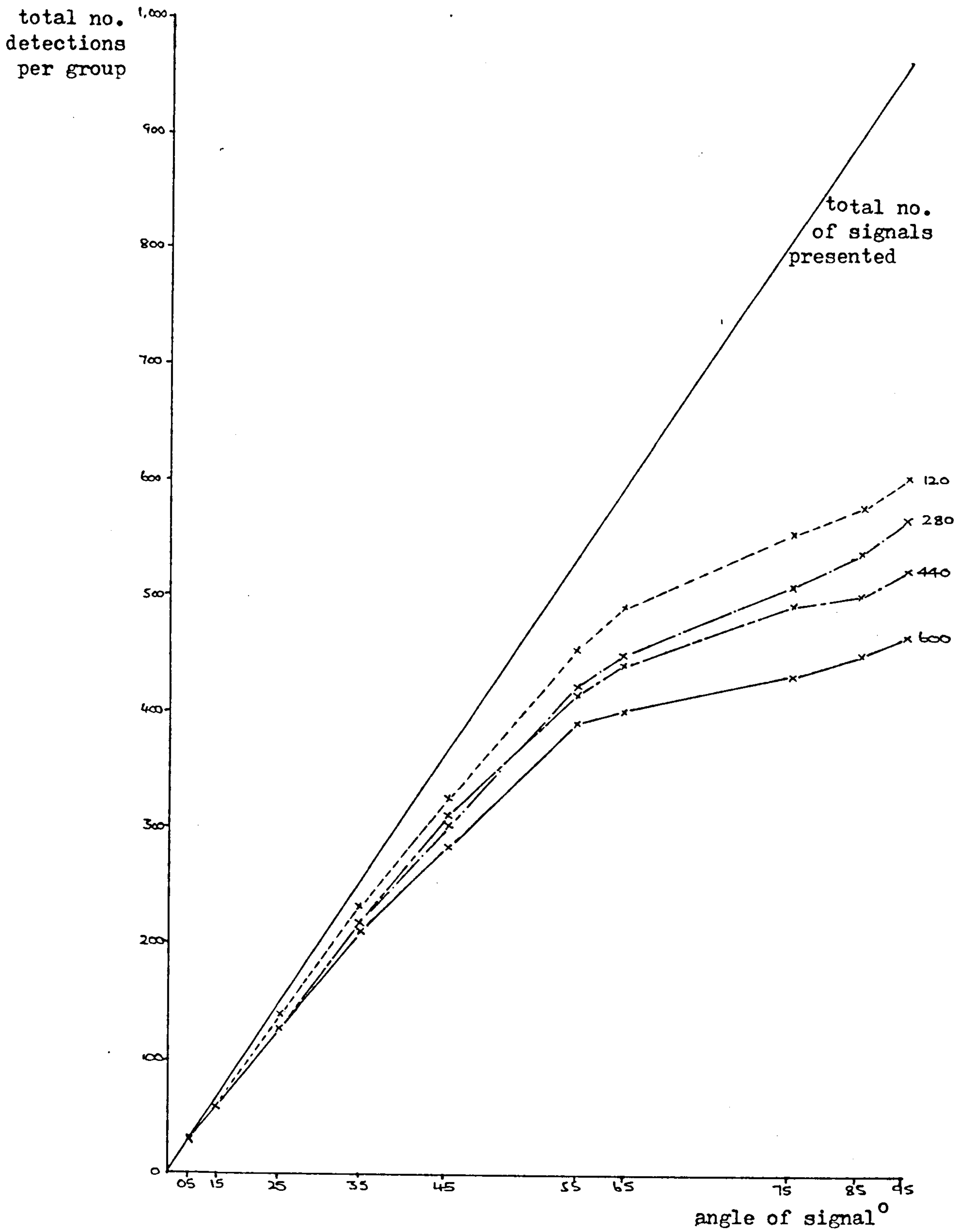
Graph 1.

Detections by an-le of signal by group (cumulative).



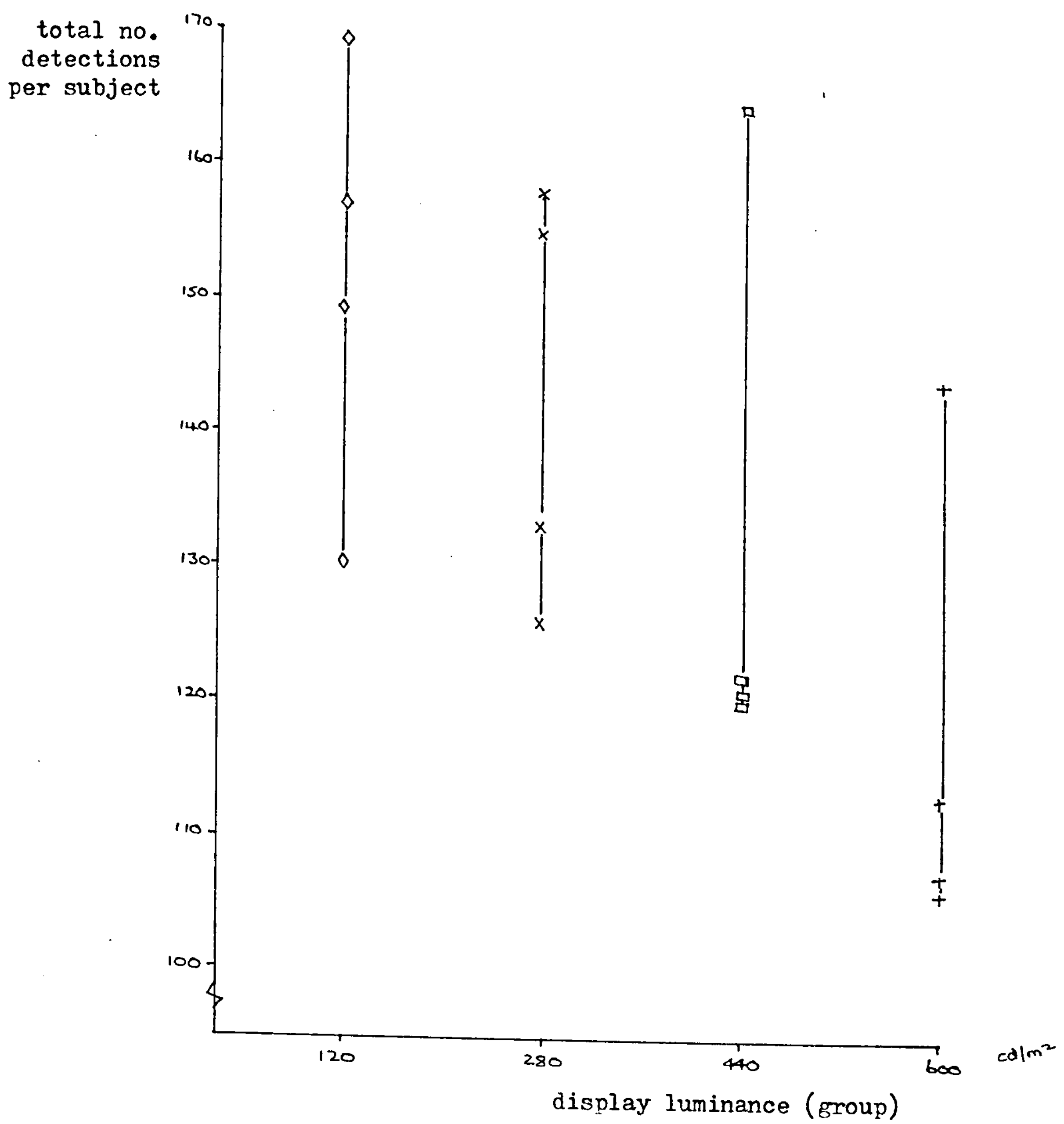
Graph 2.

Detections by angle of signal by group (cumulative - adjusted).



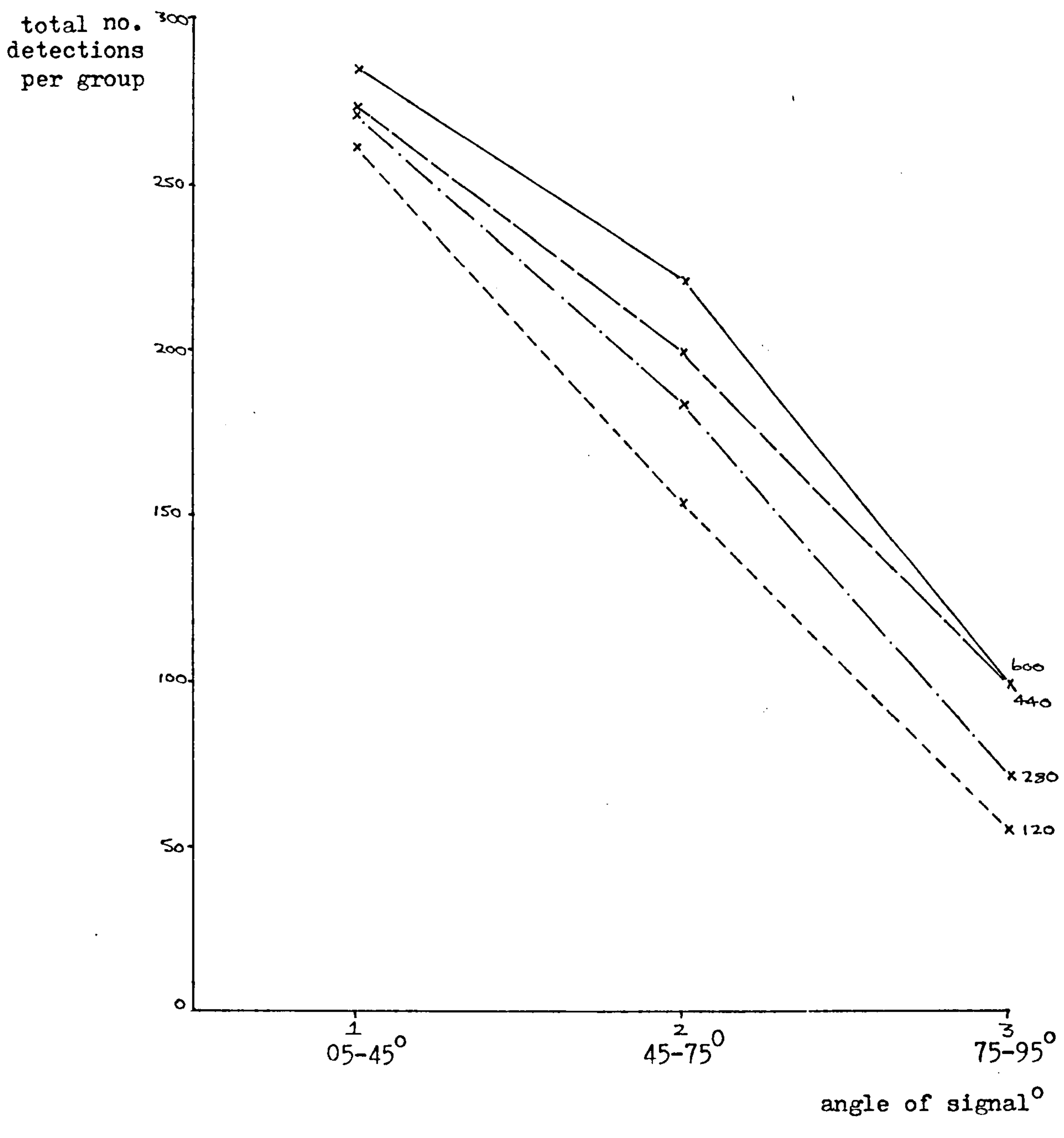
Graph 3.

Detection scores - distribution between groups.



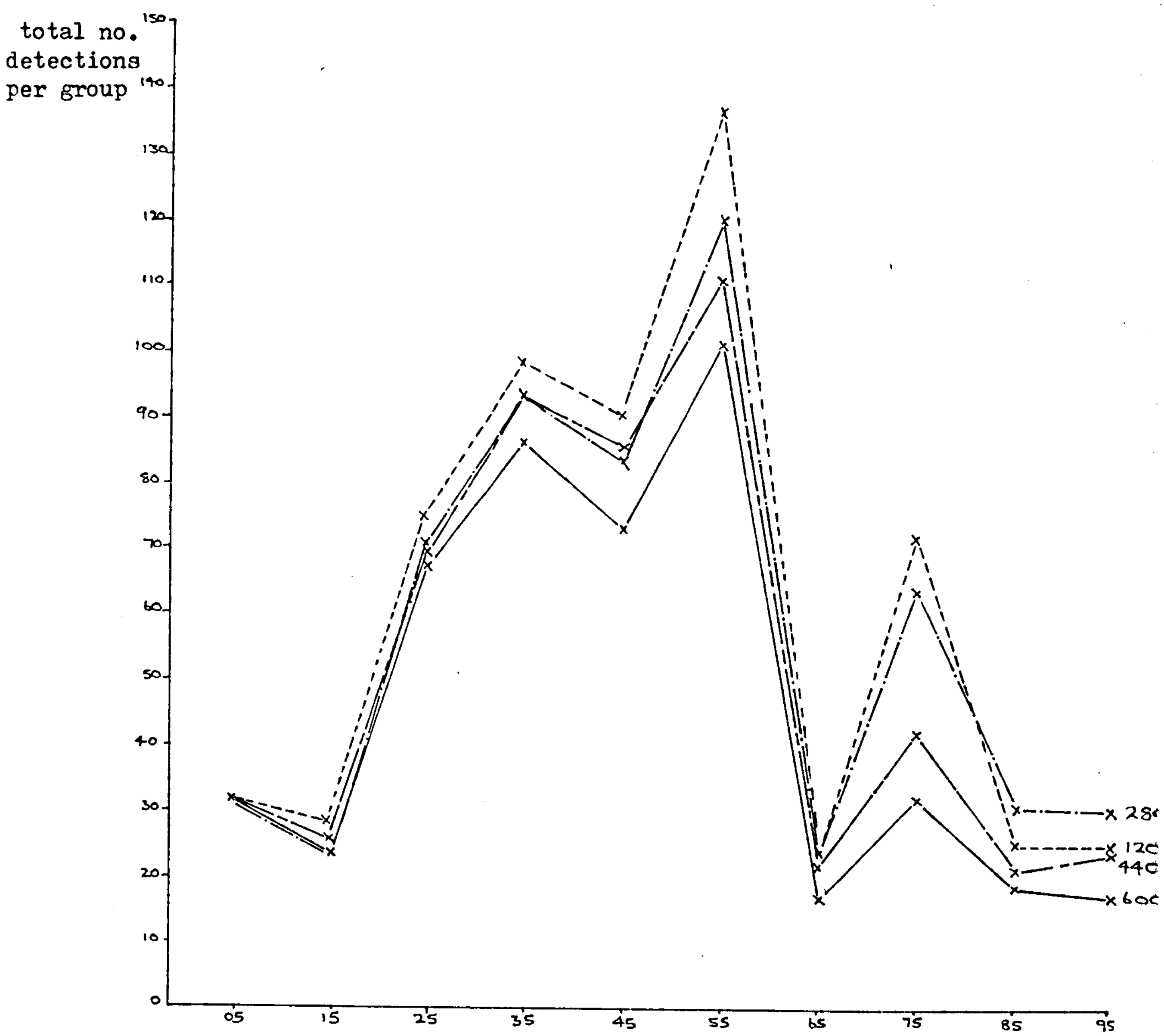
Graph 4.

Detections by visual angle (grouped) by display luminance.



Graph 5.

Detections by angle of signal by display luminance (group).

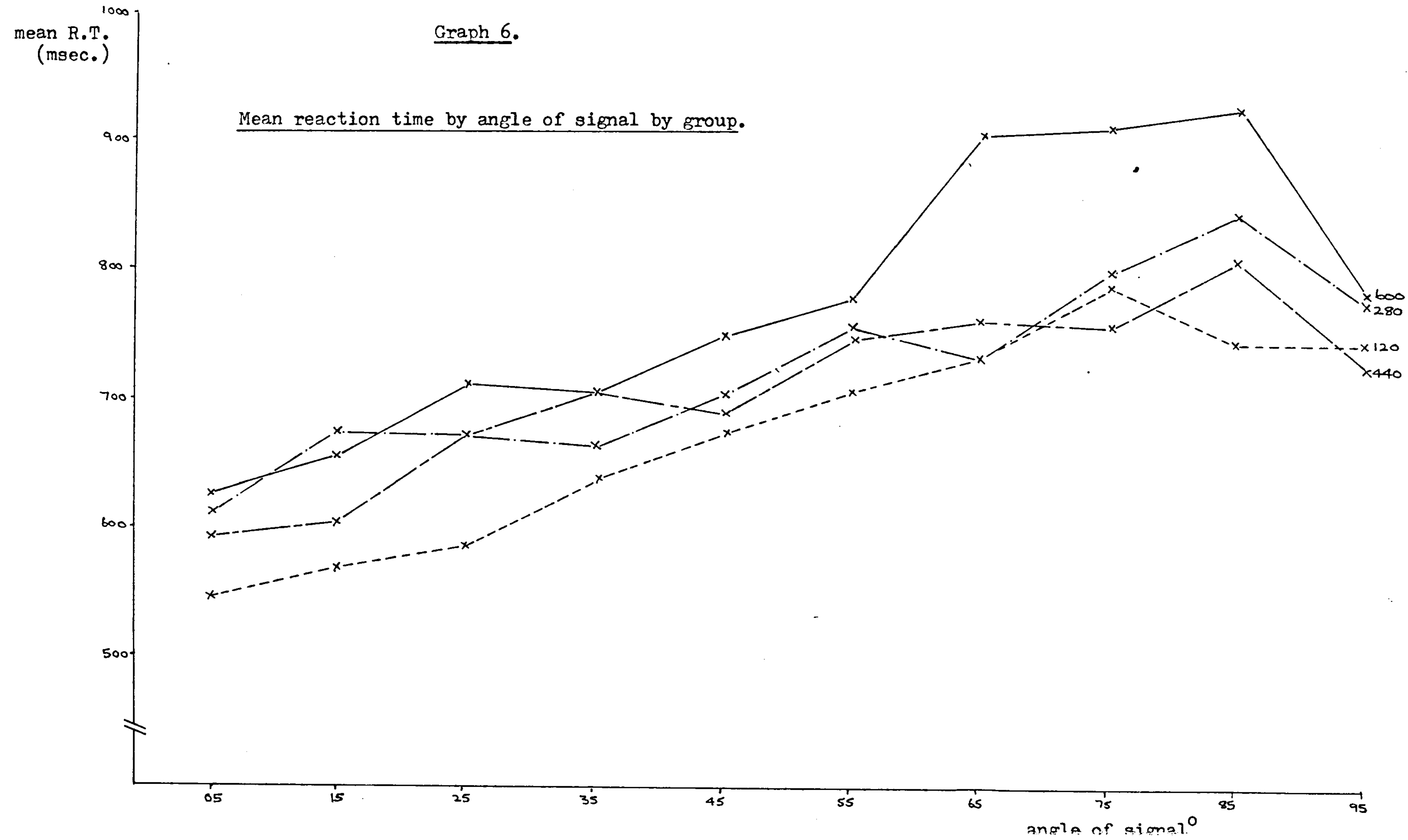


Actual no. of presentations at each angle	32	32	80	112	112	176	48	208	96	64

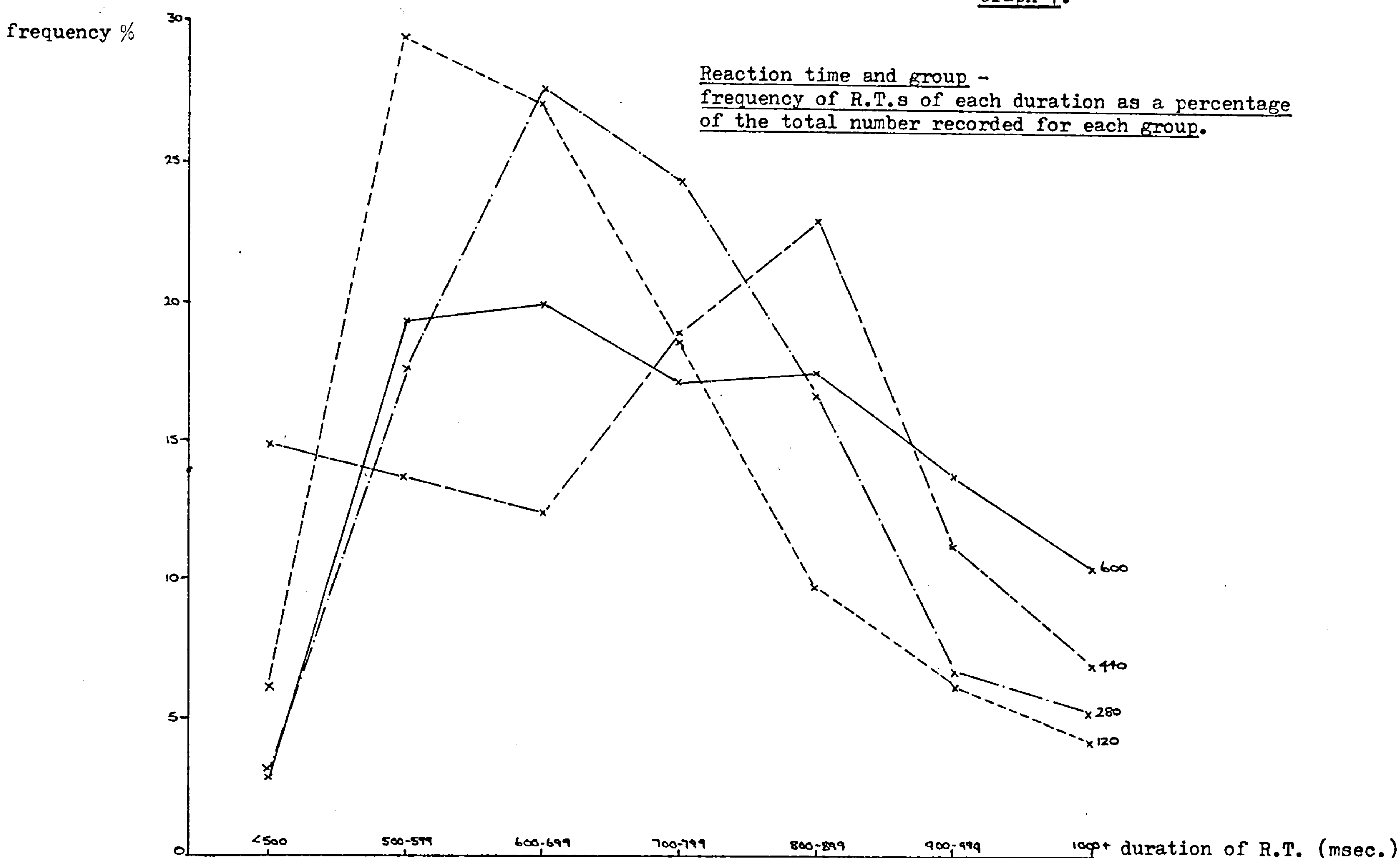
angle of signal°

Graph 6.

Mean reaction time by angle of signal by group.



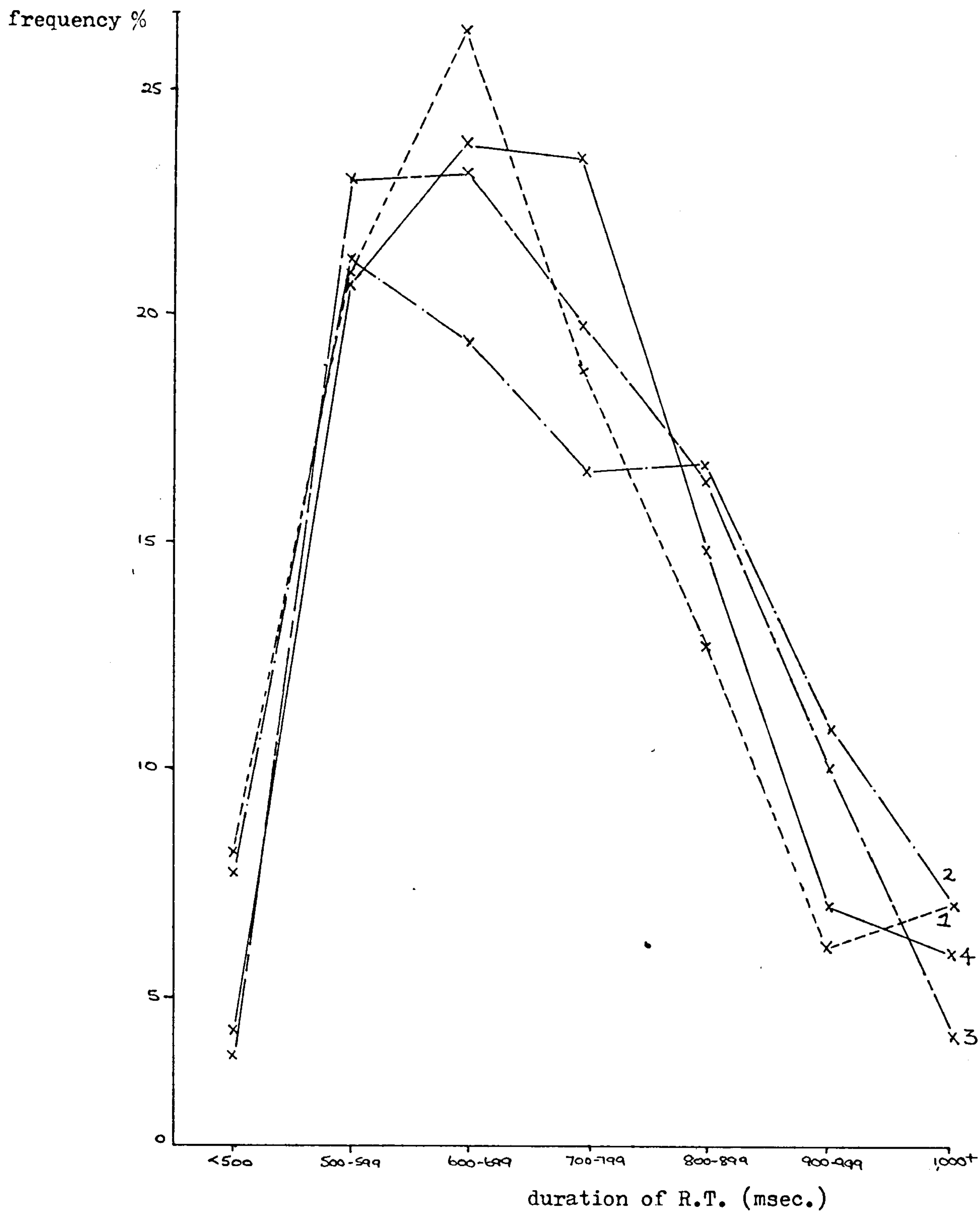
Graph 7.



frequency %
30
25
20
15
10
5
0
Reaction time and group -
frequency of R.T.s of each duration as a percentage
of the total number recorded for each group.
600
440
280
120
<500
500-599
600-699
700-799
800-899
900-999
1000+
duration of R.T. (msec.)

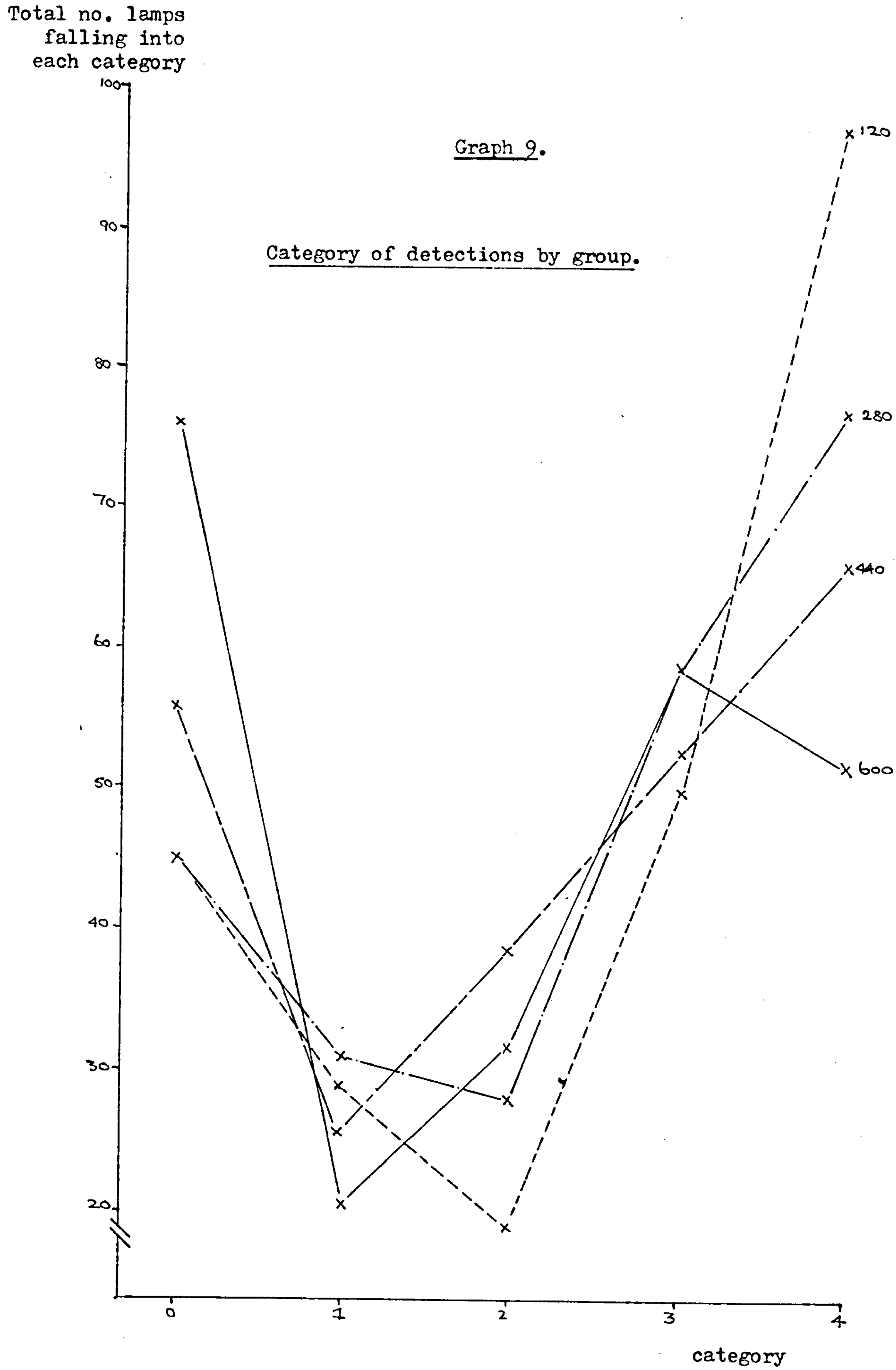
Graph 8.

Reaction time and trial -
frequency of R.T.s of each duration as a percentage
of the total number recorded for each trial.



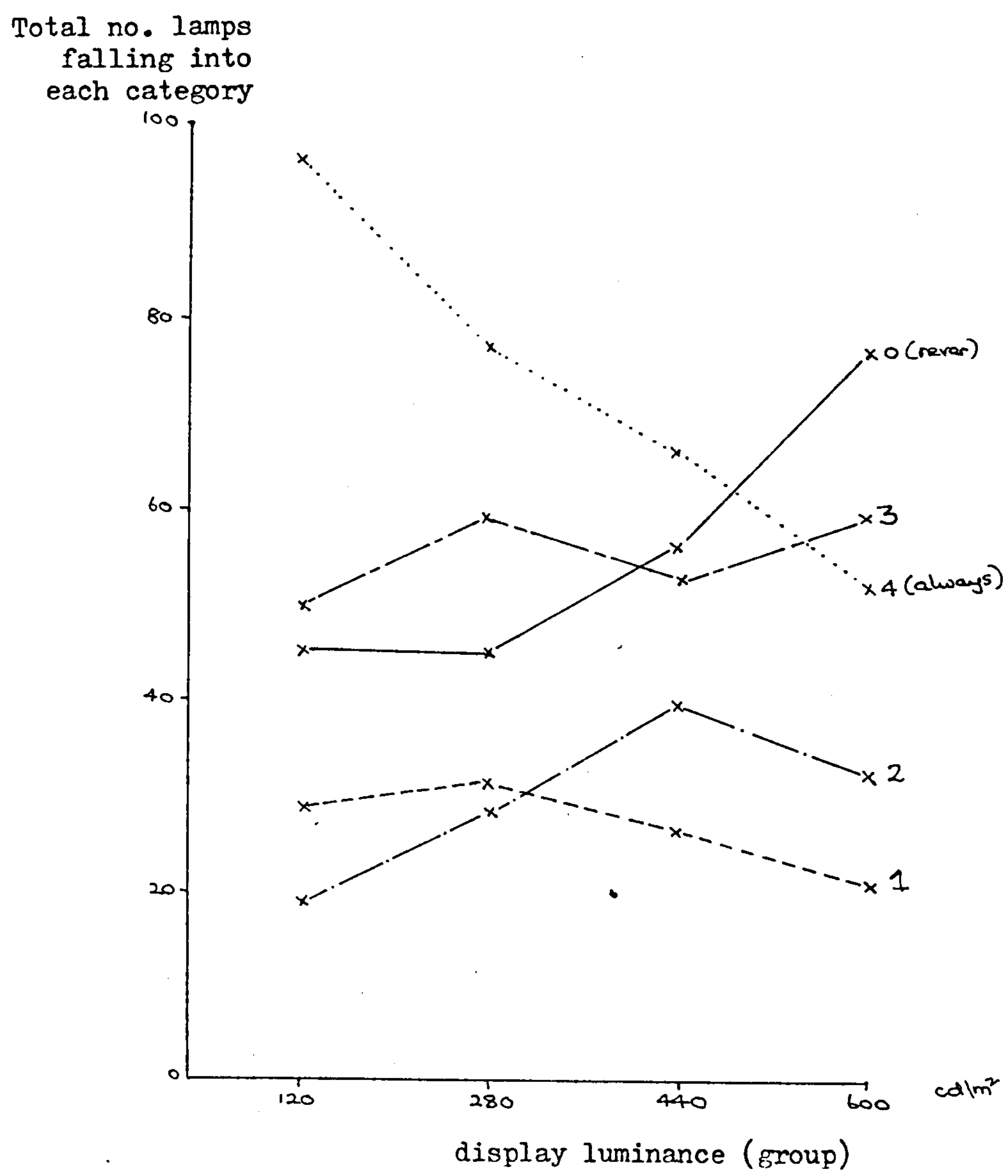
Graph 9.

Category of detections by group.



Graph 10.

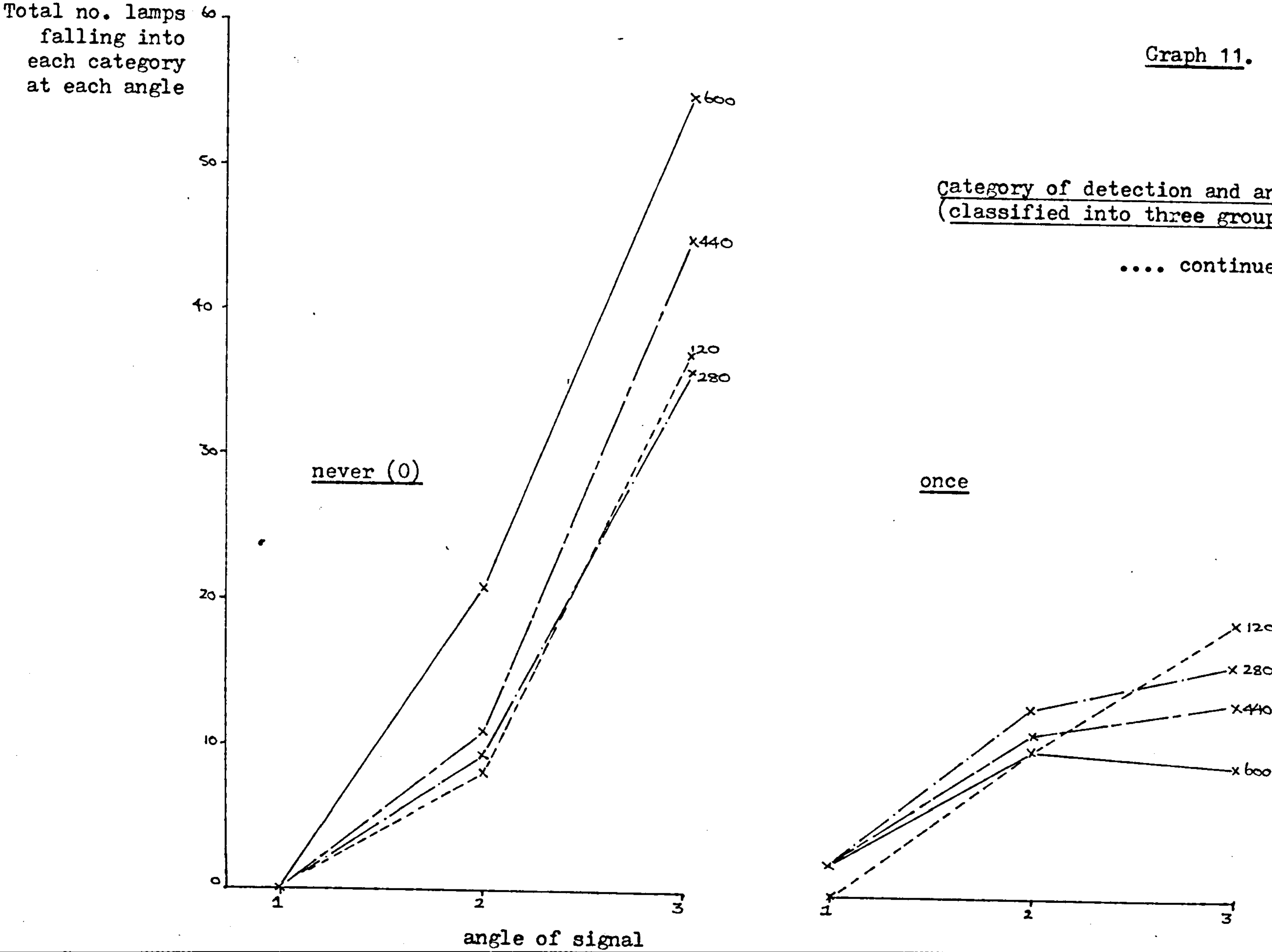
Category of detections by group.



Graph 11.

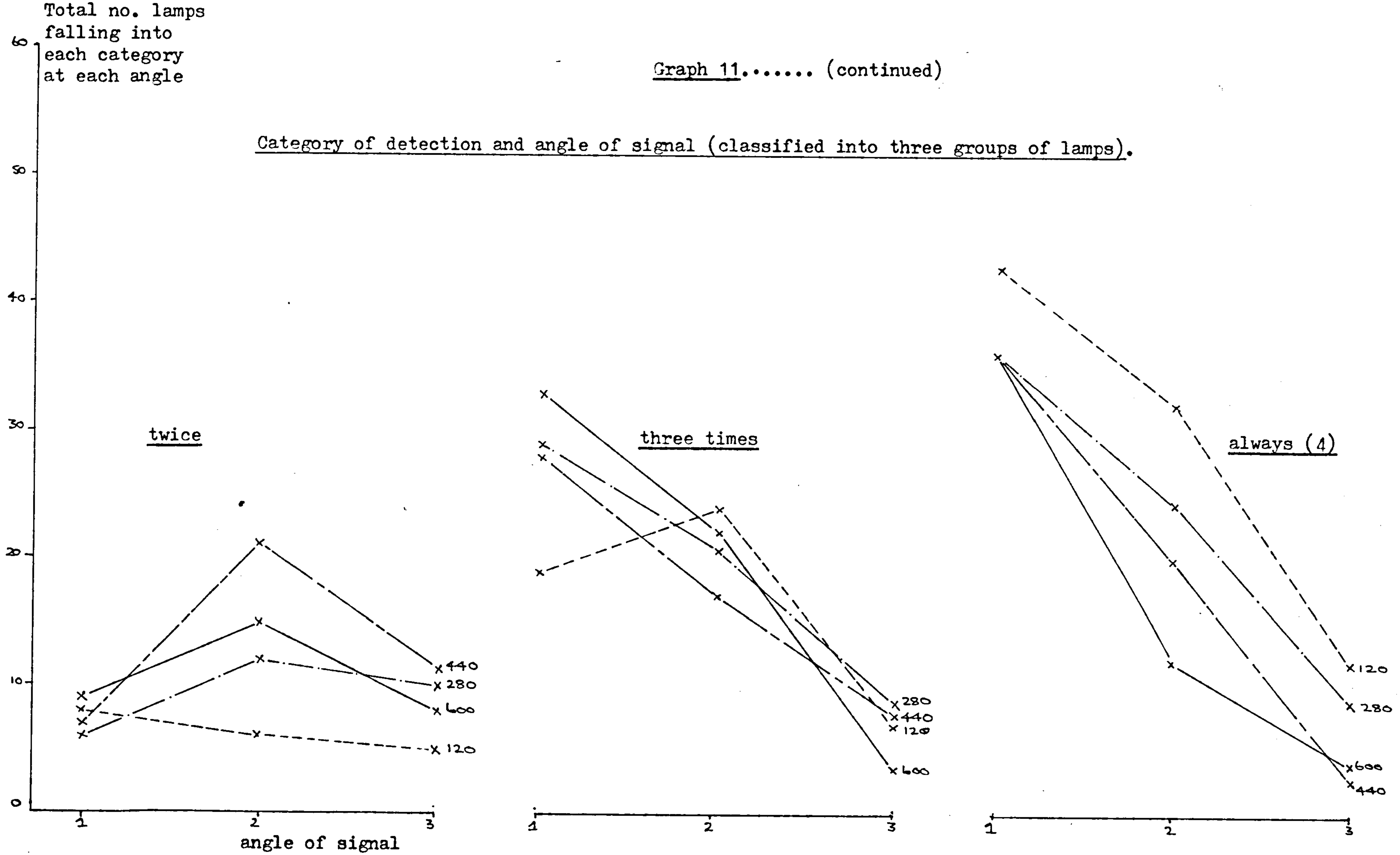
Category of detection and angle of signal (classified into three groups of lamps)

.... continued overleaf



Graph 11....... (continued)

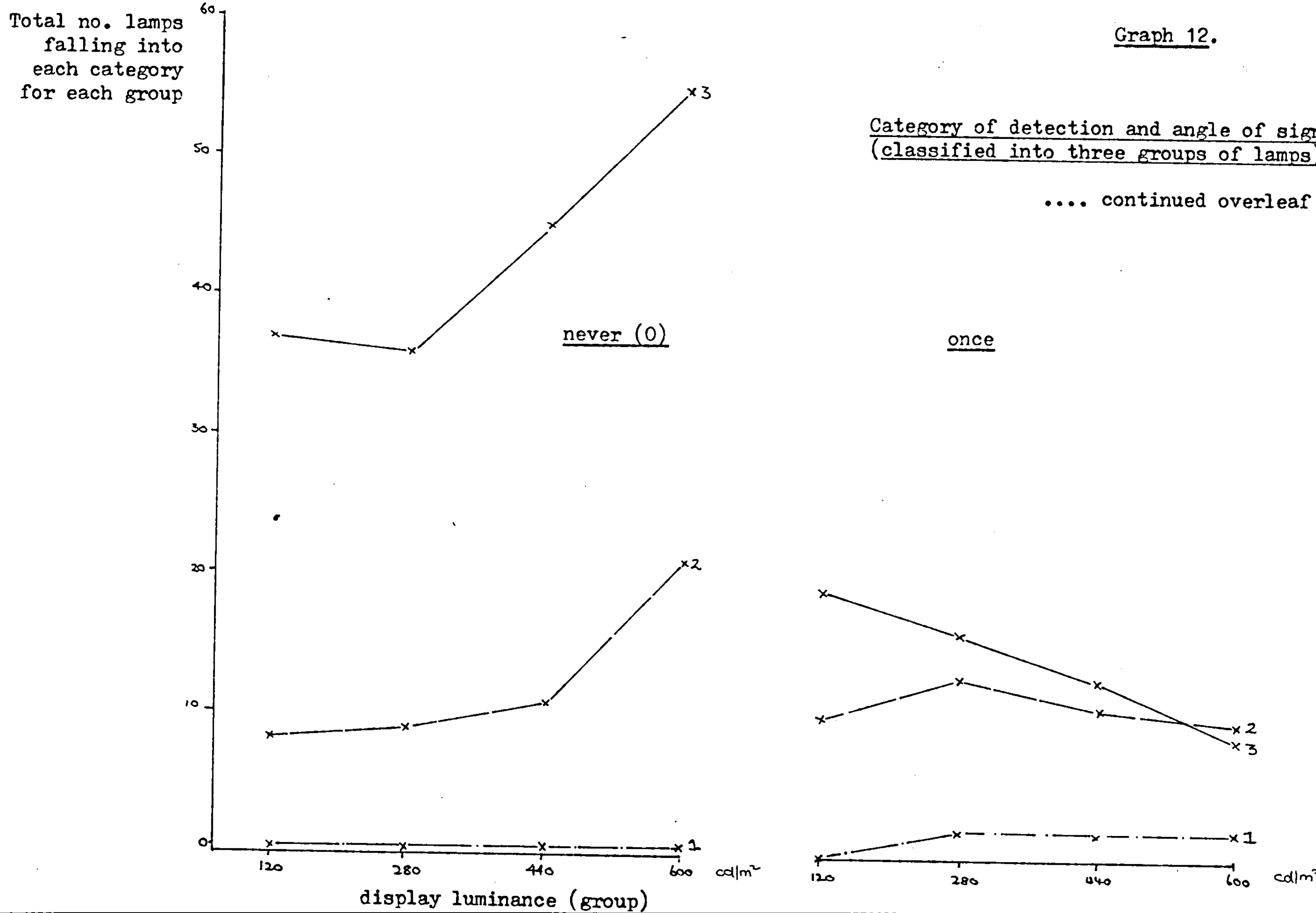
Category of detection and angle of signal (classified into three groups of lamps).



Graph 12.

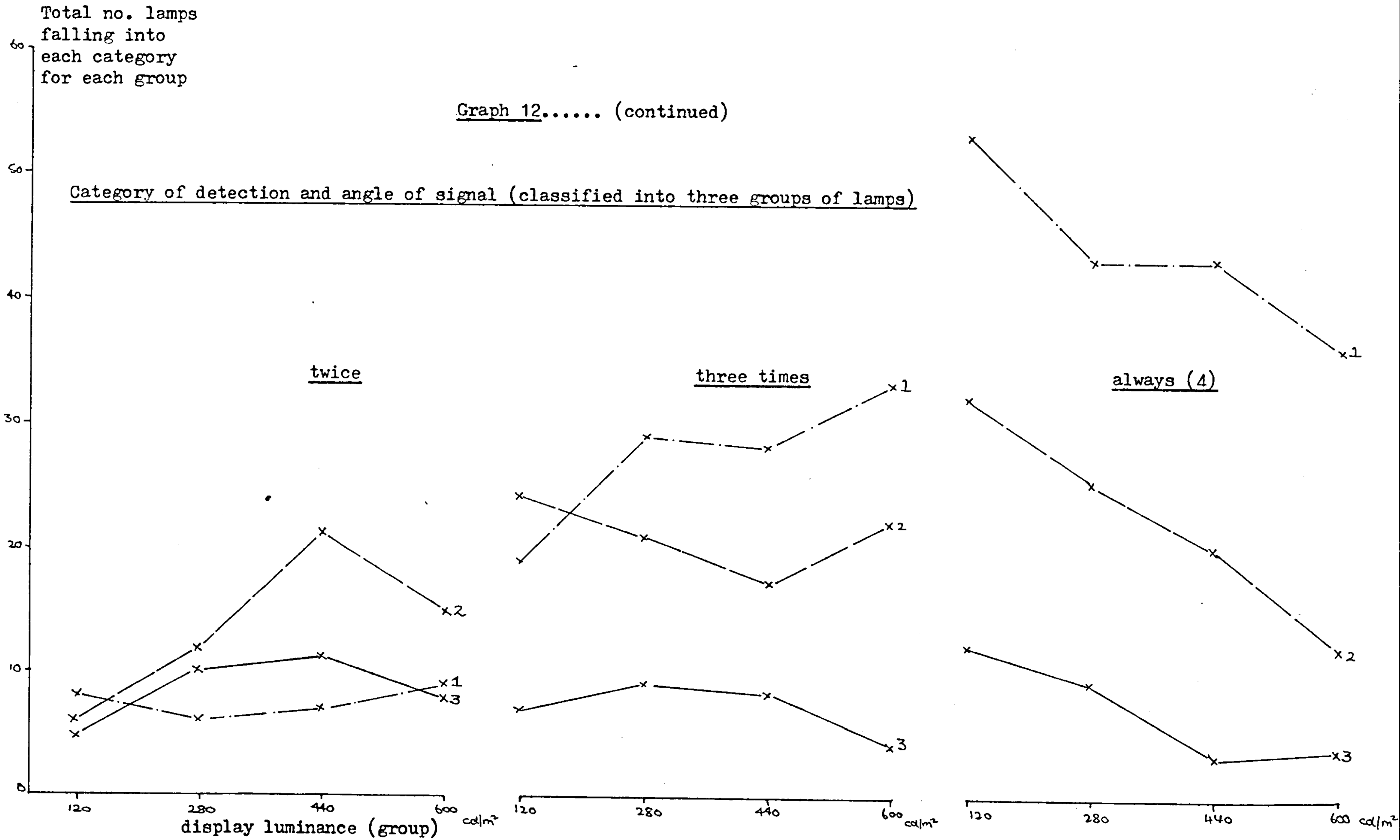
Category of detection and angle of signal (classified into three groups of lamps)

.... continued overleaf

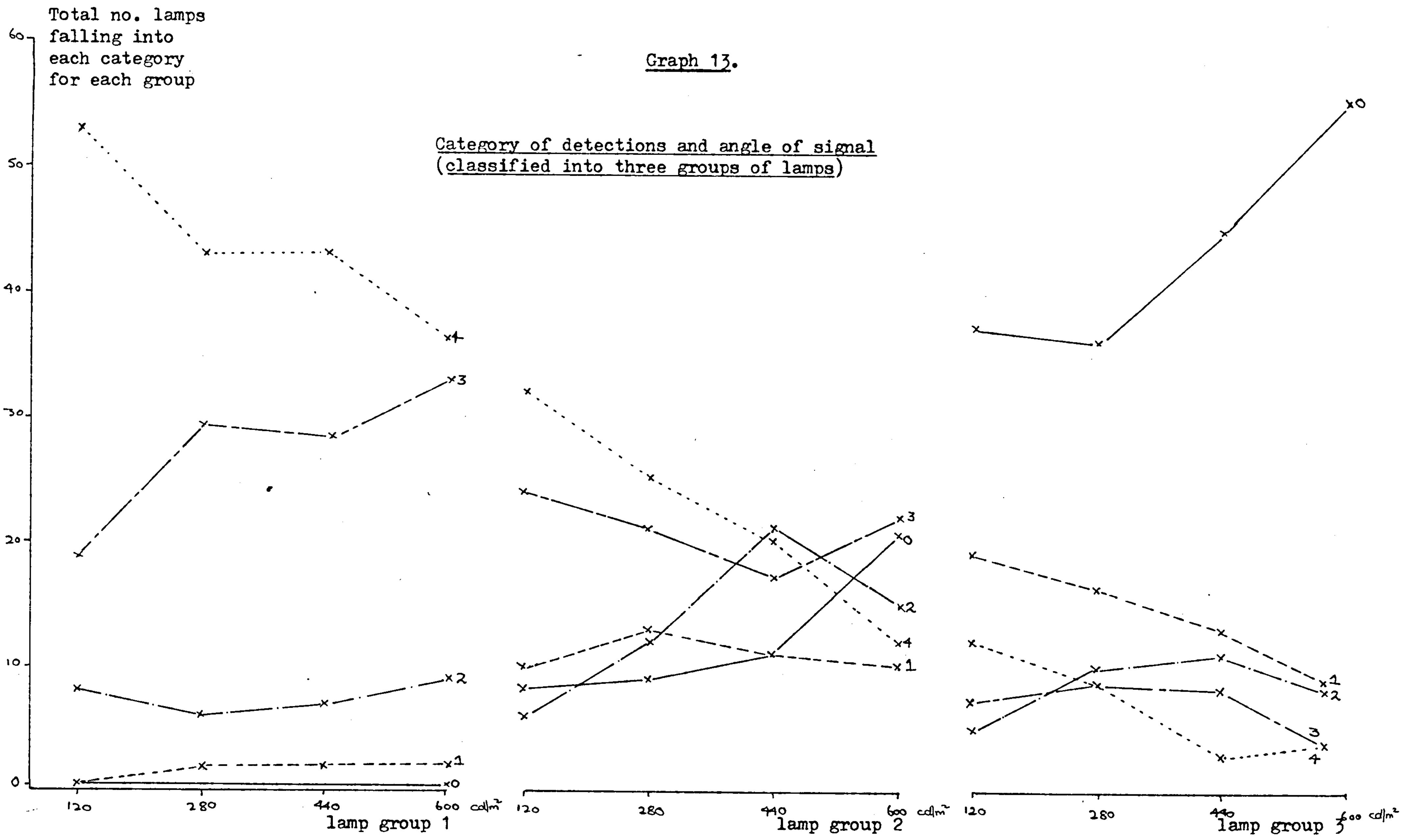


Graph 12...... (continued)

Category of detection and angle of signal (classified into three groups of lamps)

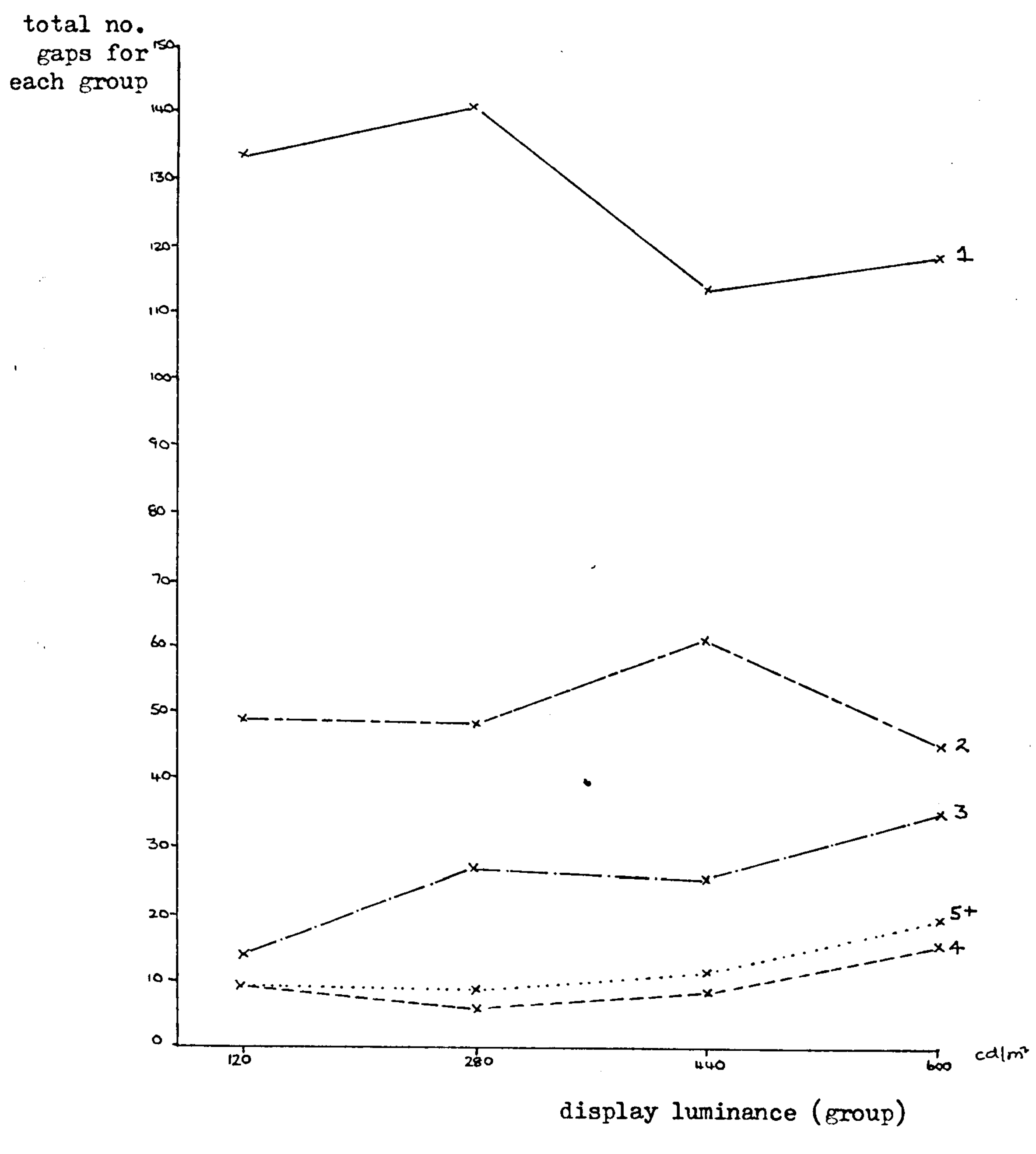


Graph 13.


Total no. lamps falling into each category for each group
Category of detections and angle of signal (classified into three groups of lamps)
60
50
40
30
20
10
0
120
280
440
600 cd/m²
lamp group 1
lamp group 2
lamp group 3
0
1
2
3
4

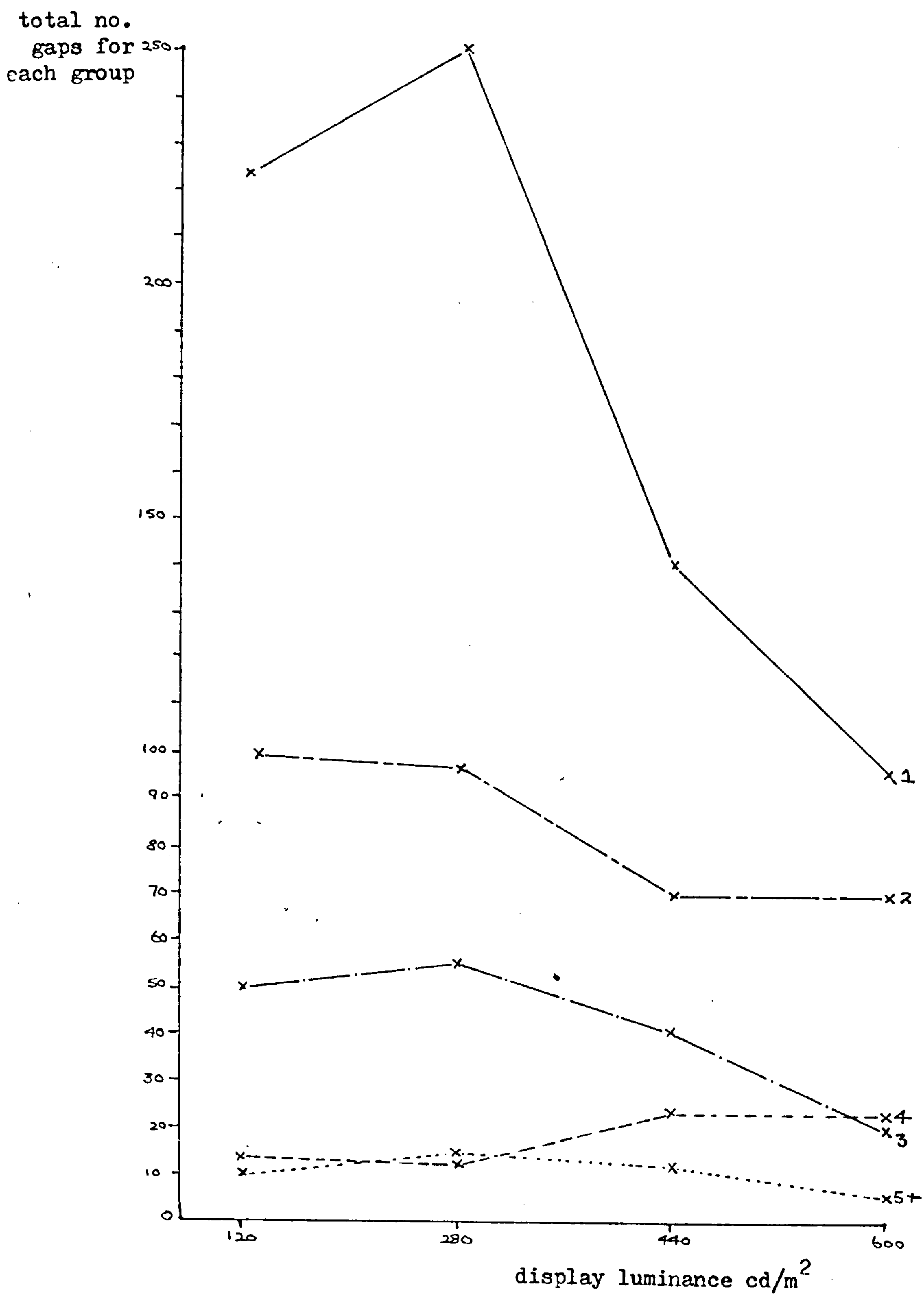
Graph 14.

Gap length and display luminance (group).



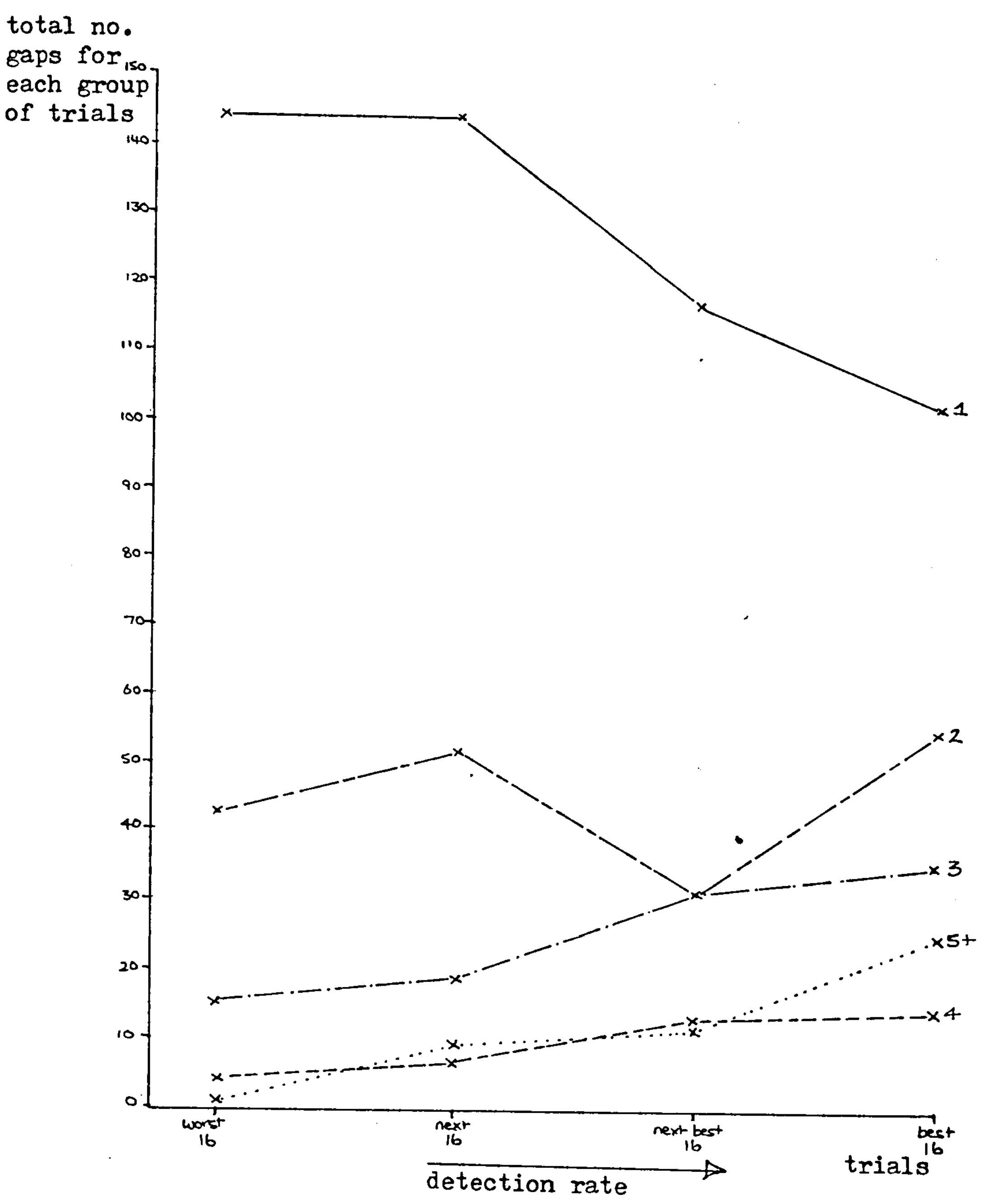
Graph 15.

Gap length and display luminance (pilot experiment).



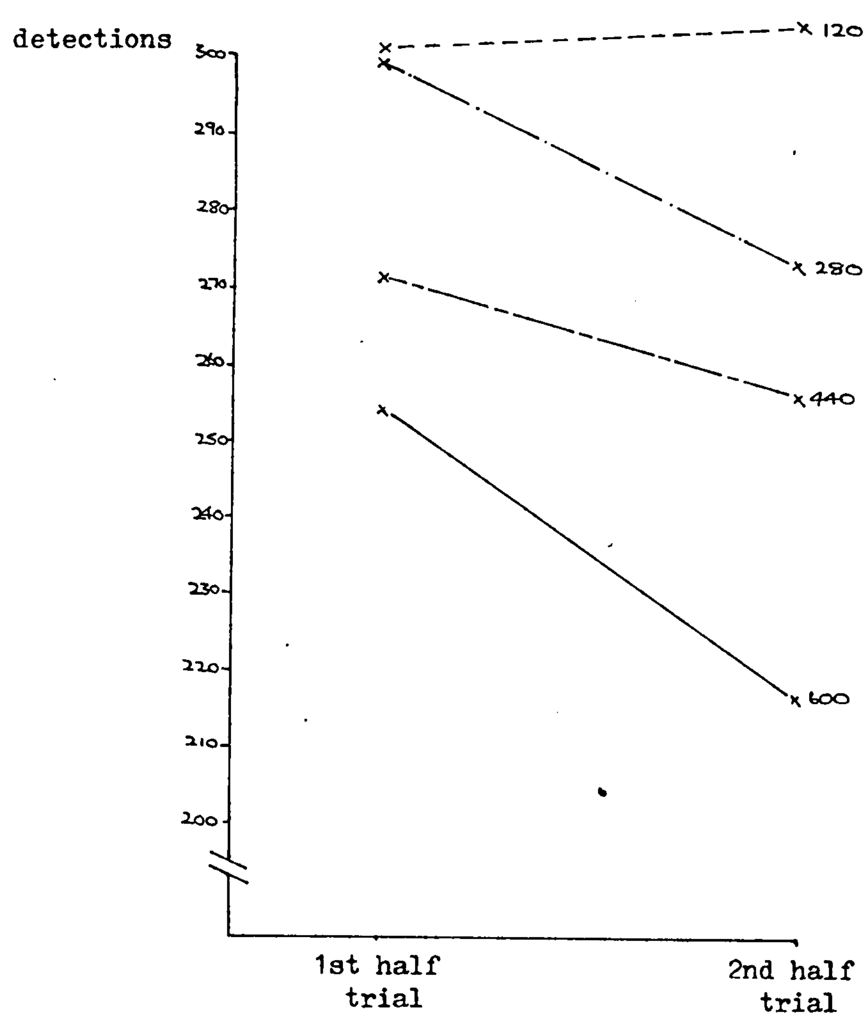
Graph 16.

Gap length and detection rate - 64 trials



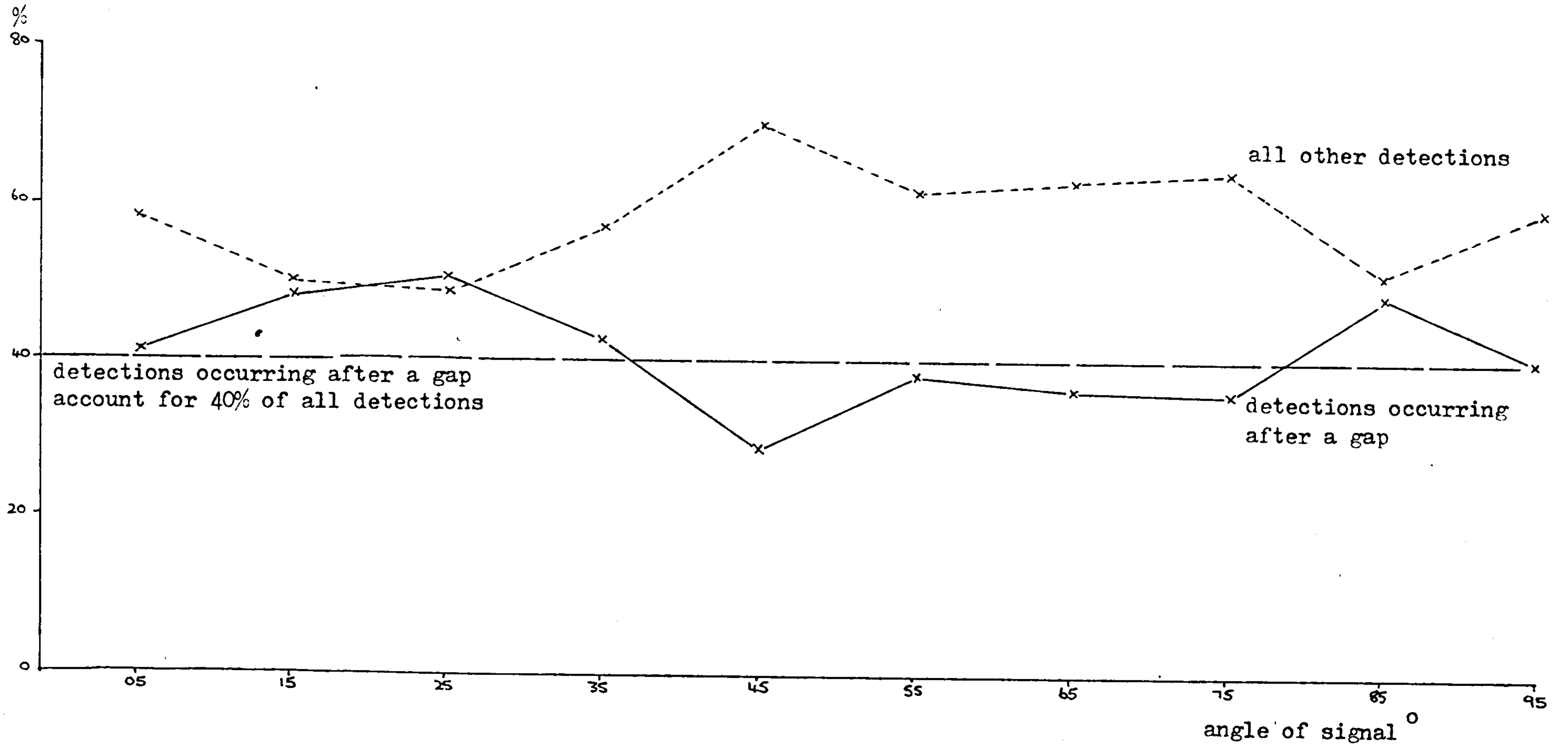
Graph 17.

Detections by half-trial.



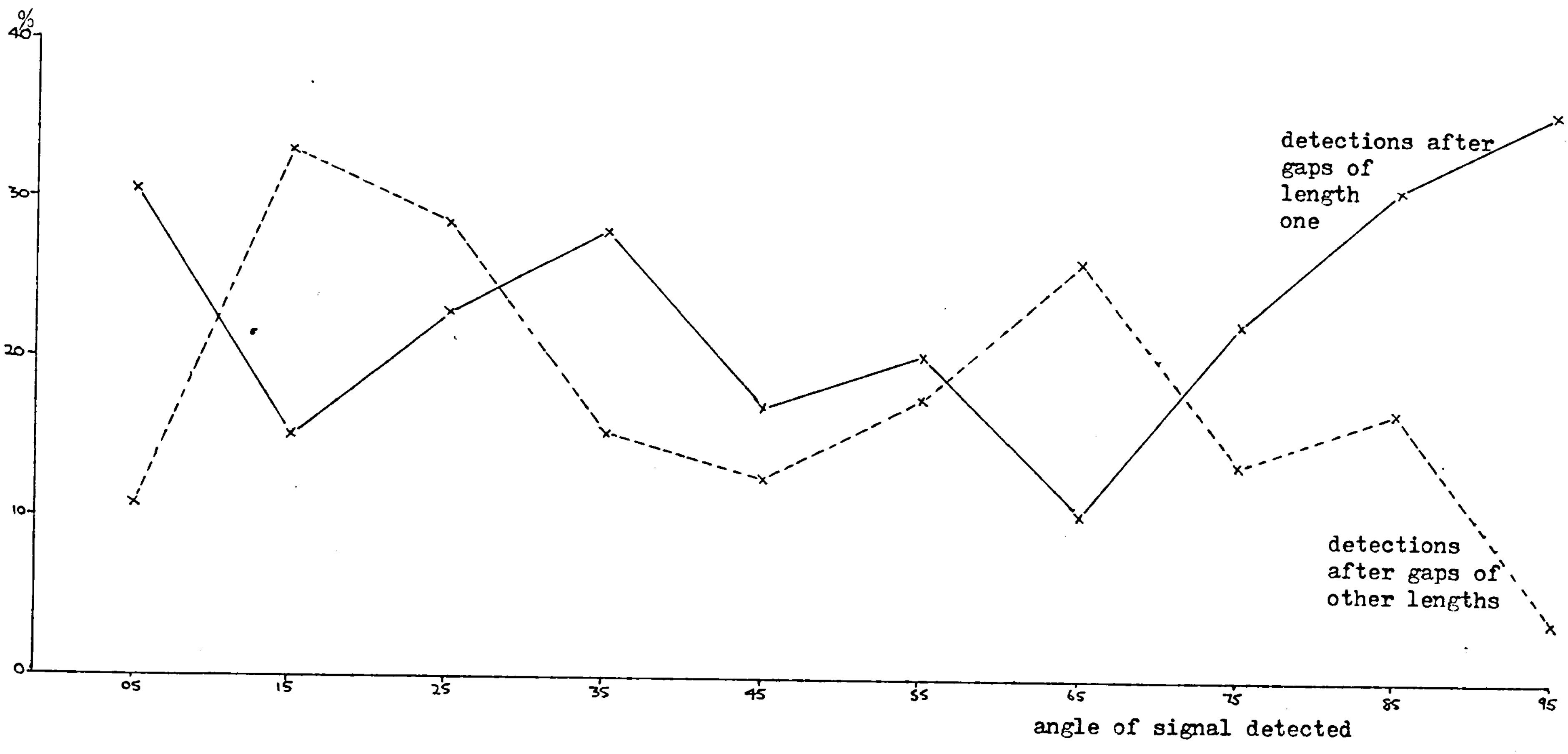
Graph 18.

Location of detections occurring after a gap compared with all other detections: as % of total detections at each angle.



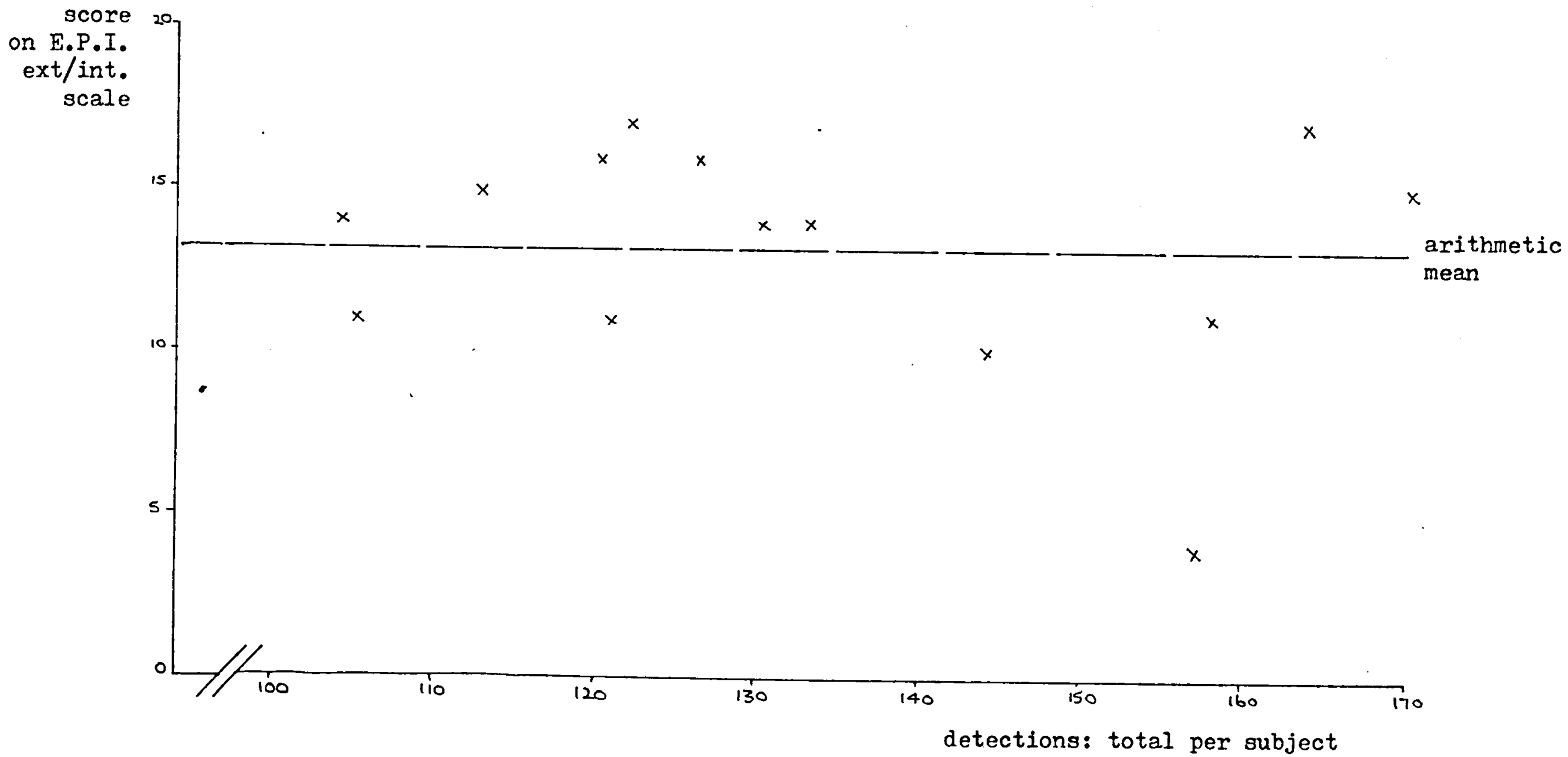
Graph 19.

Location of detections occurring after a gap: gaps of length one signal compared with all other gaps, as a percentage of total detections at each angle.



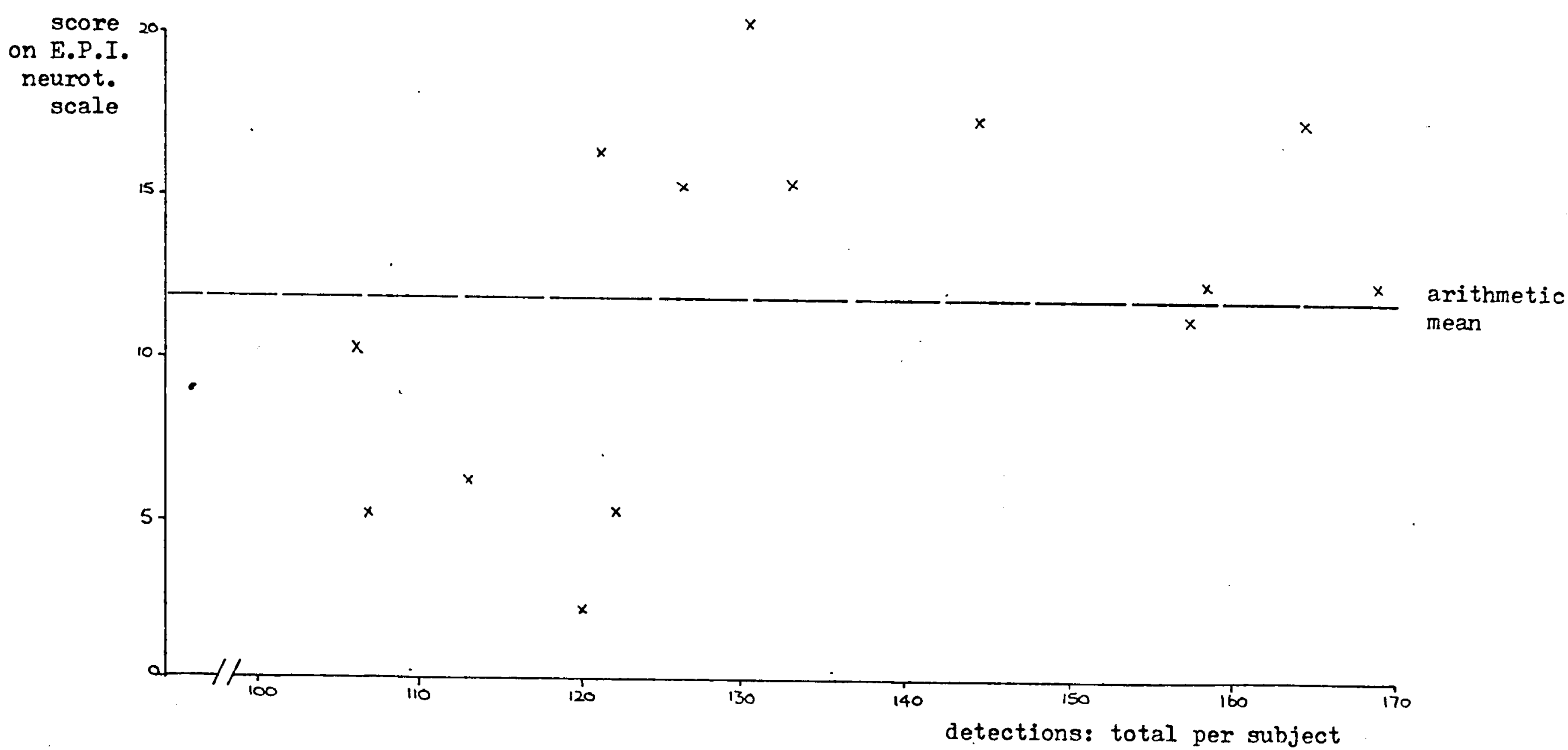
Graph 20.

Extraversion/introversion and detection rate.



Graph 21.

Neuroticism and detection rate.



Graph 22.

Neuroticism and gap length: expressed as a percentage of the total number of gaps counted for each group of subjects (classified by neuroticism score).