PERFORMANCE DECREMENT IN VIGILANCE TASKS

FACTORS AFFECTING PERFORMANCE DECREMENT IN VIGILANCE TASKS

BY

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ABSTRACT

Three experiments are reported in this thesis. The first two experiments were concerned with counteracting the performance decrement observed in vigilance tasks. Previous studies have shown that the criterion parameter β , of signal detection theory, increases during a vigilance session. The experiments reported here manipulated variables affecting β in order to keep it at a constant level throughout a session. In experiment I, signal probability was increased within sessions in an auditory vigilance task. This manipulation reduced the decrement in performance below that shown by control groups. The second experiment involved a visual task. Signal probability was held constant within sessions and artificial signal probability was increased. This also had the effect of reducing the performance decrement. The third experiment investigated the relationship between discrimination threshold and the vigilance decrement. Subjects' thresholds for discriminating between two visual stimuli were obtained by means of the PEST (Parameter Estimation by Sequential Testing) technique. A decrement in performance was found when subjects performed at a 75 or 60% correct level on the threshold task, but there was no decrement when subjects obtained 90% correct on the threshold task.

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INTRODUCTION

In studies of vigilance a decrement in performance within experimental sessions is commonly observed. Three experiments are reported in this thesis which attempt to isolate some of the variables influencing the decrement.

It has been suggested that during a vigilance session subjects' criteria become more conservative. Subjects become less willing to report the presence of a signal, and so their performance declines. According to the theory of signal detectability (TSD), one of the variables influencing criterion is signal probability.

The hypothesis underlying the first experiment was that if signal probability was increased within a vigilance session, the tendency for subjects' criteria to become more conservative would be counteracted. The experiment was also designed to investigate the effects of practise on the decrement.

The results of the experiment indicated that when signal probability was increased within a session the criteria became less conservative and the decrement in performance was reduced. Varying signal probability between sessions had no significant effect upon performance. Subjects exhibited a performance decrement on three consecutive days of testing. On the fourth and fifth days the level of performance remained stable throughout the sessions.

The second experiment involved the presentation of artificial signals. In many vigilance studies the presence of artificial signals has been shown to improve detection performance. It was hypothesized that if signal probability was held constant and the probability of an artificial signal increased within a session, the subjects' criterion would be stable and the performance decrement counteracted.

In Experiment II signal probability was increased within sessions in one condition. In another condition signal probability was held constant within sessions and artificial signal probability was increased. This manipulation had the same effect of stabilizing subjects' criteria as the condition in which signal probability was increased within sessions. The performance decrement disappeared.

An issue which arose during the running of the first two experiments was the relationship between the subjects' discriminatory ability on a task and the decrement in performance during the vigilance session.

In the third experiment subjects' thresholds for discrimination were measured before and after participation in a vigilance session. Subjects who showed 90% correct discrimination in the threshold task showed no decrement in performance in the vigilance session. Subjects maintaining 75% correct discrimination on the threshold task displayed a sharp decrement in performance in the vigilance session. The subjects who had a threshold of 60% correct discrimination showed a performance decrement on the vigilance task, but it was not as pronounced as for the 75% correct threshold group.

HISTORICAL REVIEW

Vigilance is a branch of attention theory concerned with the effect of time on the performance of monitoring tasks. Most of the research published on vigilance involves the auditory and visual modalities. If subjects (Os) carry out a task for a long period of time a decrement in performance is often observed. Researchers have been interested in determining what variables affect this decrement and what mechanisms may account for it. The experiments proposed in this report are concerned with furthering understanding of the decrement by learning how to counteract it.

In a typical vigilance experiment a series of discrete stimuli called "events" are presented. The number of events which occurs in a specified period of time is called the "event rate". There are two types of events: "nonsignals" and "signals". Signals differ from nonsignals on some continuum such as intensity or temporal length. It is the O's task to discriminate between the two types of events and make an indication to the experimenter (E) whenever a signal is perceived. There are many more nonsignals than signals in a vigilance session. The ratio of the number of signals to the number of nonsignals occuring in a given period of time is called the "signal probability". "Signal frequency" is a measure of the number of signals presented in a period of time without reference to the number of nonsignals. The length of an experimental session is usually 1 to 1½ hours. When analysing results, the E breaks the session up into blocks of time or "time periods" and looks for differences in performance from the beginning to the end of the session.

Much of the work done with the auditory modality involves discrimination between white noise pulses of differing intensity or length. A much wider variety of tasks has been investigated with vision. Detection of brighter than usual flashes in a series of light flashes, larger than usual deflections of needles on dials, and double jumps of a clock hand on a simulated clock face are examples of common visual paradigms.

In reviewing the vigilance literature one finds many discrepancies in results which are often attributed to modality effects. However Hatfield and Loeb (1968) have suggested that these discrepancies would be better accounted for if vigilance experiments were subdivided to distinguish between closely and loosely coupled tasks. A closely coupled task is one in which it is difficult for Os not to receive the stimulus information. A loosely coupled task is one in which an O's attention may be diverted from the stimuli and he may therefore fail to receive event information. Auditory tasks are generally considered to be closely coupled. An example of a closely coupled visual task is one in which an O's eyelids are taped shut and brightness discrimination is investigated. Visual tasks in which an O's gaze may wander from the display are loosely coupled. Hatfield and Loeb (1968) maintain that coupling has always been confounded with sense modality and describe an experiment in which coupling effects are shown to account for a larger proportion of the variance of the data than modality effects.

Signal Detection Theory

Until the early 1960's the measure of performance usually used to describe behavior in vigilance tasks was per cent correct detections. Many studies have used reaction time but this response measure will not be focused on here since it is not directly related to the research to be proposed. For a review of reaction time studies of vigilance see Buck (1966). One of the problems with the per cent correct detection measure is that it ignores false positive responses and is therefore an incomplete index of behavior. Swets et. al. (1961) introduced the theory of signal detectability (TSD) to the psychological literature.

TSD assumes two sensory distributions, one for noise (nonsignal) and one for signal plus noise (signal), which are located on a common observation continuum. The theory describes performance in terms of the relative position of the two sensory distributions on the continuum. The distance between the means of the two distributions is represented by the parameter d'. d' is thought of as an index of an O's sensitivity to the signal. An O sets a criterion at a point on the observation continuum and chooses his response according to the side of the criterion on which an observation falls. The ratio of the ordinates of the two distributions at the criterion is represented by the parameter β. β is a measure of an O's criterion. It may be thought of as an index of an O's willingness to indicate that a signal is perceived.

Because TSD uses false positive data, and because it provides parameters which distinguish between sensitivity and criterion in performance, it has been used extensively in studies of vigilance. In most studies in which performance decrement is found, a TSD analysis has shown that d' remains constant over a session and β increases, (e.g. Binford and Loeb, 1966; Hatfield and Loeb, 1968; Jerison et. al., 1965; Loeb and Binford, 1968). In other words, an O's sensitivity to the signal does not change, but his criterion becomes more conservative. In terms of the sensory distributions, the criterion is moved closer to the mean of the signal distribution. The O becomes less willing to indicate that a signal was observed as the duration of the session increases.

Although d' is usually constant within a vigilance session, it may increase between sessions. Colquhoun and Edwards (1970) ran subjects for eight days in three different vigilance tasks. O's in each group exhibited an increase in d' from day 1 to 8. This result is supported by some studies, (Binford and Loeb, 1966) (Buckner et al., 1960), but many researchers have found no change in d' between sessions, (Chiles et al., 1968; Ware et al., 1961; Wiener, 1963). It may be that an O's performance improves over sessions if the task is difficult, due to perceptual or discrimination learning. If the vigilance task is fairly easy the O's may be performing at a high level from the beginning and sensitivity may not increase noticeably between sessions.

There is some controversy over the validity of using TSD in a vigilance paradigm, since it has generally been found that values of d' are somewhat higher than those found in detection experiments, and values of β are sometimes so high as to be meaningless, (Jerison et. al., 1965; Taylor, 1967). Mackworth (1970) has pointed out that many vigilance paradigms do not consist of discrete trials, and that in order to use TSD the data has to be segmented into trials, thus introducing artificiality into the analysis.

Jerison et. al. (1965) found that they could account for the high β values they obtained by postulating three modes of observing during a vigilance session. Alert observing was a state of optimum performance. Blurred observing resulted in increases in the variances of both sensory distributions, and therefore an increase in d', but no change in β. The third state, distraction, was equivalent to a lack of attending by the O, and resulted in a huge increase in β. During this state no responses would be made to any signals. This division of attention into three states appears somewhat arbitrary. Most researchers continue to use the traditional approach to TSD in vigilance tasks, using the parameter values to indicate trends rather than focusing on their absolute values.

According to TSD, the value of β is influenced by payoffs and by signal probability. Levine (1966) conducted a study to investigate the effect on β of varying the cost of a Miss or a False Alarm. White noise at 72dB SPL was presented continuously throughout a session, and a signal consisted of a 300msec. 49 dB SPL pure tone superimposed upon the noise. There were several conditions involving different costs of Misses and False Alarms. The signal probability was held constant over these oonditions. The general finding was that under high cost conditions for both Misses and False Alarms, the value of β rose to a very high level by the end of a session. In low cost conditions the value of β rose from its initial level but was significantly lower than in the high cost conditions. As TSD would predict, d' was not affected by the cost manipulations.

Williges (1971) manipulated cost of Misses and False Alarms and value of Hits and Correct Rejections, with two signal probabilities. He found that payoffs did not significantly affect β but signal probability did. He attributed the difference between his results and those of Levine (1966) to the fact that Levine did not inform his O's about the signal probability. According to Williges, this meant that the O's could only base their decision performance on payoffs. In Williges' study the O's were informed about signal probability as well as payoffs. He interprets his results to mean that signal probability has a more potent influence on criterion than payoffs.

Guralnick (1972) also found that manipulating payoffs had no effect in a visual vigilance task. The O's task was to discriminate between two vertical line lengths and decide whether they were the same or different. A yes or no response was required on each trial. Two payoff groups were investigated. In group 1 O's were told that they would accumulate one point for each Hit or Correct Rejection, and lose one point for each Miss or False Alarm. In the second group 10 points were allotted for a Hit, 1 for a Correct Rejection, -10 for a Miss, and -1 for a False Alarm. O's were run for eight sessions and in both groups were told that the O with the highest point score over the eight days would receive a $25. bonus. The performance of both groups was almost identical. The reason for this may be simply that the likelihood of any one O benefiting from the bonus is small. The payoffs would probably motivate only a highly competitive O.

Most researchers in vigilance now accept TSD as a viable method of analysing results. The contribution of the theory is primarily conceptual in that sensitivity and criterion can be distinguished from the data. It should be emphasized that the values of β which are generally observed are not realistic ones, and it is the changes in these values rather than their absolute level which are of interest. It has been shown that the value of β usually rises during a vigilance session, and that the amount of increase may be affected by signal probability and payoff manipulations.

Event Rate

Performance on a vigilance task is affected by event rate. It has generally been found that the number of detections of signals decreases as event rate increases, (Colquhoun, 1961; Jerison and Pickett, 1964; Jerison et. al., 1965; Mackworth, 1965; Taub and Osborne, 1968).

In the Jerison and Pickett (1964) study, the nonsignal was a pair of deflections of a bar of light 29 mm. to the right of the fixation point. A signal occurred when the second deflection of the light was 35 rather than 29 mm. Sessions were 80 min. long. In one condition O's were presented with 15 signals during the session and a nonsignal event rate of 5 stimuli per min. In a second condition, the same number of signals occurred but the nonsignal event rate was changed to 15 stimuli per min. In the first condition, O's maintained a performance level of approximately 90% correct detections. In the second condition, performance dropped to 30% correct detections. A decrement in performance was observed only in the second condition. However by keeping the number of signals constant in each condition and changing the number of nonsignals, event rate is confounded with signal probability in this experiment. The signal probability in the first condition is .037 and in the second condition is .0062. Therefore the result may not be unambiguously attributed to variations in event rate.

The study by Jerison et. al. (1965) comes under the same criticism. Mackworth's (1965) paper also confounds several variables. The data presented by Taub and Osborne (1968) is more reliable, and indicates that on a loosely coupled vigilance task event rate does not affect the rate of decrement but does affect the level of performance. Per cent correct detections decreased as event rate increased.

Loeb and Binfold (1968) felt that the literature dealing with the influence of event rate on vigilance performance was conflicting. They ran an experiment using both auditory and visual tasks, which clearly separated the affects of signal frequency, signal probability, and event rate. The auditory task consisted of discriminating between

.5 sec. white noise pulses of 60 and 61.8 db SPL. In the visual task a series of pilot lights were arranged at 15 degree intervals around a 10 in. diameter circle. The lights were turned on sequentially for .25 sec.. A signal was a 30° jump between lights rather than the usual 15° jump. Three event rates were studied - 6, 12, and 24 events per min.. For both modalities it was found that per cent correct detections decreased with an increase in event rate. However the same signal probabilities were not present with all three event rates. At event rates of 6 and 12 per min. signal probabilities of 1/12 and 1/6 were employed, and at event rates of 12 and 24 per min. a signal probability of 1/24 was used. The results would have been more conclusive if one signal probability had been maintained for all three event rates.

The only study which has reported an increase in detection performance with increased event rate is that of Stroh (1969). Event rates of 360, 1200, and 3600 per hour were studied in a loosely coupled visual task involving brightness discrimination. The measure of performance used was d'. Stroh (1971) suggests that his results differed from those traditionally found because the task involved memory. Signals and nonsignals were presented separately in his experiment whereas in many earlier studies they were presented concurrently. He considers the type of paradigm used by Jerison and Pickett (1964) as concurrent presentation of signals and nonsignals. There may be some validity in distinguishing between tasks which involve memory, (i.e. comparison of an event with the previous event), and those which do not, however this dichotomy does not seem adequate to account for Stroh's unexpected results. The auditory vigilance task used by Loeb and Binfold (1968) involves memory, but their results do not conform with Stroh's.

It may be tentatively concluded that event rate has an inverse relation to per cent correct detection on a vigilance task. However, the studies which report this finding are generally inadequately designed, and the conflicting result found by Stroh (1969) still has to be accounted for.

Signal Frequency and Signal Probability

The literature on the effects of signal frequency and signal probability on performance also contains many conflicting results. Studies of signal probability are concentrated on in this review since those investigating signal frequency often confound event rate and signal probability.

After reviewing many studies, Davies and Tune (1969) conclude that increased signal frequency leads to an increased number of correct signal detections. They add that signal probability may be even more important as a determinant of performance. On the other hand, Stroh (1971) concludes , after reviewing the literature, that neither signal frequency nor signal probability influence performance on vigilance tasks.

A large number of studies have reported an increase in per cent correct detections as signal frequency increases, (e.g. Baker, 1958; Jenkins, 1958; Jerison, 1959; Polack & Knoff, 1958). Stroh (1971) admits to the validity of the studies but criticizes them on the grounds that per cent correct detections is a misleading measure to use. He points out that if a fixed number of signals is missed, the per cent that this represents will vary with different signal frequencies. However as signal frequency varies, the opportunity to detect or miss signals also varies, so his criticism does not necessarily detract from the value of these studies.

Colquhoun (1961), investigating signal probability, had O's perform a visual brightness discrimination task for 40 min.. He ran three conditions: 72 nonsignals and 72 signals, 12 nonsignals and 12 signals, and 132 nonsignals and 12 signals. Detection performance was best in the first condition and worst in the last condition. However a decrement in performance was observed in the first two conditions and not the last. These results are difficult to interpret, partly because of the short length of the session, and also because a ratio of signals to nonsignals of 1 is not a typical vigilance situation. The study is useful in that it points out that manipulations of some variables may have different effects on detection performance and performance decrement.

Jerison (1965) and Johnston et. al. (1966) have reported that if there is a large number of nonsignal events, signal probability is an effective variable. Jerison (1966) found that signal probability influences performance only when observing responses are elicited from the O at least once per four sec. Stroh (1969) varied signal probabilities from .0017 to .17 in a visual intensity discrimination task and found no significant effect of this variable.

Loeb and Binford (1968), in the paper mentioned earlier, investigated signal probabilites of 1/6, 1/12, and 1/24 in both the auditory and visual tasks. For both modalities the probability of a correct detection and d' increased as signal probability increased. A recent report by Williges (1971) involving a brightness discrimination task, also indicates that increases in signal probability increase the per cent detection of signals. Williges used signal probabilities of 1/1 and 1/9. Although a signal probability of 1/1 is not a typical vigilance task, these results suggest that some of the studies which have not found an effect of signal probability may not have used a large enough range of values.

Many experimenters employ pretests of various time lengths before running O's in a long vigilance session. The signal probabilities used in the pretests often differ from those of the test session. Colquhoun and Baddeley (1964, 1967) hypothesized that an expectancy set regarding the signal probability is formed during the pretest, and that this set affects performance when signal probability is changed in a later session. Using both a visual brightness discrimination task and an auditory intensity discrimination task they employed pretest signal probabilities of .18 and .02. The later session also employed these two signal probabilities and the probabilities were combined in a factorial design so that there were four conditions.

It was found that the O's trained with the higher signal probability detected more signals in the second session than those trained on the lower signal probability. O's exposed to the low signal probability on the pretest detected more signals in the later session when it had the same signal probability rather than the high probability. It is suggested that their expectancy was consistent with the actual state of events, whereas the latter group had their expectancy violated and so their performance deteriorated. Decrements in performance were greatest for the two groups who received a different signal probability in the second session. These experiments indicate that signal probability has a substantial effect on both performance decrement and overall level of performance.

The results of the studies on signal probability lead one to the conclusion that in some cases it has a significant effect on performance and in other cases it does not. It would appear that there is some factor which has yet to be identified which leads to the differential effects of this variable.

Signal Intensity

There are only a few studies dealing with the effect of signal intensity on vigilance performance. In general it has been found that overall detection performance varies directly with the magnitude of the signal. The relation between the vigilance decrement and signal magnitude has not been clearly ascertained.

Davenport (1968) investigated signal intensity in an auditory vigilance task. O'S auditory thresholds for the intensity of a 1000 Hz. tone were measured by the method of limits. Signals were then set to 1, 2, 3, or 4 dB SPL above each O's threshold. The four intensity levels were combined with four signal durations for 16 possible signals. The experimental session lasted for 80 min., and during each 40 min. period each of the 16 signals was presented once. There were no nonsignals, and signals were separated by random intersignal intervals. The O's task was to indicate when he perceived a signal.

The results showed that detection performance improved as signal intensity increased. The decrement in detection had an inverse relation to signal intensity. In this experiment different signal intensities were presented within a single vigilance session. The responses to each type of signal were then analysed separately. The results may not be directly generalized to the case of an O monitoring only one signal intensity during a session. Moreover the task employed by Davenport is perceptual, whereas the majority of vigilance studies utilize tasks involving discrimination between two or more stimuli.

Mackworth and Taylor (1963) ran several experiments with a Mackworth clock stimulus. A signal was a pause in the movement of the clock hand lasting for .32 or .38 sec. This signal was readily detectable to O's, and a performance decrement was found in all the experiments. The authors concluded that the rate of the decrement is not affected by the magnitude of the signal, and that the decrement is not confined to signals near threshold. These conclusions are based on general observations of the data and not on specific investigation. The experiments reported do not conclusively support the statement that performance decrement is independent of signal magnitude.

An experiment designed to investigate modality effects, but which is also relevant to this discussion was reported by Buckner and McGrath (1963). Three conditions of the experiment were called visual, auditory, and redundant. In the visual condition O's had to detect an increment in the brightness of a light source. In the auditory condition they had to detect an increment in the amplitude of a 750 Hz. tone. In the redundant condition O's monitored both the visual and the auditory field, and signals occurred simultaneously in both fields. O's detection performance in each task was measured before and after a 60 min. vigilance session. An average of the per cent correct obtained in the pre and post-tests was called a measure of alerted performance.

Alerted performance was highest in the redundant condition and lowest in the visual condition. The authors plotted the change in detection from alerted performance to the last 15 min. of the vigilance session. In all three conditions a decrement was observed. The degree of decrement was directly related to the level of alerted performance. In other words, there was least decrement in the redundant task and most in the visual task.

Buckner and McGrath interpreted these results to mean that the level of initial detection performance varies inversely with degree of decrement. This conclusion should be accepted with caution, since task requirements and modality effects are confounded. The effect of high initial detection performance due to task or modality specifications may differ from that of high performance induced by a high signal magnitude.

In a line length discrimination task Guralnick (1972) distinguished between an easy and a difficult condition. In the easy condition line lengths were adjusted so that O's obtained 99.75% Hits and no more than .2% False Alarms in a pilot study. In the difficult condition the lines were adjusted so that a d' value of 1.5 to 2.5 was obtained. This represented an initial Hit level of about 70% in the vigilance task. The vigilance sessions lasted for one hour.

A decrement in performance as measured by per cent Hits was observed in both groups. The decrement was slightly greater in the difficult group, but the difference is probably not significant. Guralnick did not test for differences between the two decrement functions. This study suggests that the slope of the decrement function is not significantly influenced by signal magnitude. This conclusion has also been reported by other researchers, (Baker and Harabedian, 1962; Stroh, 1971; Weiner, 1963).

A study by Hawkes and Loeb (1962) indicated that reaction time to signals in a vigilance task is consistently shorter the more intense the stimuli. However this response measure does not relate directly to detection performance or to the decrement in vigilance, (Davies & Tune, 1970).

It can be concluded that overall detection performance is directly related to signal magnitude in vigilance, but that the performance decrement has a more variable relationship. One of the problems in this area of vigilance is that few studies have been designed specifically to investigate the effects of signal intensity and so conclusions must be drawn from incomplete data.

Artificial Signals.

Many researchers have studied the effects of increasing task complexity in a vigilance situation. One way of doing this is by including artificial or "dummy" signals which are not to be responded to. With some exceptions the general finding in this area has been that the addition of artificial signals to a task improves monitoring performance, (e.g. Baker & O'Hanlon, 1968; Budin, 1965; Faulkner, 1962; Luce, 1964).

Budin (1965) found that a small number of dummy signals contributed towards stable performance, but that a large number increased performance decrement. Bakan (1959) investigated the problem in a task that cannot be considered as vigilance since it lasted for only eight min. However his results may be applicable to vigilance. O's listened to a series of three digits presented auditorily at the rate of 10 per 16 min. An artificial signal, consisting of the spoken digit "6" was presented at a rate of 100 per 16 min. Inclusion of the artificial signal improved detection of the primary signals.

An interesting experiment, which varied presentation of artificial signals with knowledge of results, was reported by Wilkinson (1964). The vigilance task involved discrimination of .5 sec. auditory tone pulses from .37 sec. pulses, presented against a background of white noise. Signal probability and event rate were held constant across all conditions. A control condition contained no artificial signals. Three conditions contained 40 artificial signals, however these signals were identical to the primary signals. Knowledge of results was manipulated so that one group had full knowledge, one group had partial knowledge, and one group had no knowledge. In a fifth condition, 40 different artificial signals (tone pulses of .66 sec.) were presented and full knowledge of results was provided. O's were run in one 1 hr. session once a day for five days. Each O was run in the control condition for three sessions and one of the other conditions for two sessions.

The results indicated that presentation of artificial signals which were identical to the primary signals improved performance. Artificial signals which differed from the primary signals had an even greater beneficial effect on performance. Detection of primary signals was better with knowledge of results than without. More False Alarms were emitted in the artificial signals conditions than in the control condition, and it was concluded that the criterion shifts in a less conservative direction when artificial signals are present. The conditions in which the artificial signals were identical to the primary signals were equivalent to increasing signal probability as far as the O's were concerned. The results therefore lend support to the position that signal probability does influence detection performance.

Baker and O'Hanlon (1968) studied the effect of artificial signals in a 90 min. visual brightness discrimination task. The artificial signal was a reference display identical to the main display and located beside it. O's in a control group were never shown the artificial signal. In a second group O's could push a button to activate the reference display which would remain on for 14 events. During this time two signals would be presented. O's in a third group received the reference display once each half hour at a random time. The display remained on for 14 events, two of which were signals. In the last group the reference display was also presented once per half hour but no signals were presented during the time it was activated.

In the second and third conditions, the probability of correct detection of the first signal which occured after the artificial signal was activated was higher than for signals presented at other times. However since in these groups two signals always occurred within 14 events after the artificial signal was activated, the presence of the artificial signal may have cued the O's to become more alert. There was no significant difference in the mean level of performance for the four groups. The lack of significance found in this experiment may be due to the unusual nature of the artificial signal. The signal was in fact a duplicate of the original display. A dummy signal which differs from the primary signal might be expected to have a greater effect on performance. In addition, the rate of presentation of the artificial signal was very slow in this experiment, even in the condition where O's activated it themselves. It may be that there is a median rate which artificial signals improve performance and beyond which they have a neutral or deletorious effect.

The inclusion of a dummy signal in a vigilance task generally improves performance on the task. The similarity of the dummy signal to the primary signal and the presentation rate of the artificial signals are relevant variables which have not yet been completely assessed.

Theories of Vigilance.

Several theories have been proposed to account for the results of vigilance experiments. The two which have emerged as the most probable explanations of vigilance behavior are expectancy theory and arousal theory.

Expectancy theory was formulated by Deese (1955). The theory has two main postulates. The first is that the pattern of previous events determines an O's expectancy about future signal events. The second is that an O's expectancy determines his performance level. The theory proposes that O's are engaged in a continuous procedure of averaging inter-signal intervals. They extrapolate their results and form an expectancy or prediction about when the next signal will occur. The expectancy is thus low just after presentation of a signal, and increases as the mean inter-signal interval is approached.

Baker (1963) maintains that as well as signal probability, the distribution of inter-signal interval lengths influences an O's performance. Expectancy level is related to the conditional probability of a signal at any time since the last signal was perceived.

Baker explains the vigilance decrement in terms of expectancy theory. When an O misses a signal his estimate of signal probability decreases, and his estimate of the distribution of inter-signal intervals is distorted. This misinformation leads to further misses which compound the false estimates of signal probability and inter-signal interval. Thus errors become more frequent and a decrement in detection performance is observed. Baker calls this a vicious circle effect.

Mackworth (1970) hypothesizes that an O will assume that the experimenter has imposed constraints upon random presentation of signals, and will work to find some sort of pattern so that he need only pay attention when the signal is expected. The simplest assumption to start with is that signals will not occur close together in time, so that attention can be relaxed immediately after a signal has been presented.

An experiment related to this issue was reported by McGrath and Harabedian (1963). O's were engaged in a bimodal vigilance task, in which they had to report an increase in the brightness of a light or an increase in the amplitude of a tone. In one condition the distribution of inter-signal intervals was rectangular. In the second condition the distribution was skewed, with nearly half the intervals being less than 60 sec. The range of inter-signal intervals was 9 to 300 sec. for both groups. O's receiving the rectangular distribution of inter-signal intervals showed an increase in the probability of a Hit as the length of the interval increased. In the skewed condition the probability of a Hit decreased as inter-signal interval increased.

These results support expectancy theory. In the firstgroup, O's expectancy that signals would not occur close together was reinforced, so they maintained the strategy of increasing attention as the inter-signal interval lengthened. In the second condition a large proportion of signals occurred within a minute of the previous signal, and so expectancy was highest after detection of a signal and then decreased. This decrease was not as marked as the increase in expectancy displayed by the first group.

One difficulty with expectancy theory is that it does not explain the effect of short rests on performance. If an O is given a break from the task, his performance will resume at the initial high level and then deteriorate again, (Broadbent, 1971; Mackworth, 1970). Since the rest does not influence estimates of signal probability, expectancy theory cannot explain the improvement in performance.

This result is handled easily by arousal theory.

Broadbent (1971) explains the changes in β observed in vigilance tasks in terms of expectancy theory. He states that $\beta = (1-p)/p$, where p is the probability of a signal. This equation ignores the influence of payoffs, which should enter into a likelihood ratio definition of β. If p is less than .5, as it is in most vigilance experiments, the ideal observer who uses β as defined above, will report signals less often than they actually occur. This will lead to a re-evaluation of the signal probability by the vicious circle theory of Baker (1963). The assumed p will become smaller and β will increase. If p is greater than .5 the signals will be reported more often than they occur, and by a similar argument β should decrease.

A result obtained by Simpson (1967) is damaging to this interpretation. He presented signals with p greater than .5 and found that β increased and a decrement was observed. This result could be encompassed by expectancy theory but not by Broadbent's interpretation of it.

Expectancy theory gives a good explanation for many results found in the vigilance literature. However several studies have failed to find the expected relation between expectancy and inter-signal interval, (for a review see Frankman and Adams; 1962), and the theory does not account for the effect of rest periods and distractions on the O.

Some of the vigilance results which do not conform to expectancy theory can be rationalized by arousal theory. The arousal theory of vigilance stems from work by Hebb (1958). Hebb suggested that stimuli, as well as guiding certain goal-directed responses of an O, also serve the function of arousing, or maintaining a level of alertness. When sensory stimulation is monotonous, as in a vigilance task, the arousal level of an O decreases. One factor responsible for this decrease may be sensory habituation, (Mackworth, 1969; Scott, 1957).

An O's level of arousal may affect the intensity with which behaviour occurs, the level of performance displayed, and the efficiency of performance. The obvious prediction of the theory is that inclusion of a greater variety of stimuli, whether relevant to the task or not, will lead to improved performance. There is a large body of evidence, (some of which was cited in the section on artificial signals), which indicates that this is so.

A typical experiment is that of McGrath (1963). A visual vigilance task was run with constant background noise or with varied sounds in the background. An auditory task was run without visual stimulation or with interesting visual stimulation. Detection performance was superior in the visual task with a varied auditory background and the auditory task with visual stimulation, even though the background stimuli were irrelevant to the task itself. Adams et. al. (1961) found that performance was superior when O's had to evaluate a stimulus as being in one of four categories, rather than simply reporting that the stimulus was present.

A contrary result was reported by Bakan and Manley (1963) who found that O's participating in an auditory vigilance task did better when they were blindfolded than when they had ordinary visual stimulation. They suggest that conditions may have been sufficiently arousing for maximum performance without visual stimulation, and the addition of the visual stimulation may have increased the arousal level so that it was too high for maximum performance.

Stroh discusses this type of result with cases where a vigilance decrement was not observed. He proposes that the arousal level of many people, especially younger people, may generally be too high for efficient performance. When confronted with a vigilance situation, the arousal level drops to a point at which performance is more efficient, and so no decrement is displayed.

These ideas lead to the hypothesis that there is an ideal level of arousal at which performance is maximal, and that performance will deteriorate when the arousal level is above or below the ideal.

There have been many efforts to find physiological measures of arousal which correlate with vigilance performance. These efforts have been largely unsuccessful. Part of the reason for this may be that the indices measured have actually been correlated with arousal, which will not correlate with task performance if the level of activation is too high.

Studies measuring skin conductance, heart rate, and EEG have generally failed to find a correspondence of these measures with vigilance performance. Two exceptions are Gale et. al. (1972) and Hatayama and Komatsu (1971) who found correlations between the alpha and beta bands of the EEG respectively and vigilance performance. Surwillo and Quilter (1965) measured spontaneous changes in skin potential during a visual vigilance task and found that the frequency of spontaneous changes just before the signal arrived correlated positively with detection of signals. A problem with such a correlation is that peripheral physiological indices may not be related in a fixed way to the central state of the organism, (Broadbent, 1971).

The present status of arousal theory is that it accounts for many of the phenomena observed in vigilance which cannot be explained by other theories. A weakness of the theory is that it is based on physiological concepts, but physiological indices which correlate with vigilance performance have seldom been found. A combination of arousal and expectancy theory would seem to give the best description of vigilance performance.

In this literature review the vigilance task has been defined and the effects of several variables on performance level and performance decrement have been assessed. The application of TSD to analysis of vigilance data was described. Event rate, signal frequency, signal probability, signal intensity, and the presence of artificial signals in the task have been discussed. Finally, an overview of the status of the two major theories of vigilance was provided.

Three experiments are reported in this thesis. They are concerned with isolating some of the variables which affect performance decrement in vigilance tasks.

Most vigilance studies employing a TSD analysis have found that if there is a performance decrement during the session, d' remains constant and β increases. According to the signal detection model this indicates that the O's criterion is becoming more conservative. As mentioned above, β may be affected by two things: manipulation of payoffs, and manipulation of prior odds, i.e. the probability of a signal.

The research undertaken here is an attempt to counteract the vigilance decrement by manipulating variables which affect β . If the criterion of an O can be maintained at a constant level, and d' is constant, the detection behavior of the O should remain constant throughout the session. The first two experiments succed in stabilizing the O's criteria. The third experiment is designed to investigate the relationship between the initial level of discrimination performance and the form of the decrement function.

EXPERIMENT I

Researchers of vigilance performance have investigated the effects on β of manipulating payoffs, (Guralnick, 1972; Levine, 1966; Williges, 1971), and signal probability, (Jerison et. al., 1965; Loeb and Binford, 1968; Williges, 1971). These papers are described in the historical review. Briefly, when a high cost is imposed upon False Alarms, β increases. However if information about signal probability is supplied, an O will utilize this information and be less responsive to payoff manipulations. Signal probability has not always been found to be an effective variable. It appears to depend upon the type of vigilance task employed.

The published studies have only reported manipulations of these variables between sessions, usually between groups. If signal probability is manipulated within a session so that it rises as time spent on the task increases, the tendency of β to increase should be counteracted, and a stable criterion maintained. The first experiment was performed to investigate this possibility.

The experiment involved an auditory vigilance task 90 min. in length. O's were run for five days in order to investigate the effects of practise on performance. Events were pure tones of constant frequency and length; a signal was a tone of slightly higher amplitude than a nonsignal. The O's task was to press a button when a signal was detected. For experimental purposes the 90 min. was divided into six 15 min. time periods. (Subjects were not aware of this.)

In a control condition the signal probability was constant throughout the session. In the experimental condition the signal probability was increased between the first and last time periods. Two control and experimental groups were run using two different signal probabilities. If increased signal probability is effective in keeping β constant, different signal probability levels should lead to different levels of performance in the two groups.

Method:

Auditory signals were generated by a Hewlett Packard wide range oscillator, model 200CD. The amplitude of the signals was attenuated by passing the output of the oscillator through two Grason-Stadler electronic switches, model 829E. The output of the switches led to a pair of earphones in each of two experimental rooms. The earphones were Elega, model DR-61C, and Pioneer, model SE-1. Presentation of stimuli throughout the experiment could be monitored with the aid of an Advance Instruments Oscilloscope, model OS 1000. Each experimental room contained a response panel with one response button located on it. Presentation of stimuli was controlled by means of a DEC PDP8-E computer. Amplitude of the tones at the earphones was measured with a General Radio Company Sound Level Meter, model 1551-C. Background noise was controlled by dials built into the rooms. Experimental rooms were illuminated by a shaded red 25 watt bulb.

The vigilance task involved discrimination between two tones of different amplitude. A nonsignal event was a 100 msec. 1000 Hz. tone of 60 dB SPL. A signal event was a 100 msec. 1000Hz. tone of 61.8 dB SPL. The silent inter-event interval was always 2.5 sec., so that event rate remained constant throughout the experiment.

There were four conditions in the experiment. Two signal probabilities, .012 and .021 were employed, and an experimental and control group were run for each signal probability. All O's were run for five 90 min. sessions, one on each of five consecutive days. Each session was preceded by a 10 min. pretest. The signal probability during the pretest was .087 for all conditions. This resulted in 20 signal presentations during the pretest.

In the control conditions occurrence of signals was programmed randomly, with the restriction that in the .012 signal probability condition four signals were presented during each 15 min. time period, and in the .021 signal probability condition seven signals were presented during each 15 min. time period. The signal probability for the control groups remained constant over all five sessions.

In the experimental groups signal probability was increased throughout the session. The number of signals presented to the .012 signal probability group in time periods 1 to 6 was 4,4,7,7,10,10. The .021 group received 7,7,10,10,13, and 13 signals in time periods 1 to 6. The number of signals presented to these groups in each of the first two time periods was equal to the signal probability of the group. The distribution of signal probabilities was identical for all five sessions within a group.

In order to mask extraneous sounds from outside the experimental rooms, low level white noise was present throughout all sessions. This provided a uniform background noise and masked sudden irregular noises which would alert the O's. The effect of background white noise on vigilance performance varies with the specific task used, (Grethier, 1971), so that the effect it would have on the task employed here is unpredictable. It was felt however that a constant background noise was preferable to an irregular one.

Four O s were run in each condition. They were all McMaster University undergraduates and received $2.00 per hour for their services. They were told that they were participating in an experiment concerned with the effect of time on performance of a task. They were asked to remove their watches before the sessions began and not to refer to them during the sessions. The nature of the task was explained to them. They were instructed to depress the response button when they detected the signal. They were also told that they had to press the button within the 2.5 sec. inter-event interval following the signal or their response would not be counted as correct.

O s in the experimental group were not informed that the signal probability would change within the session. All O's were told that the signal probability in the pretest was .087 and that the signal probability in the main session would be lower.

Results:

The raw data obtained in the three experiments reported in this thesis are reproduced in Appendix I.

The data were analysed separately for each of the six time periods in each session. Per cent correct detections of signals, and d' and β values were calculated for each session. The methods for calculating d' and β which will be used in this report were taken from Jerison et. al. (1965).

To calculate d', the number of correct detections of signals (Hits) is changed into a percentage. Using a table of areas under the normal curve the distance in standard deviation units between the mean of the signal distribution and the criterion may be obtained. Similarly, by tabulating the per cent of "False Alarms" made and subtracting from100 to arrive at the per cent "Correct Rejections", the distance between the mean of the nonsignal distribution and the criterion can be found. The two figures may then be added to give d', the distance in standard deviation units between the means of the two distributions.

To find β , the ordinate of the signal distribution at the criterion is divided by the ordinate of the nonsignal distribution at the criterion. These two figures may be obtained from the percentages of Hits and False Alarms calculated when finding d', and a table of ordinates under the normal curve. This method of calculating β assumes that the O's are utilizing the likelihood ratio when making a response decision. Whether O's actually do respond in conformity with this ratio has not been specifically tested for vigilance tasks.

An alternative method of calculating β is to measure the distance between the criterion and the mean of the noise distribution in standard deviation units. This method has the advantage that it does not make strict assumptions about how the O sets his criterion.

The former method of calculating β is used in this thesis since that method is usually reported in vigilance studies. β values calculated by the second method, for all three experiments, are given in Appendix II. The values of β obtained with both methods show the same trends.

The raw scores of the four O's in each group were pooled, so that the results reported for each group are an average for the O's in that group. Mackworth and Taylor, (1963) have reported that such averageing techniques maintain the integrity of the data.

There was no difference between the two signal probability conditions in either the control or experimental groups.

Per cent correct data for the two control groups for each of the five sessions is plotted in Fig. 1. A definite decrement in detection performance from the first to the last time period is observed in the first three sessions. In the last two sessions performance levels off, although somewhat erratically.

In Fig. 2 the per cent correct data for the control groups is averaged over all five sessions. The decrement is less pronounced in this graph due to the lack of decrement in the fourth and fifth sessions. Nevertheless a clear decrement for both groups is visible. In Figs. 1 and 2 it can be seen that in the .012 signal probability control group performance improved in the third time period.

The d' level remained stable within sessions for both control groups. d' values for each time period in each of the five sessions are presented in Table I. A graph of d' averaged over the five sessions is shown in Fig. 3. Except for the increase in d' in the third and fourth time periods for the .012 group, d' is seen to be fairly constant.

Values of β for each session are shown in Table II. Fig. 4 is a plot of β values for the control groups averaged over the five sessions. As reported in other studies, a few extreme values of β

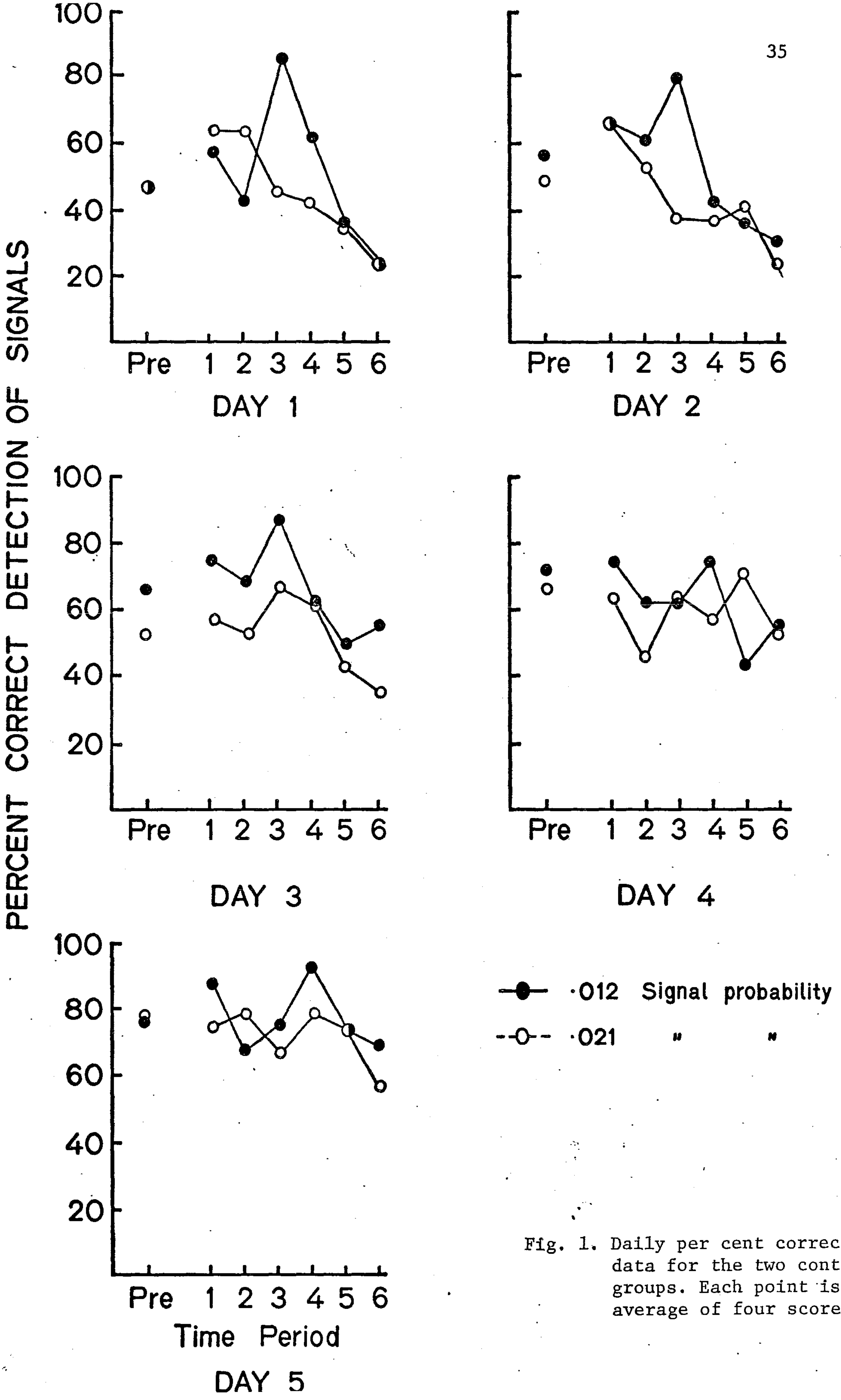

Fig. 1. Daily per cent correct data for the two control groups. Each point is an average of four scores.

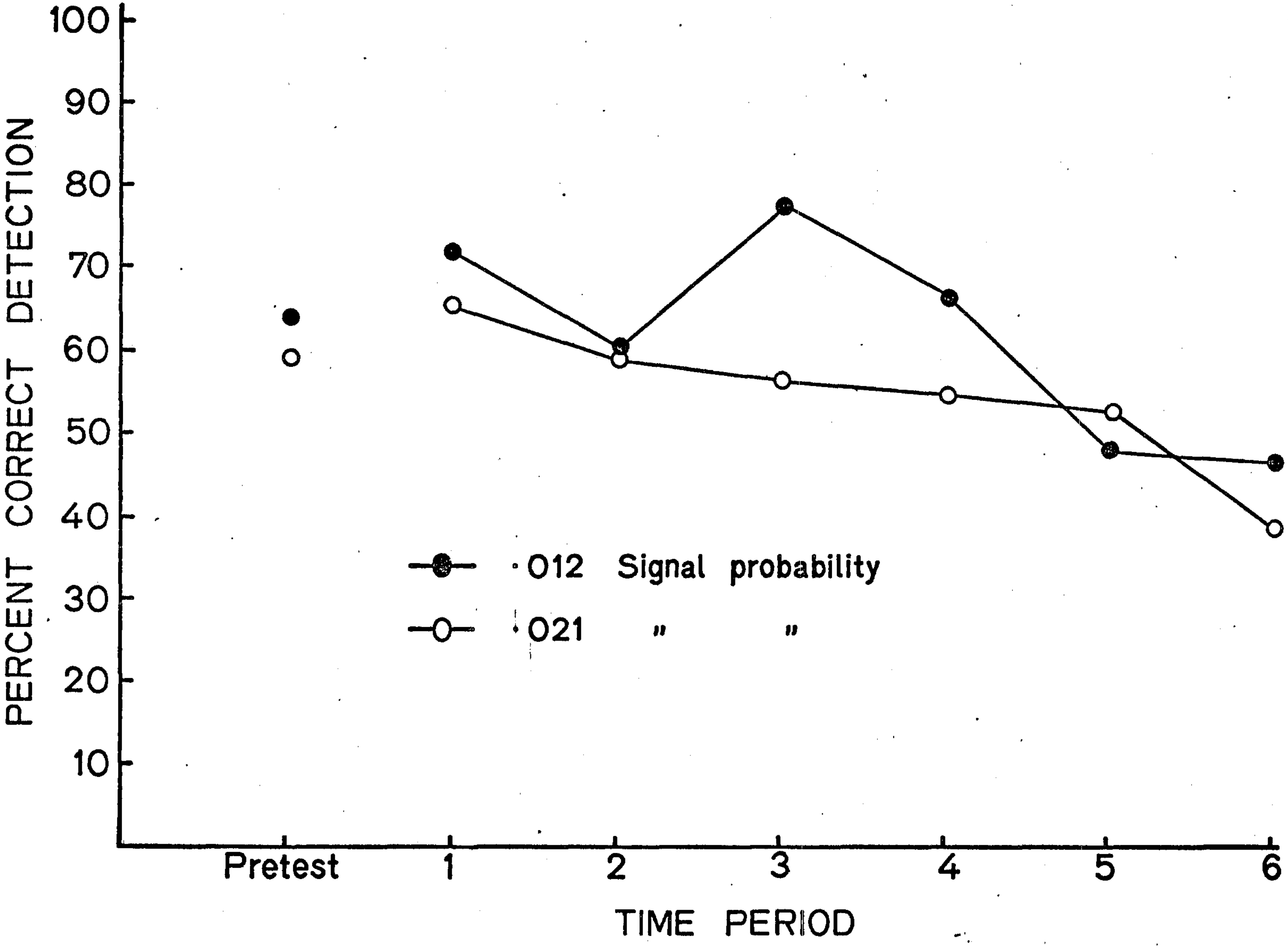

Fig. 2. Per cent correct detections for the two control groups averaged over five sessions.

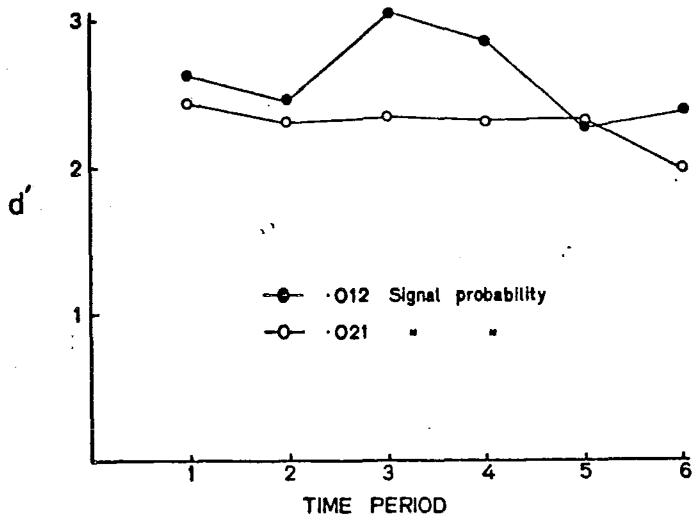

Fig. 3. d' values for the two control groups averaged over five sessions.

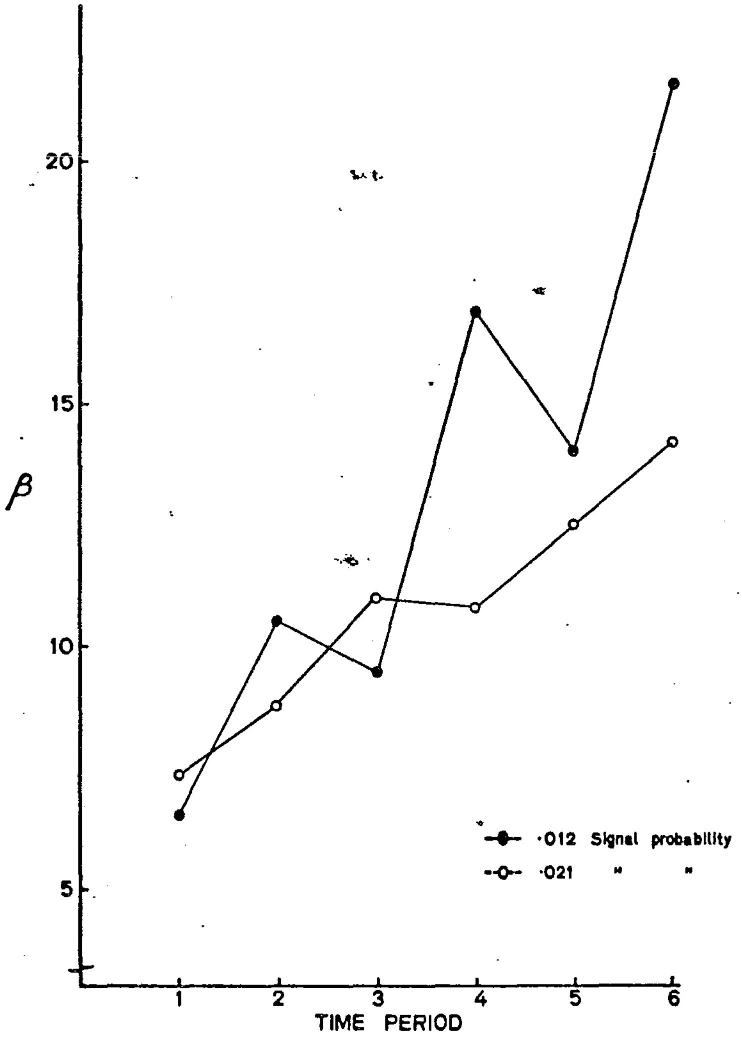

Fig. 4. β values for the two control groups averaged over five sessions.

Time Period	Day 1		Day 2		Day 3		Day 4		Day 5	
Condition	.012	.021	.012	.021	.012	.021	.012	.021	.012	.021
1	1.79	2.21	2.45	2.24	2.79	2.25	3.26	2.63	3.68	3.1
2	1.78	2.21	2.47	2.02	2.66	2.34	2.59	2.2	3.37	3.37
3	3.15	1.84	3.14	1.86	3.58	2.74	2.73	2.78	3.21	3.17
4	3.22	1.73	2.02	1.89	3.20	2.69	3.39	2.36	4.23	3.49
5	1.83	1.56	1.85	2.0	2.32	2.34	2.19	2.8	3.21	3.12
6	1.53	2.0	1.83	1.57	2.51	2.15	2.87	2.51	3.20	2.88

Table 1. Daily d' data for the two control groups. Each d' value is the average for 4 O's.

Time Period	Day 1		Day 2		Day 3		Day 4		Day 5	
Condition	.012	.021	.012	.021	.012	.021	.012	.021	.012	.021
1	3.73	5.07	6.06	4.3	7.3	8.39	22.1	12.0	12.6	14.9
2	6.48	5.07	9.57	6.4	9.3	12.5	12.5	13.7	56.2	20.4
3	3.81	6.41	8.47	9.3	9.9	11.5	17.3	17.0	19.4	35.4
4	63.17	6.09	10.62	9.9	60.1	18.1	31.3	10.6	11.9	28.1
5	11.96	6.01	10.0	10.5	14.7	23.5	15.6	11.7	19.4	15.6
6	9.12	8.33	13.10	9.9	15.6	22.3	39.0	18.6	176.9	37.7

Table 2. Daily β values for the two control groups. Each β value is the average for 4 O's.

were obtained. There was a clear tendency for β to rise within a session. β values in the first time period of a session were similar for both groups, but by the sixth time period was much higher for the lower signal probability group. This is largely due to the extreme value of β obtained in the sixth time period of the fifth session in the .012 signal probability group.

Per cent correct detections in each session for the experimental group are plotted in Fig. 5. No performance decrement is apparent in the first three sessions. In the last two sessions a very slight decrement may be observed. Detection performance is averaged over the five sessions in Fig. 6. The curves are quite flat and there is no change in performance over the different time periods.

The data from the two signal probability groups is much more similar in experimental conditions than in the control conditions. When the control O's were being run, the .012 signal probability group always ran at 4:00 in the afternoon and the .021 group always ran at 6:00 in the evening. When the experimental groups were being run, half the O's in each group ran at 4:00 and half at 6:00. It is possible that the time of day had some effect on results, and that this effect was counterbalanced in the experimental groups.

Table III reports the d' measures of performance for the five sessions for the two experimental groups. Fig. 7. is a graph of the d' data averaged over the five sessions. As with the control groups, d' is stable over the six time periods. If Figs. 7 and 3 are compared it can be seen that there is less variability in the experimental group data.

Values of β for the experimental groups for the five sessions

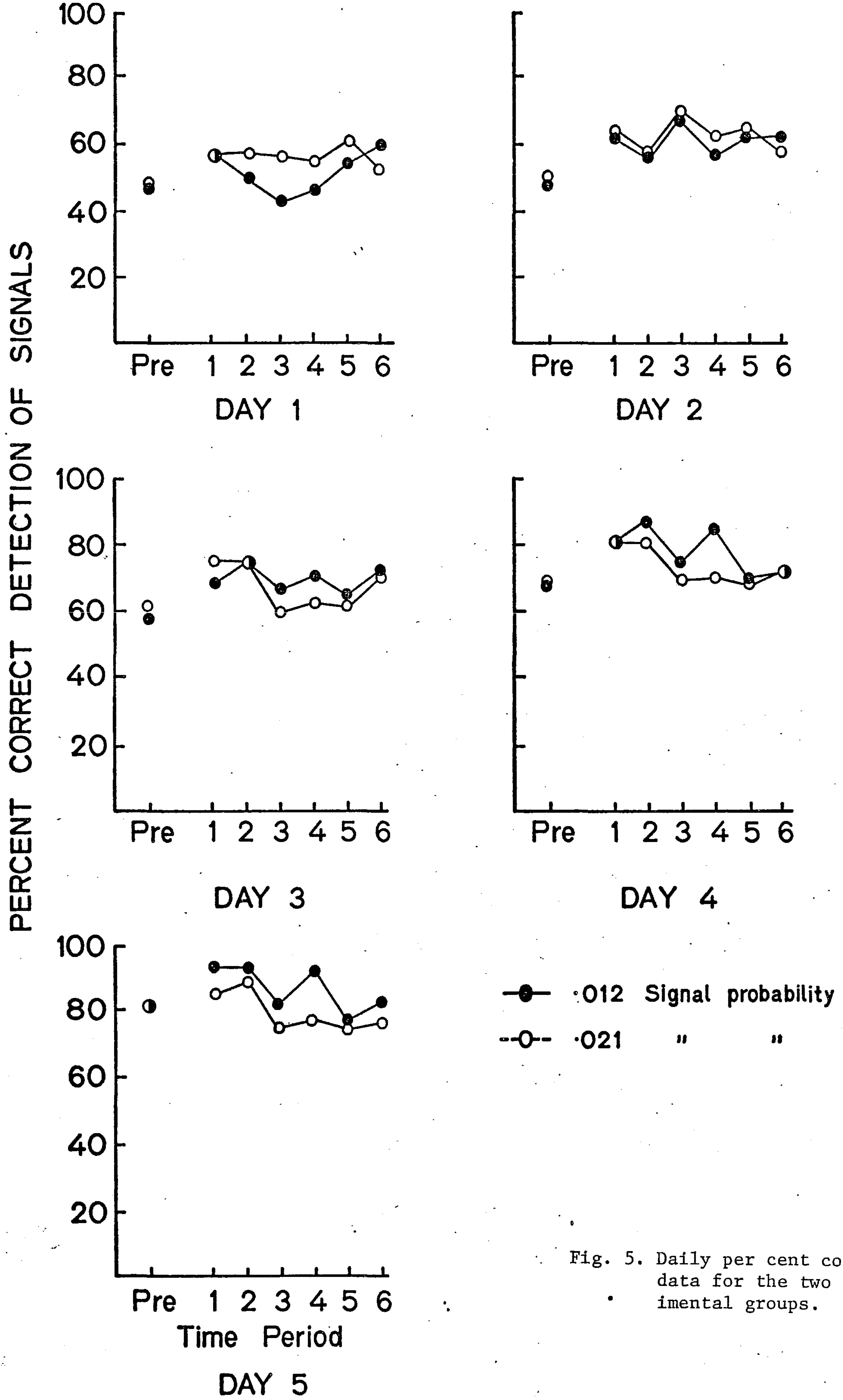

Fig. 5. Daily per cent correct data for the two experimental groups.

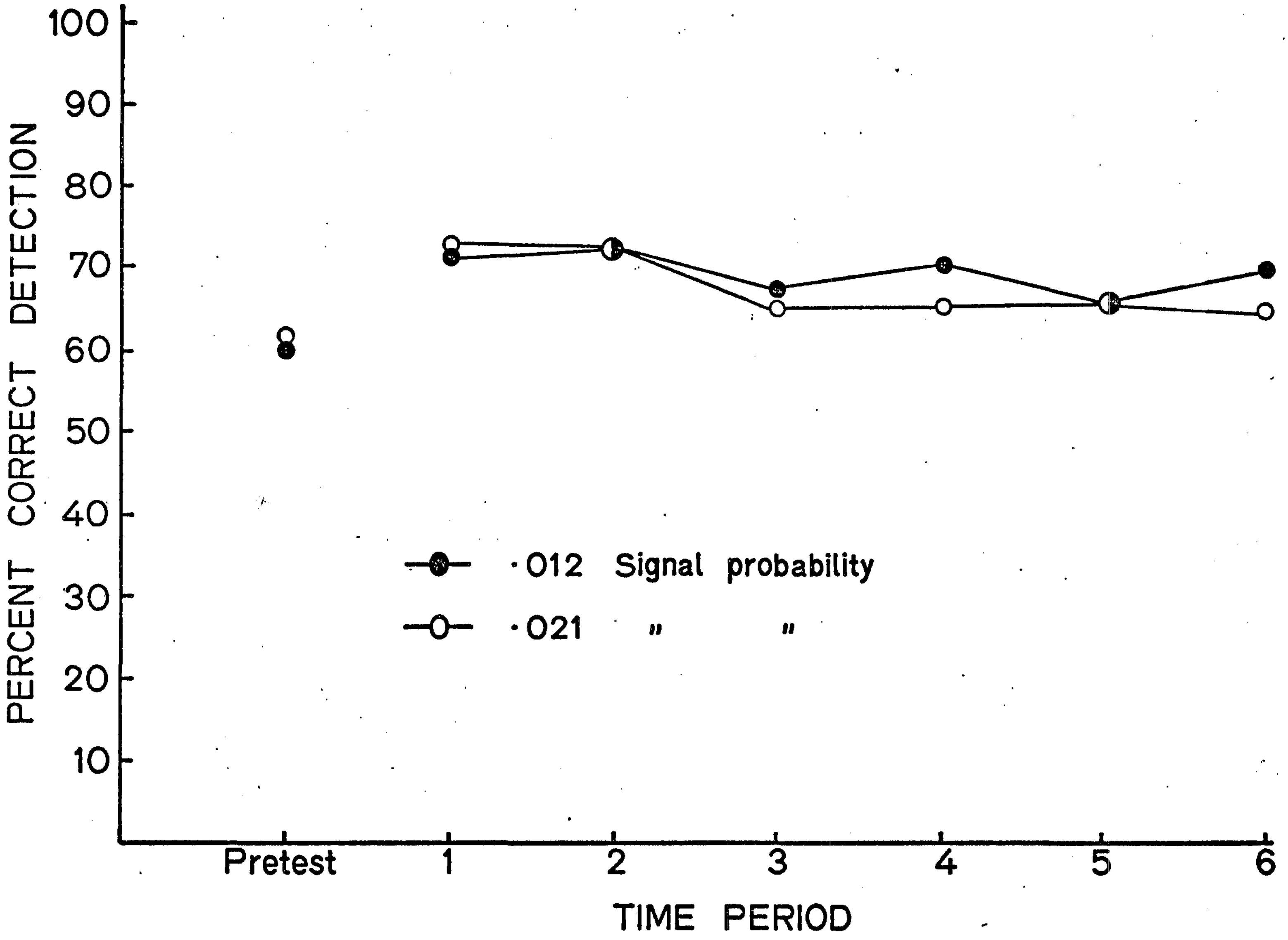

Fig. 6. Per cent correct detections for the two experimental groups averaged over five sessions.

Time Period	Day 1 .012	Day 1 .021	Day 2 .012	Day 2 .021	Day 3 .012	Day 3 .021	Day 4 .012	Day 4 .021	Day 5 .012	Day 5 .021
1	1.85	1.81	2.14	2.19	2.79	2.8	3.16	3.18	3.97	3.48
2	1.79	1.8	2.18	1.98	2.79	2.88	3.47	3.24	3.95	3.56
3	1.67	1.9	2.64	2.4	2.97	2.5	3.24	2.9	3.26	3.02
4	1.98	1.98	2.44	2.44	2.7	2.51	3.49	2.81	3.78	3.0
5	2.2	2.18	2.57	2.49	2.51	2.52	2.93	2.87	3.04	3.08
6	2.27	1.89	2.55	2.27	3.04	2.82	2.88	2.93	3.2	3.08

Table 3. Daily d' data for the two experimental groups. Each d' value is the average for 4 O's.

Time Period	Day 1 .012	Day 1 .021	Day 2 .012	Day 2 .021	Day 3 .012	Day 3 .021	Day 4 .012	Day 4 .021	Day 5 .012	Day 5 .021
1	4.12	3.71	4.98	5.0	12.5	7.5	8.86	8.43	6.1	10.3
2	4.96	3.65	7.59	4.97	7.3	8.92	7.62	9.68	5.81	6.85
3	5.44	4,23	9.67	6.99	21.0	11.9	20.9	14.4	10.1	12.3
4	8.5	5.49	12.7	8.98	8.21	10.4	10.6	11.7	5.1	9.2
5	8.45	5.72	11.6	8.4	8.76	11.5	15.5	14.6	10.1	14.1
6	7.29	4.94	11.1	7.63	16.4	11.0	11.2	14.1	8.3	11.8

Table 4. Daily β values for the two experimental groups. Each β value is the average for 4 O's.

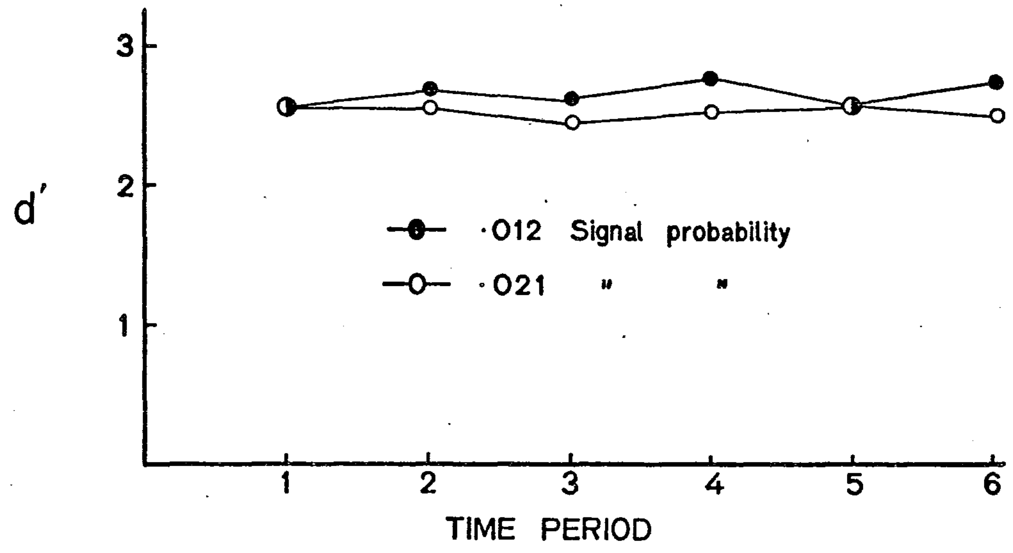

Fig. 7. d' values for the two experimental groups averaged over five sessions.

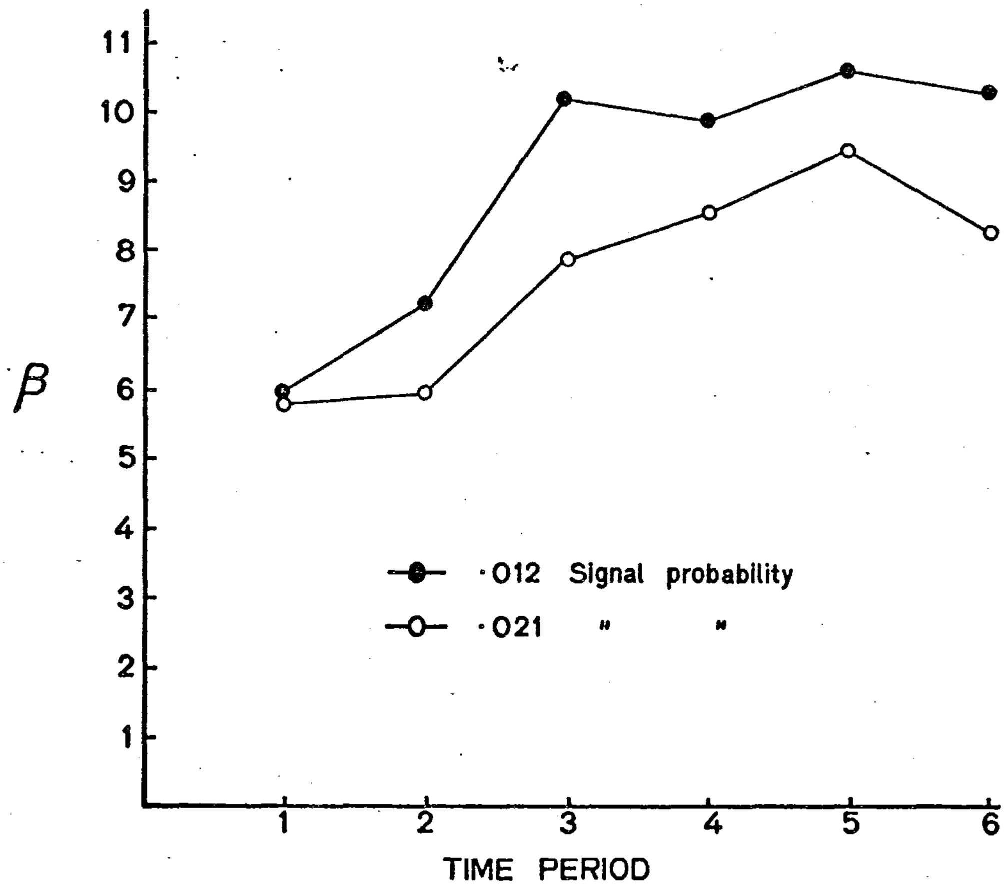

Fig. 8. β values for the two experimental groups averaged over five sessions.

are shown in Table IV. The data averaged over the five sessions is graphed in Fig. 8. β does rise from the first time period to the last, however it does not rise as much as in the control groups, as can be seen by comparing Figs. 8 and 4. These two graphs are drawn to the same scale. Most of the increase in β in the experimental groups seems to take place in the first three time periods. Higher values of β for the .012 signal probability group are seen in the experimental group as well as the control group.

In all groups, detection performance was usually better in the first time period of a session than in the pretest. In addition per cent correct detection and d' values increased from session one to session five for all groups. Since the trends of the data are obvious from the graphs tables, it was not felt necessary to perform tests of significance on the data.

Conclusion:

Although there was no difference between the two signal probability groups in the experiment, the manipulation of signal probability within sessions had the predicted effect of attenuating the change in Os' criteria and maintaining performance at a stable level.

Before discussing the major results of the experiment, some of the minor findings should be assessed. When looking at performance curves for individual sessions there is a fair amount of variability in the data. This is to be expected with only four O's in each group, since inter-subject differences have been found to be very high in vigilance tasks, (Buckner et. al; 1968).

The improvement in performance in the .012 signal probability control group in the third time period in sessions 1 to 3 is a surprising result. It may be an artifact in the data. On the other hand, Colquhoun and Baddeley (1964) obtained a similar effect when they pretested O's with a higher signal probability than was present in the main session. If the different signal probabilities are the cause of the improved performance it is difficult to know why the effect was only seen in one group. A larger amount of data needs to be obtained before the importance of this effect can be ascertained.

In a pilot study it was found that a performance decrement could only be obtained when O's were detecting signals about 50% of the time. The signal and nonsignal amplitudes were set so that this rate of performance was obtained from naive O's. It is not surprising then that the overall level of O's' performance improved from the first to the last session. They were learning to discriminate between signals and nonsignals. The pretests were employed because it typically took O's a little while to adjust to the task. Very often the first few signals presented in the pretest were missed, thus accounting for the higher level of performance in the first time period.

Since the vigilance decrement was observed for three sessions only, it may be acceptable to restrict future studies to three sessions rather than five.

The fact that manipulating signal probability within sessions affected performance and manipulating it between sessions did not may indicate that the two signal probabilities used were too similar. It is conceivable, however, that signal probability is not an influential variable when manipulated between sessions in this task, and is when manipulated within sessions. If a larger number of O's were run, it could be seen whether the different β levels attained by the two signal probability groups were a function of signal probability or differences between O's. The difference between the β levels is in the direction that one would predict if signal probability was the underlying cause. β values are higher in the .012 signal probability group than in the .021 group. This means that in the lower signal probability group O's adopted a more conservative criterion. Since there were fewer signals in the .012 signal probability group, a stricter criterion would be appropriate. Even though per cent correct and d' are not influenced by signal probability in this experiment, it may be that β is.

It was reported that β rose over time periods in the two experimental groups, but less so than in the control groups. The number of signals by which the signal probability was increased in the experimental groups was chosen arbitrarily since there were no previous data to indicate suitable figures. Since the per cent correct and d' measures of behavior indicated stable performance, and β rose slightly, it seems that the signal probability was not increased quite enough. A more pronounced increase in signal probability should result in an even flatter distribution of values within sessions.

EXPERIMENT II

The first experiment indicated that increasing signal probability within a session counteracts an O's tendency to set a more conservative criterion as time spent on the task increases. The vigilance decrement was reduced by this manipulation.

It would be interesting to know whether performance can be maintained at a constant level without changing the task demands of the situation. In other words, can β be kept constant without manipulating the number of signals to be presented in a session?

The beneficial influence of artificial signals on detection performance was described in the historical review. Artificial signal probability is defined as the ratio of the number of artificial signals to the number of signals plus nonsignals. In the second experiment signal probability was held constant within a session. Artificial signal probability increased over time, taking the place of the increased signal probability. The artificial signals were discriminable from the signals, but not easily discriminable. Thus attention had to be paid to the dummy signals when they occurred in order to decide whether to respond or not.

The substitution of artificial signals for the increased signal probability should have the same effect of keeping β constant within a session. In this way performance should be kept at a stable level without changing the signal probability in the task.

In this experiment the modality was changed from auditory to visual. In the previous experiment the equipment had not been sufficiently precise for the experimenter to be certain of the accuracy of sound amplitude at all times. The new task involves discrimination between horizontal lines of differing lengths. Subjects were run for one session only. Each session lasted for one hour and was preceded by a ten minute pretest.

Method:

Stimuli were presented on a three-channel tachistoscope made by Scientific Prototype MFG Corp., model 320 GB. The stimulus field measured 5" by 7". The stimuli consisted of white lines one mm. wide in the centre of a black background. Black Letrafilm was used for the background and the lines were made with white Letraset. A Spectra photometer, model 1505-UB was used to ensure that the light intensity in all three channels was equal. The presentation of stimuli was controlled by a DEC PDP-8E computer. During sessions the experimental room was illuminated by a shaded 25 watt red bulb.

There were three conditions in the experiment and ten O's were run in each condition. All O's were students at McMaster University. Each O participated in a 10 min. pretest, in which signal probability was .09, and a one hour vigilance session. Event rate was the same for all three conditions.

A nonsignal was a horizontal line 3 cm. long. A signal was a horizontal line 3.1 cm. long. A few O's could not discriminate between these two line lengths during the pretest. For these O's the signal was increased to 3.2 cm. in the main vigilance session. All O's could discriminate this difference.

O's sat with their faces in a viewing mask. When a stimulus was presented they had to decide whether it was a signal or a non-signal. When they perceived a stimulus to be a signal they depressed a response button. Each stimulus was presented for 300 msec., and the intertrial interval was 2.5 sec.

In the first condition, signal probability was held constant at .013. Presentation of signals was random, with the restriction that 4 signals occurred during each of the four 15 min. time periods.

In the second condition signal probability was .013 in the first two time periods, .022 in the third, and .032 in the fourth. This resulted in 4,4,7, and 10 signals respectively in each of the four time periods. This resembles the experimental groups in Experiment I.

The third group received a signal probability of .013 throughout the vigilance session as did the first. However in the third time period 3 artificial signals were presented and in the fourth time period 5 were presented. Therefore the probability of a signal or an artificial signal was equal to the signal probabilities in the second condition. The artificial signal was a horizontal line 2 mm. longer than the signal. O's did not press the response button when they discriminated an artificial signal.

Instructions to the O's were similar to those described in the first experiment.

<u>Results</u>:

The data were analysed separately for each of the four time periods in each session. Scores were averaged over the ten O's in each group.

The O's' performance in all three conditions is plotted in terms of per cent correct in Fig. 9. In group one, in which signal probability was constant throughout the session, a decrement in

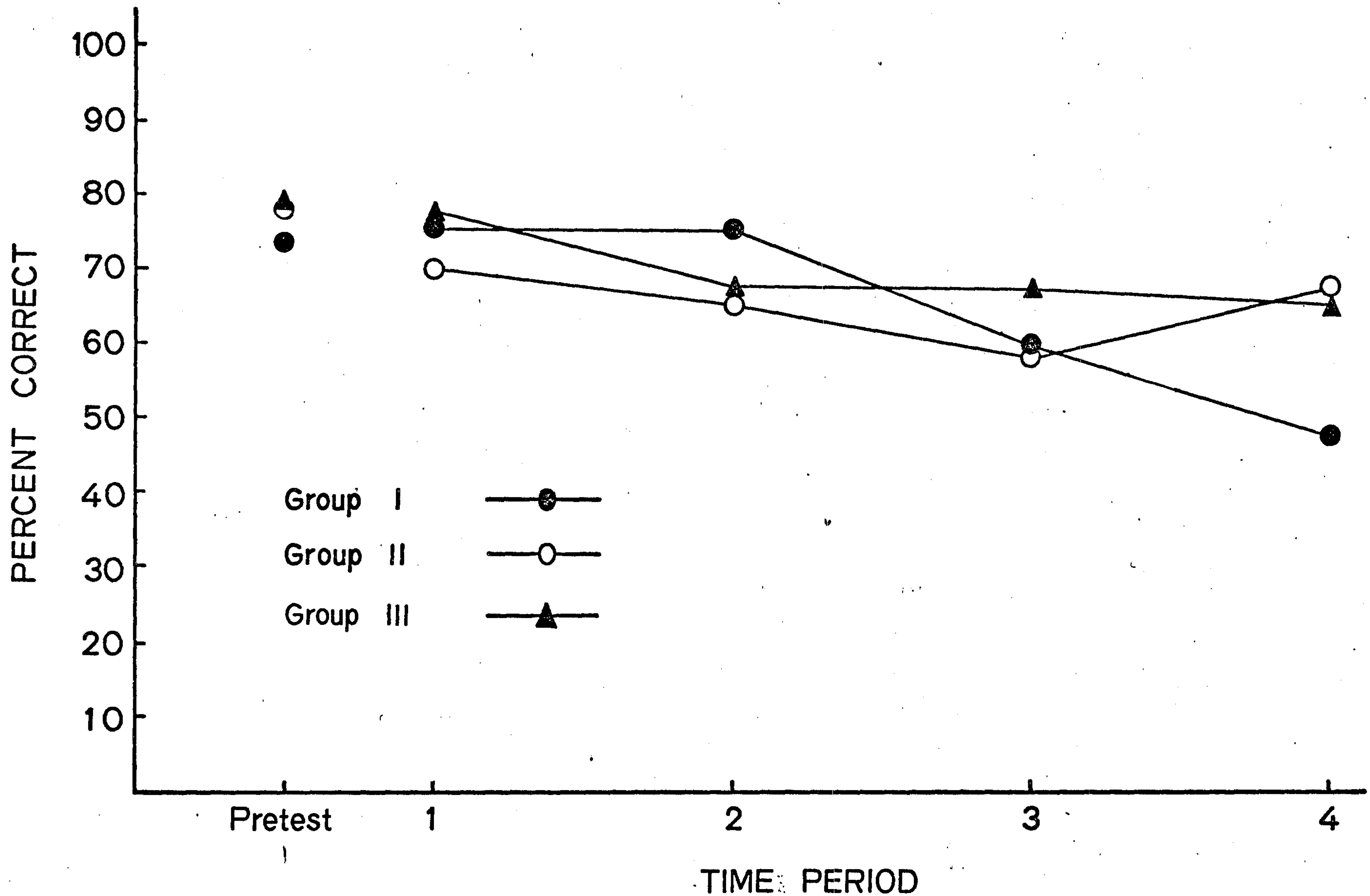

Fig. 9. Per cent correct performance in each of the four time periods for the three conditions.

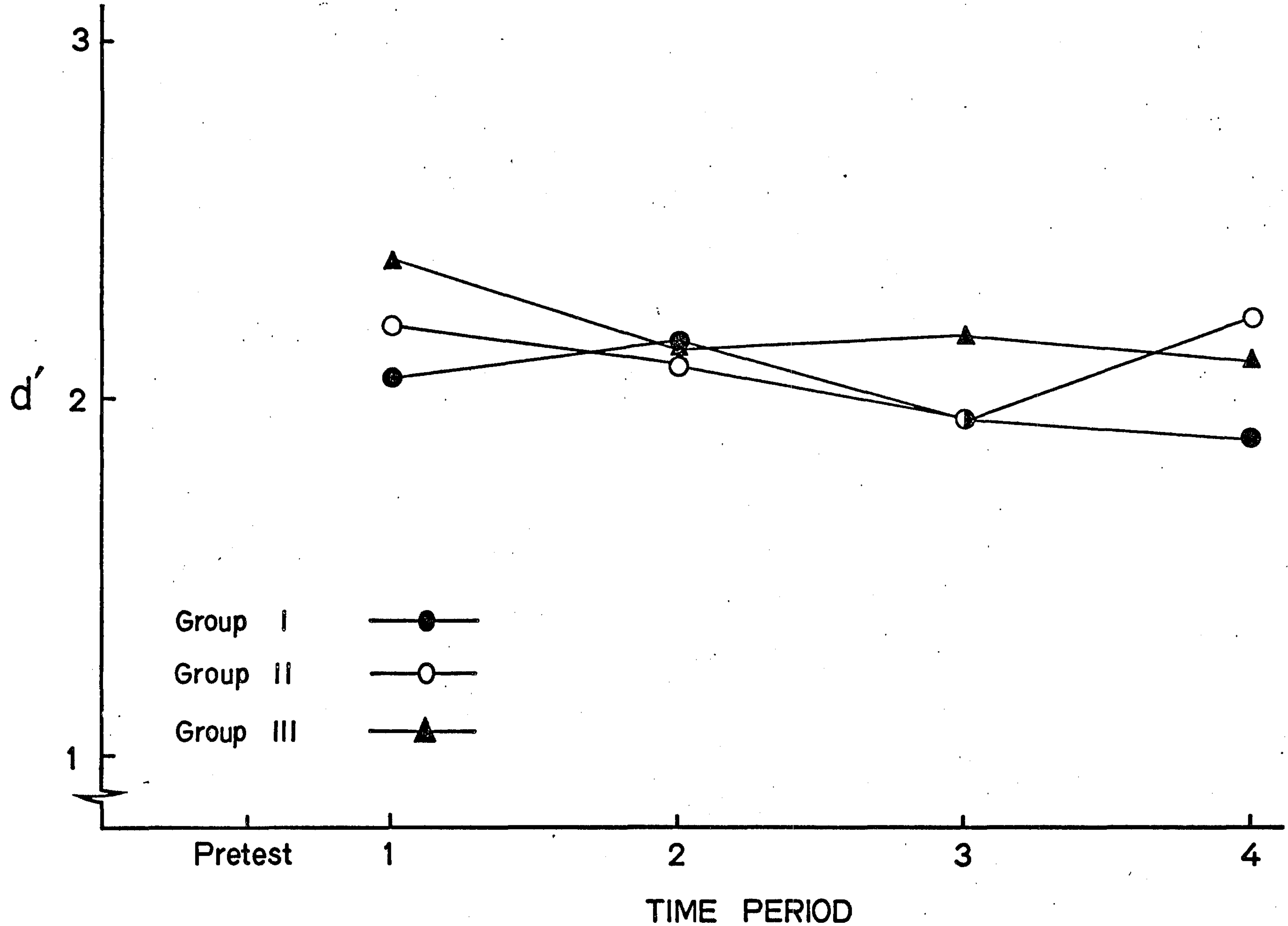

Fig. 10. Values of d' obtained in each of the four time periods for the three conditions.

		Time Period 1	4
Group 1	d'	2.07	1.90
	SE	.2185	.2039
Group 2	d'	2.21	2.24
	SE	.2125	.1335
Group 3	d'	2.40	2.12
	SE	.2241	.2079

Table 5

d' values and standard errors for the first and fourth time periods in the three conditions.

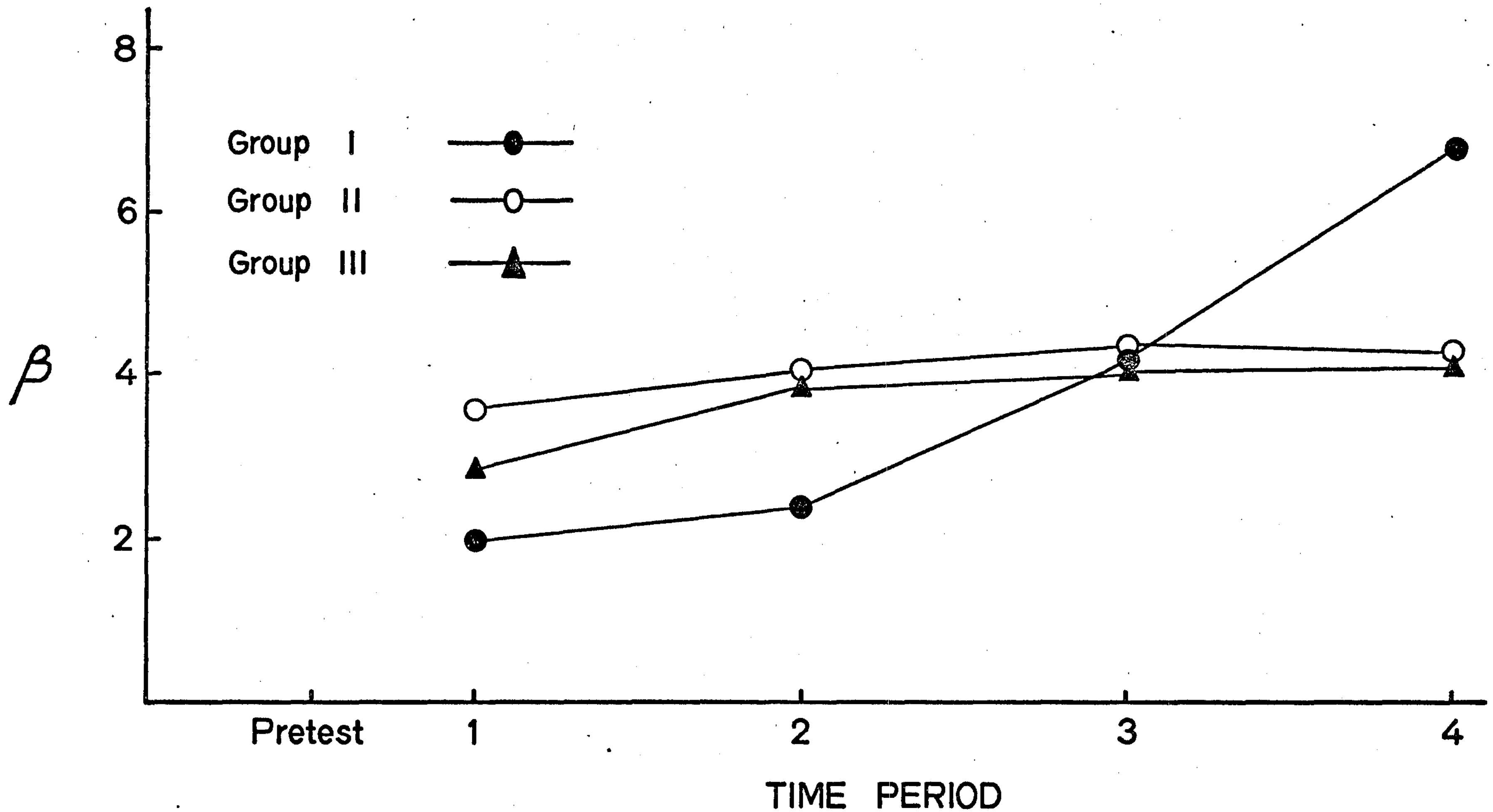

Fig. 11. Values of β obtained in each of four time periods for the three conditions.

performance from the first to the fourth time period is observed. A direct difference t test indicates that the difference in per cent correct between the first and fourth time period is significant at the .001 level, (t=4.74). The second and third groups show more stable performance. There is no significant difference between per cent correct performance in the first and fourth time periods for these groups, (t=.357 and 1.35 respectively).

O's obtained between 70 and 80% correct on the pretest in this experiment and a significant decrement was still found in condition one. In the first experiment a decrement could not be obtained with such a high initial level of discrimination.

In Fig. 10 the d' values obtained for each condition are plotted. The standard errors for the d' scores of the first and fourth time periods are given in Table 5. The variance of d' used in the calculation of the standard error was derived by Gourevitch and Galanter (1966). The standard errors of the two time periods overlap in each of the three conditions. d' was fairly constanct throughout all of the vigilance sessions, as was expected.

β values for all three groups are shown in Fig. 11. There is a definite increase in the value of β from the first to the fourth time period in condition one. The size of this increase is much smaller than that observed for the control groups in Experiment I. In groups two and three, a small increase in β from the first to the second time period is observed. It remains constant from the second to the fourth time period.

O's made very few responses to the artificial signals.

<u>Conclusion</u>:

In general, the results of Experiment II were as predicted. Substitution of artificial signals for the additional signals occurring when signal probability is increased within a session had the effect of maintaining O's' criteria at a constant level.

There are two differences in the results of Experiments I and II. First, in Experiment II, a performance decrement was obtained with an initial discrimination level of about 75% correct. In the first experiment a decrement could only be obtained when initial discrimination was between 50 and 60% correct. One explanation for this may be that since the first experiment was more tightly coupled than the second, O's had to pay more attention to the stimuli. This may have caused the more stable performance at higher discrimination levels in the auditory task.

The second major difference between the two experiments is the range of the increase in β when signal probability was held constant within sessions. β values occupied a much smaller range in Experiment II. This is partially due to the fact that sessions lasted for $1\frac{1}{2}$ hours in Experiment I and 1 hour in Experiment II. Rather than leveling off after one hour, the criteria continued to become more conservative until completion of the $1\frac{1}{2}$ hour sessions.

However if the first hour data only is analysed, β values still show a higher increase in the first experiment. Event rate was slightly higher in the first experiment than in the second, (1484 vs. 1284 events per hour). This could conceivably have influenced the increase in β, but seems improbable as the difference in event rates is very small.

Another possible explanation is that just the knowledge that a session was going to last $1\frac{1}{2}$ hours rather than 1 hour would cause O's in the former group to shift their criteria more rapidly. It may also be that the difference in range of criteria may be due to the differences in the nature of the two tasks.

In the second and third conditions a slight increase in β was observed between the first and second time periods. The signal probability in the pretest was higher than in the vigilance session. The early decrease in False Alarms, resulting in a small increase in β, may have been the result of shifting expectations about signal probability, (cf. Colquhoun and Baddeley, 1964).

Experiment III

In pilot studies for Experiments I and II, an unexpected result was found. If the initial discrimination performance of O's was too high, no decrement in performance occurred. In the auditory experiment a decrement was only obtained when the O's performed at a 50 to 60% Hit rate on the pretest. In the visual experiment a decrement was shown at a 70 to 80% initial discrimination level. It did not occur if the Hit rate was higher on the pretest.

The reason that these results were unexpected is that many studies report a vigilance decrement with a Hit rate of about 90% on the pretest or first part of the vigilance session, (e.g. Buckner and McGrath, 1963; Mackworth and Taylor, 1963; Williges, 1971). The relationship between discrimination level and the decrement has not been clearly established, (Mackworth; 1969), and so the third experiment was designed to investigate this problem.

The studies concerning the relationship of signal intensity to vigilance, mentioned in the historical review, fall short of clarifying the issue, since signal intensity is not defined in terms of the O's capabilities. In Davenport's (1968) study the thresholds of O s for a 1,000 Hz tone were found by the Method of Limits. The amplitude of signals was then set at 1, 2, 3, or 4 dB SPL above the threshold of each O. It is known that each O was performing at the 50% correct detection level at threshold. However O's' thresholds for differences in amplitude also vary, and 4 dB above threshold may result in different levels of performance for different O's. In addition, Davenport's experiment had the complication mentioned earlier, that the four signal intensities were presented within sessions.

Guralnick's (1972) experiment had an easy and a difficult condition. In the easy condition O-s were making 99.75% Hits and in the difficult condition they were making approximately 70% Hits in the first part of the vigilance task. If the relationship between discrimination level and the vigilance decrement is to be found, the initial level of performance should be ascertained by a threshold test, and not simply by how the O performs in the vigilance task.

The third experiment reported here attempts a straightforward approach to this issue. Each O's threshold for discriminating between two lines of different lengths was obtained. The standard line remained a constant length and the comparison line was adjusted in length until a desired level of performance was reached by the O. Discrimination threshold was defined in three ways: that comparison line length at which the O attained 90%, 75%, and 60% correct detections.

There were three groups of O's, corresponding to the three threshold levels. An O's threshold at a certain level was ascertained. The O then ran in a one hour vigilance session. After the session his threshold was measured again, to see whether it had shifted during the session.

The procedure which was used for estimating thresholds was PEST (Parameter Estimation by Sequential Testing), (Taylor and Creelman; 1967). PEST is an adaptive procedure for determining the level of an independent variable, (in this case line length), which leads to a specified probability of an O responding in a particular way on a single trial. In this method of threshold estimation, the initial line length is set at an arbitrary level and is then changed according to the history of the O's responses.

A series of stepping rules govern the change in line length. In general, as an O continues to make correct responses the line length becomes shorter, and if many errors are made it becomes longer. The decision to change the line length or to halt the testing procedure when the desired level of performance is reached is governed by the Wald (1947) sequential likelihood-ratio test.

The advantage of PEST is that it gives a stable estimate of threshold in a small number of trials. The estimate can thus be obtained in a short period of time and then used in a different type of paradigm, as is described below.

The stimuli in Experiment III were similar to those presented in Experiment II. However they were presented on an oscilloscope since the tachistoscope did not have enough channels to encompass the varying line lengths needed for the PEST sessions.

Method:

Stimuli were presented on a Hewlett-Packard X-Y Display scope, model 1300A. Presentation of the stimuli was controlled by a DEC PDP8-E computer, and could be monitored by means of a Tektronix Scan Converter Unit, Type 4501. The PEST program used in obtaining thresholds was obtained from one of the authors of PEST, C. D. Creelman. A shaded, red, 45 watt bulb illuminated the experimental room during all sessions.

The parameter values used in the PEST program were as follows. The deviation limit of the sequential test was set to 1.5

as suggested by Taylor and Creelman, (1967). The changes in line length were made in terms of units, with one unit being equal to .275 mm. The minimum step size for PEST was set at 3 Units and the maximum step size at 15 units. This is in conformity with the suggestion that, "starting and stopping sizes be chosen to allow at least four reductions in step size before the end of the run", (Taylor and Creelman; 1967).

The parameter values were chosen in reference to guidelines set by the authors of PEST, but were to some extent arbitrary. Nevertheless they can be considered to be satisfactory since a large number of computer simulations testing PEST led to the conclusion that the efficiency of the test is almost independent of conditions, and that the threshold estimate is unbiased under a wide variety of conditions.

There were three groups of 10 O's, distinguished by the threshold levels obtained prior to and after the vigilance session. The threshold levels were 90%, 75%, and 60% correct discrimination. During the threshold test the length of the standard line was 3 cm. At completion of the test the length of the comparison line at which the O achieved the required level of discrimination was known.

The threshold test consisted of a two-alternative forced-choice task. On each trial the standard and comparison lines were presented sequentially. The order of presentation was random. Each stimulus was presented for 300 msec. and there was a 300 msec. interval between presentation of the two stimuli. The inter-trial interval was 2.5 sec. O's had to decide whether the longer line was presented first or second, and press a response button to indicate their decision. O's were seated 3 ft. from the screen of the display scope.

The threshold test was followed by a one hour vigilance session. In this session the nonsignal was a horizontal line 3 cm. long. The signal was a line whose length was determined by the previous threshold test. The signal probability in the vigilance session was .012 for all groups. The presentation of signals was random, with the restriction that four signals occurred in each 15 min. time period. On each trial the stimulus was presented for 300 msec. and the intertrial interval was 2.5 sec.

Instructions to the O s prior to the vigilance session were similar to those described in Experiments I and II. In this experiment it was stressed that the signal probability would be low in the vigilance session, in order to avoid a disproportionately high signal expectancy after the threshold test.

After the vigilance session the O's' thresholds were again determined, in order to check for changes in threshold during the vigilance session.

Results:

The length of the comparison lines at which thresholds were reached for the three groups is shown in Table 6. Group 1 attained 90% correct performance with an average comparison line length of 3.84 cm. Group 2 performed at 75% correct with an average line length of 3.43 cm., and group 3 reached a 60% threshold level at a line length of 3.23 cm. The line lengths corresponding to each threshold level before the vigilance session did not change significantly when thresholds were tested again after the session.

The average number of trials which were needed to arrive at the threshold estimate are also shown in Table 6.

In experiment II, O s attained a 75% correct detection level on the pretest when the comparison line length was 3.1 or 3.2 cm. In this experiment the line was an average of 3.4 cm. at this performance level.

The performance of O s in the vigilance session isplotted in terms of per cent correct in Fig. 12. O s in group 1 maintained a fairly constant level of performance throughout the session. There was no significant decrement in performance. The second group of O s did show a steep decrement from the first to the fourth time period. The third group showed a decrease in per cent correct scores from the first to the third time period, and a slight increase from the third to the fourth time period. The performance decrement shown by this group was not as steep as that of group 2.

In the first time period of the vigilance task, group 1 averaged 85% correct and group 2 averaged 72.5% correct. This is quite close to the threshold level for each group. The third group averaged 47.5% correct detections in the first time period of the vigilance session. This is considerably lower than the 60% threshold level of the group.

d' values for the groups are shown in Fig. 13. At first glance the d' scores do not seem to be constant from the first to the last time periods. However the standard errors of the d' values for the first and fourth time periods overlap for each group. If the numerical values of the d' scores in each group are compared, they are seen to be very close. The largest difference between d' scores from the first to fourth time period is shown in group 2.

	Threshold Level		
	90%	75%	60%
Pre-vigilance threshold	3.84	3.43	3.23
# trials	142.9	147.6	140.8
Post-Vigilance threshold	3.85	3.40	3.28
# trials	150.9	129.0	134.5

Table 6. Pre- and post -vigilance thresholds for the three groups. The threshold is given in terms of the length of the comparison line in cm. The number of trials taken to arrive at the threshold is also shown. Each figure is an average over 10 O s.

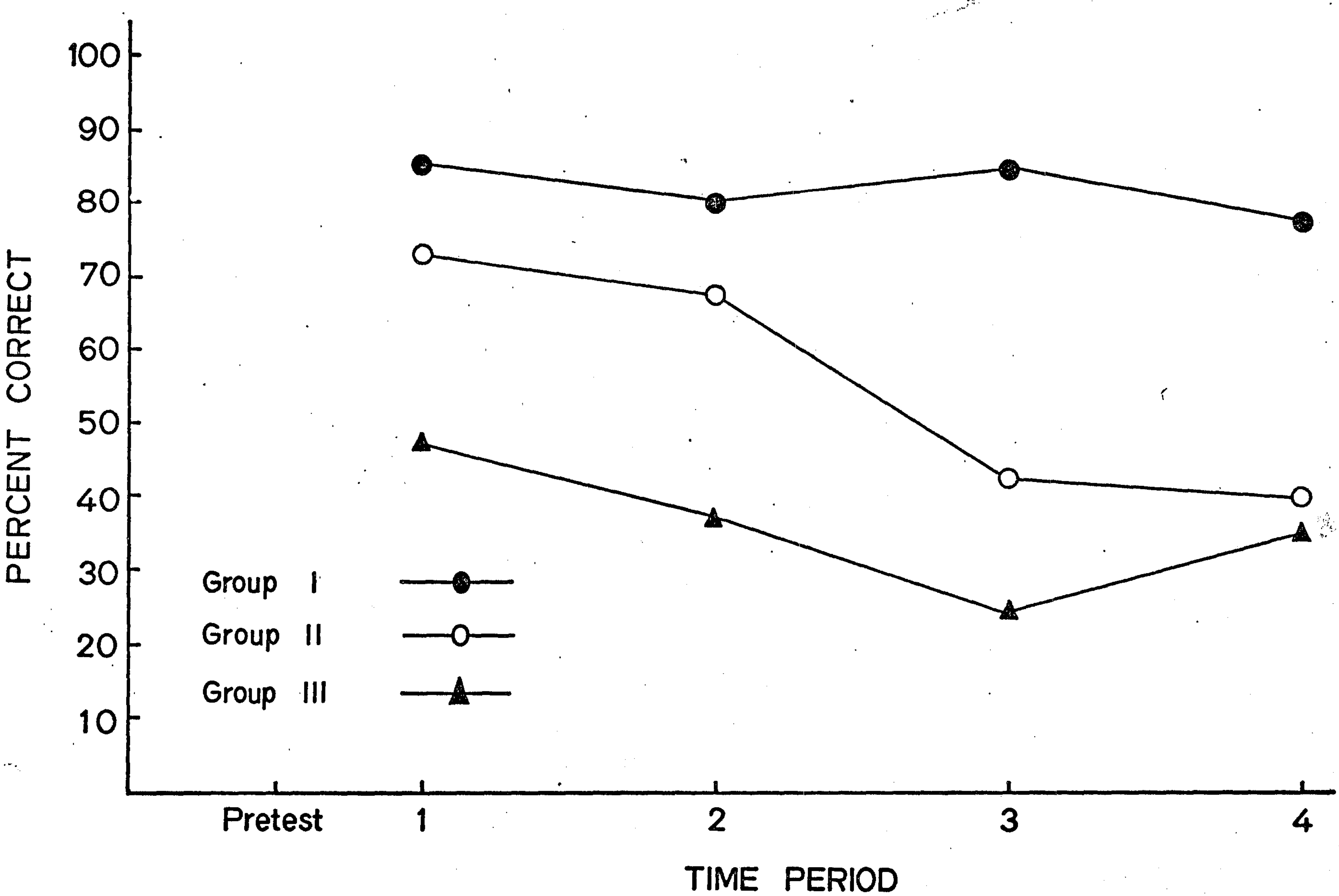

Fig. 12. Per cent correct performance in the three groups.

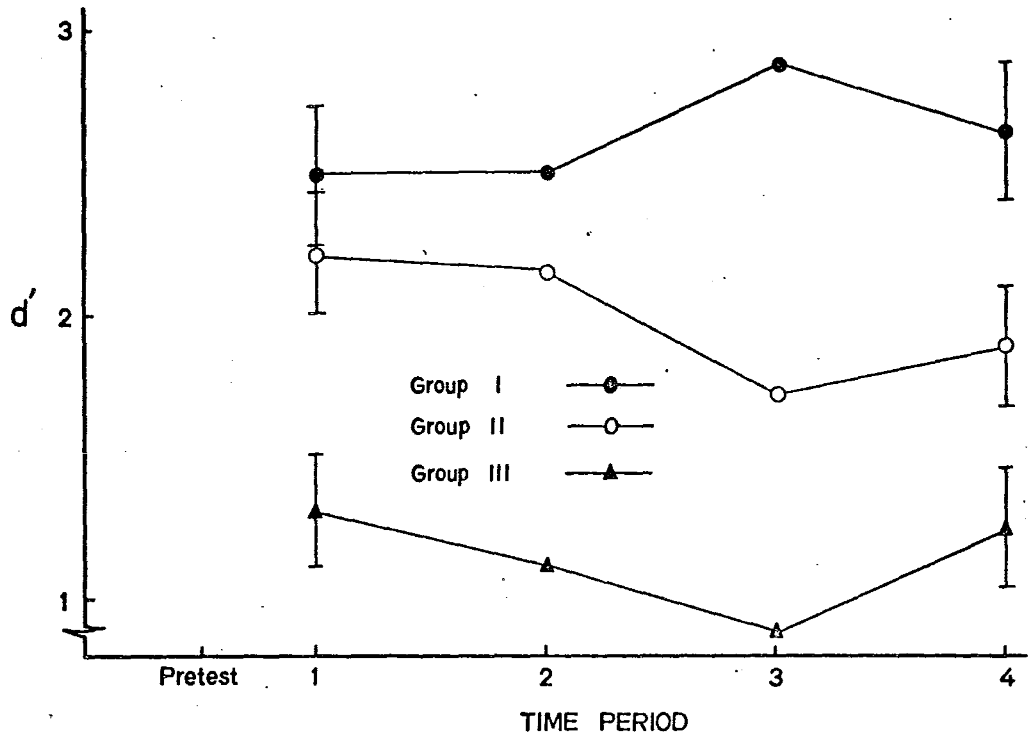

Fig. 13. d' values for the three groups. The standard errors of the d' scores in the first and fourth time periods are plotted.

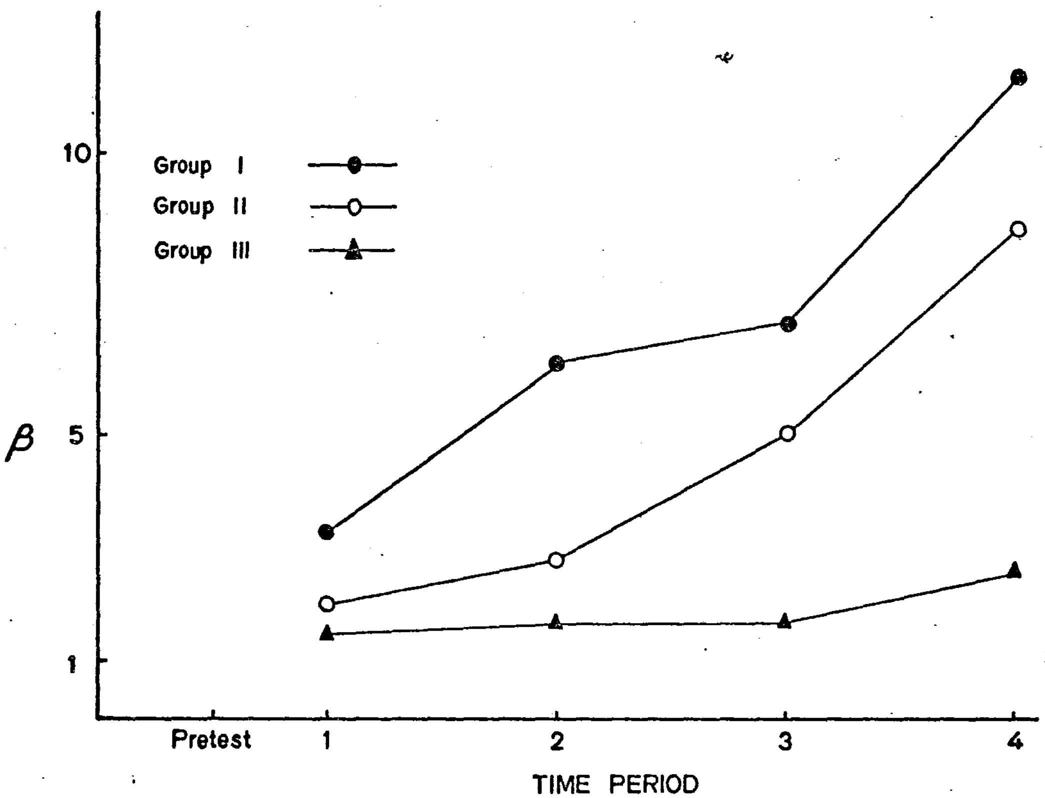

Fig. 14. β values for the three groups.

d' does appear to decrease in this group. In each group the trend for d' to increase or decrease is counteracted in the fourth time period.

Fig. 14 illustrates the β values obtained in the three groups. A substantial increase in β throughout the vigilance session is observed in groups 1 and 2. In group 3 β remained almost constant throughout the vigilance session.

Conclusion:

The PEST procedure for setting stimulus values corresponding to a specified level of discrimination appeared to give a good estimate of threshold. In the first two groups the percentage of Hits made in the first time period of the vigilance task was identical to the threshold level set for that group. The performance of the third group on the initial part of the vigilance task was lower than the threshold level of 60% correct. This may be due to the fact that discrimination was very difficult for this group, and as signals occurred infrequently in the vigilance session the difficulty of discrimination would be combined with fluctuations in attention.

In Experiment II the comparison line length associated with 75% correct performance was 3.1 or 3.2 cm. In the third experiment the line length for the same performance level was 3.4 cm. This may be explained by the fact that the vigilance task was more tightly coupled in the second experiment. O s sat with their faces in a viewing mask which was connected to the tachistoscope. In the third experiment O s simply sat facing the display 3 ft. away from them. Discrimination performance would be expected to be superior in the more closely coupled task.

The relationship between initial discrimination level and the form of the vigilance decrement was resolved for the specific type of task used in Experiment III. A decrement in performance was found when O's performed at 75 or 60% correct on a threshold task, but not when they performed at 90% correct. These results may not be generalized to all types of vigilance tasks. In Experiment I a decrement in performance was not obtained when O's attained 75% Hits on a pretest. The results of Experiment III may apply to some visual discrimination tasks in which discrete presentation of stimuli occurs at regular intervals.

DISCUSSION

The major findings obtained in the research described in this thesis may be summarized as follows:

1. O's run daily in a $1\frac{1}{2}$ hr. auditory vigilance task exhibit a performance decrement for the first three days. On subsequent days no decrement is observed. (Experiment I)

2. There is no difference in performance on a $1\frac{1}{2}$ hr. auditory vigilance task with signal probabilities of .012 or .021. (Experiment I)

3. If signal probability is increased within a session, the tendency for β to rise is counteracted and performance is stabilized. This is true for auditory and visual vigilance tasks. (Experiments I and II)

4. If artificial signal probability is increased within a session in a visual vigilance task, the increase in β is counteracted. (Experiment II)

5. O's who perform at a 90% correct level on a threshold task do not display a performance decrement on a subsequent vigilance task utilizing the same visual stimuli. O's performing at a 75 or 60% level prior to the vigilance session do show a decrement during the session. (Experiment III)

6. When the signal probability in a one hour visual vigilance task is .012, O's' thresholds as measured before and after the vigilance

session are not significantly different. (Experiment III)

The vigilance literature is characterized by disorder and inconsistency in results. The question of the generality of the findings reported here is thus raised.

In the first experiment, signal probability was found to be unrelated to performance when manipulated between sessions. Loeb and Binford (1968) used the same experimental paradigm as reported in Experiment I, with the one change that white noise pulses were used instead of pure tones. They found that signal probability was an effective variable. Performance improved as signal probability increased. They used signal probabilities of .167, .083, .042, and .021. It may be that the lack of effect of signal probability between sessions in Experiment I was due to the closeness of the two probabilities used.

The effect on criterion of increasing signal probability within a vigilance session was demonstrated in an auditory and a visual task. This may indicate a generalizable result.

The results of Experiment III may be specific to visual line length discrimination tasks. As has been seen they do not conform with the data obtained on the auditory task. The relation between discrimination level and performance decrement has not received much attention in the literature, and it would be fruitful to explore this area with a variety of tasks.

The finding that increasing signal probability or artificial signal probability within sessions reduces the performance decrement can be encompassed by both expectancy theory and arousal theory. Expectancy theory would maintain that as signal probability increased, the length of the mean inter-signal interval would decrease and O's would expect signals more often. In addition, the vicious circle effect, as described on page 22, would be counteracted, because although missing signals would increase the O's estimate of inter-signal interval, the increased number of signals would give more opportunities for Hits and revisions of the estimate.

With regard to arousal theory, the increased number of signals would serve to alert the O and counteract the effect of decreasing arousal during the session. When signal probability is increased within a session O's make more motor responses of pressing the response button, as shown by the increased number of Hits and False Alarms. These motor responses may also contribute to preventing the decline in arousal level during a session.

It should be stressed that the experiments reported here show that signal probability manipulated within sessions is one determinant of behavior in vigilance tasks. It cannot be thought of as the determinant. The field of vigilance covers a wide range of experimental tasks. Changes in performance manifested over a long period of time are studied. It is highly unlikely that one variable causes the performance decrement which is usually observed. A complete explanation of vigilance behavior would cover a composite of factors.

A survey of the vigilance literature indicates that the general approach to research in this field needs reevaluating. The first studies of vigilance grew out of a need for solutions to practical watchkeeping problems. Present studies are not directly applicable to applied psychology, (Smith and Lucaccini, 1969; Stroh, 1971), and yet the approach to the research remains the same as it was at its inception in the 1940's. The study of vigilance could make significant contributions to the general area of psychophysics, but the two fields remain separated. A few brief suggestions for improvement in the study of vigilance are listed below.

It would be worthwhile to develop a mathematical model which can be used to account for and make predictions from vigilance results. TSD is a useful model, in that the separation of performance into sensitivity and criterion can lead to predictions about the effects of variables on these parameters. It was used in this fashion in this thesis. The influence of the manipulations on the per cent correct scores indicate that the manipulations originated in terms of the model had the predicted effect on performance measured without reference to the model. However, as mentioned in the historical review, some of the assumptions underlying TSD are probably violated in a vigilance paradigm, and the model should be used conceptually only. A model with assumptions corresponding to the vigilance situation, and providing a quantitative description of the data, would introduce some precision to the field and would be a definite contribution to the development of the area.

Many psychophysical studies are concerned with the performance of O's within short periods of time. The behavior of O's within these short intervals is tested over long periods of time. The interaction between performance on the specific discrimination or perception task and the effect of session length on performance is often ignored. The study of vigilance should be able to contribute to this area. If signal probability were increased to ressemble that of most psychophysical experiments, the effects of decreasing arousal on performance of these tasks could be investigated.

Within the framework of expectancy theory, a more mathematical and probabalistic approach is desirable. The most competent study in this area is that of McGrath and Harabedian (1963) in which the effect of rectangular and skewed distributions on expectancy were investigated. Too many studies make one small manipulation whose effects can be interpreted in many different ways. The procedure of converging operations (Garner et. al; 1956) is alien to most of the vigilance literature.

Stroh (1971) suggests that complex factor analytic studies are the answer to the increasing confusion in the literature. This would be an improvement over the present type of research, however it is still in the same vein.

It is concluded that the study of vigilance has significant contributions to make to other areas of psychology, but that a fresh approach to the field is needed.

APPENDIX I

Raw data of experiments I, II, and III.

Raw Data from Experiment I:

Control Group - Signal Probability = .012

Hits Day	Time Period	Subject 1	2	3	4
	Pretest	9	10	9	11
	1	3	3	1	2
	2	1	2	1	3
	3	3	4	3	4
1	4	2	2	3	3
	5	2	1	2	1
	6	1	1	0	2
	Pretest	13	14	9	10
	1	3	3	2	3
	2	2	4	1	3
	3	3	3	3	4
2	4	1	1	3	2
	5	3	2	1	0
	6	2	1	1	1
	Pretest	15	13	15	10
	1	3	2	4	3
	2	3	1	3	4
	3	4	4	3	3
3	4	3	3	1	3
	5	1	1	4	2
	6	1	3	3	2
	Pretest	15	16	17	10
	1	3	2	4	3
	2	1	3	4	2
	3	2	3	4	1
4	4	4	2	4	2
	5	1	1	4	1
	6	3	2	3	1
	Pretest	17	17	16	10
	1	3	4	4	3
	2	4	3	2	2
	3	3	3	4	2
5	4	4	4	3	4
	5	2	4	4	2
	6	3	3	4	1

Control Group - Signal Probability = .012

False Alarms

Day	Time Period	Subject 1	Subject 2	Subject 3	Subject 4
1	1	18	27	12	17
	2	8	12	4	12
	3	12	8	0	11
	4	4	4	6	12
	5	4	3	1	9
	6	6	2	2	9
2	1	7	12	8	7
	2	2	6	7	7
	3	0	9	4	4
	4	5	3	8	4
	5	0	7	7	7
	6	2	2	6	4
3	1	3	2	9	10
	2	3	4	5	9
	3	0	1	4	7
	4	0	2	1	0
	5	2	1	4	7
	6	4	1	5	3
4	1	1	1	5	0
	2	4	3	3	6
	3	3	2	4	2
	4	0	2	4	0
	5	1	5	3	4
	6	0	1	1	4
5	1	2	2	3	1
	2	1	2	0	0
	3	0	4	2	2
	4	1	1	2	1
	5	2	3	1	2
	6	0	0	1	0

Control Group - Signal Probability = .021

Hits Day	Time Period	Subject 1	2	3	4
	Pretest	12	9	10	7
	1	5	4	5	4
	2	4	6	4	4
	3	3	5	5	0
1	4	2	4	3	3
	5	5	2	3	0
	6	1	2	1	3
	Pretest	11	10	11	8
	1	5	5	5	4
	2	3	5	3	4
	3	1	4	3	3
2	4	2	3	2	4
	5	1	4	5	2
	6	1	2	1	3
	Pretest	13	13	9	7
	1	4	6	5	1
	2	3	5	3	4
	3	5	6	5	3
3	4	5	4	5	3
	5	3	4	3	2
	6	6	2	2	0
	Pretest	15	17	14	8
	1	5	6	5	2
	2	5	4	4	0
	3	6	4	3	5
4	4	6	3	2	5
	5	5	7	5	3
	6	3	7	4	1
	Pretest	18	17	17	10
	1	6	5	5	5
	2	6	7	4	5
	3	6	6	4	3
5	4	5	7	5	5
	5	7	7	3	4
	6	6	6	2	2

Control Group - Signal Probability = .021

False Alarms

Day	Time Period	Subject 1	Subject 2	Subject 3	Subject 4
1	1	10	4	9	12
	2	13	7	15	10
	3	3	3	20	11
	4	3	4	22	9
	5	1	5	18	13
	6	0	2	14	11
2	1	11	7	18	15
	2	9	2	13	13
	3	4	1	15	4
	4	5	2	10	4
	5	4	3	8	5
	6	2	2	11	3
3	1	3	5	8	10
	2	4	2	3	9
	3	1	0	4	11
	4	1	3	3	5
	5	3	0	2	3
	6	1	0	4	3
4	1	1	3	4	8
	2	2	2	2	9
	3	1	4	2	4
	4	1	8	4	7
	5	2	3	3	7
	6	1	4	1	6
5	1	0	2	3	7
	2	0	0	4	3
	3	4	0	2	0
	4	3	1	0	1
	5	3	3	1	3
	6	0	0	2	3

Experimental Group - Signal Probability = .012

Hits Day	Time Period	Subject 1	2	3	4
	Pretest	9	11	8	9
	1	3	2	3	1
	2	2	1	2	3
	3	3	3	4	1
1	4	3	4	4	2
	5	5	6	5	6
	6	7	6	6	5
	Pretest	10	11	9	9
	1	3	2	2	3
	2	1	3	3	2
	3	5	4	5	5
2	4	3	4	4	5
	5	6	7	5	7
	6	7	6	6	6
	Pretest	12	13	11	10
	1	3	3	2	3
	2	2	3	3	4
	3	5	6	5	4
3	4	5	5	6	4
	5	7	6	7	6
	6	8	6	8	7
	Pretest	14	13	14	13
	1	4	2	3	4
	2	3	3	4	4
	3	4	5	6	6
4	4	5	6	7	6
	5	7	7	6	8
	6	6	8	7	8
	Pretest	16	15	17	16
	1	4	3	4	4
	2	4	4	3	4
	3	6	6	5	6
5	4	6	7	7	6
	5	8	9	8	6
	6	9	9	8	7

Experimental Group - Signal Probability = .012

False Alarms

Day	Time Period	Subject 1	2	3	4
1	1	13	19	22	8
	2	13	14	18	5
	3	12	10	15	7
	4	5	7	10	4
	5	6	5	11	4
	6	8	8	9	5
2	1	9	14	17	7
	2	6	9	10	5
	3	3	7	6	4
	4	2	5	6	3
	5	3	4	5	5
	6	3	7	4	4
3	1	9	8	9	3
	2	5	6	8	2
	3	1	3	7	0
	4	9	5	8	3
	5	9	7	6	1
	6	0	4	5	1
4	1	5	1	7	3
	2	3	6	4	1
	3	0	2	2	3
	4	2	1	5	4
	5	3	2	4	2
	6	3	5	4	3
5	1	3	0	5	2
	2	2	3	4	3
	3	3	3	2	5
	4	4	5	2	3
	5	5	6	0	4
	6	4	3	4	5

Experimental Group - Signal Probability = .021

Hits Day	Time Period	Subject 1	2	3	4
1	Pretest	8	10	9	11
	1	4	3	4	5
	2	2	5	5	4
	3	5	6	7	5
	4	5	5	6	6
	5	7	8	9	8
	6	6	9	4	9
2	Pretest	10	12	9	10
	1	4	4	5	5
	2	5	3	3	5
	3	4	9	6	7
	4	6	8	5	6
	5	9	9	7	9
	6	8	7	7	8
3	Pretest	12	12	11	13
	1	5	6	4	6
	2	5	5	6	5
	3	6	7	6	5
	4	7	6	6	6
	5	8	9	8	7
	6	9	10	8	10
4	Pretest	13	15	14	13
	1	6	5	5	7
	2	6	6	5	6
	3	8	7	7	6
	4	7	7	8	6
	5	9	8	9	10
	6	8	9	10	10
5	Pretest	15	17	16	17
	1	6	7	6	5
	2	7	6	6	6
	3	7	8	7	8
	4	8	8	7	8
	5	10	9	11	9
	6	11	10	9	10

Experimental Group - Signal Probability = .021

False Alarms

Day	Time Period	Subject 1	Subject 2	Subject 3	Subject 4
1	1	26	17	12	15
	2	22	19	11	19
	3	20	12	9	17
	4	8	14	13	8
	5	10	11	8	10
	6	16	9	10	14
2	1	14	8	14	10
	2	13	16	9	11
	3	9	8	6	7
	4	8	6	3	6
	5	4	4	10	7
	6	9	3	8	8
3	1	7	5	9	2
	2	6	3	8	2
	3	8	0	5	4
	4	5	4	7	3
	5	4	3	5	5
	6	4	3	6	3
4	1	3	2	7	4
	2	1	3	5	5
	3	5	1	3	3
	4	4	3	4	4
	5	2	2	6	2
	6	4	2	4	2
5	1	2	3	4	2
	2	3	4	4	3
	3	3	2	5	3
	4	5	1	6	5
	5	3	0	4	4
	6	2	4	5	2

Raw Data from Experiment II:

Condition I

Hits:

Subject	Pretest	Time Period 1	2	3	4
1	13	1	3	2	1
2	18	2	2	2	1
3	12	3	4	3	2
4	15	4	3	3	2
5	17	3	3	4	3
6	10	3	2	1	2
7	17	4	3	2	2
8	13	3	4	2	2
9	14	3	3	2	2
10	18	4	3	3	2

False Alarms:

Subject	Time Period 1	2	3	4
1	22	17	19	8
2	20	15	9	5
3	36	31	24	13
4	37	33	24	17
5	13	7	4	0
6	31	26	9	7
7	18	13	8	3
8	24	21	8	4
9	33	27	18	13
10	28	25	20	9

Condition II

Hits:

Subject	Pretest	Time Period 1	2	3	4
1	15	2	1	3	5
2	16	3	4	5	8
3	18	4	4	6	10
4	18	4	4	7	9
5	13	1	0	2	3
6	11	2	2	1	5
7	17	3	2	3	7
8	15	2	3	5	6
9	15	3	3	4	7
10	18	4	3	5	8

False Alarms:

Subject	Time Period 1	2	3	4
1	10	9	15	9
2	13	12	8	11
3	9	7	5	6
4	11	13	9	10
5	22	20	17	16
6	25	23	24	20
7	17	16	13	14
8	19	17	20	16
9	12	9	10	11
10	12	11	7	5

Condition III

Hits:

Subject	Pretest	Time Period 1	2	3	4
1	17	4	3	4	3
2	14	3	2	2	2
3	13	2	3	1	2
4	15	3	3	2	3
5	18	4	3	2	4
6	16	4	2	3	2
7	14	3	2	3	1
8	17	3	4	3	2
9	16	2	3	3	4
10	18	3	2	4	3

False Alarms:

Subject	Time Period 1	2	3	4
1	10	5	9	8
2	20	23	18	19
3	24	22	16	21
4	15	12	12	14
5	6	3	4	2
6	18	19	17	17
7	17	15	16	15
8	14	11	9	7
9	28	25	22	23
10	9	5	7	6

Raw Data from Experiment III

Group I

Hits:

Subject	Time Period 1	2	3	4
1	3	2	4	3
2	4	3	4	4
3	4	2	2	2
4	3	4	3	3
5	2	3	4	3
6	3	4	3	4
7	4	4	4	3
8	3	4	4	2
9	4	2	4	3
10	4	4	2	4

False Alarms:

Subject	Time Period 1	2	3	4
1	10	4	3	0
2	5	2	0	1
3	7	9	4	6
4	14	8	9	11
5	12	14	9	6
6	3	0	1	0
7	5	2	3	0
8	4	1	1	0
9	11	8	4	5
10	3	1	0	0

Group I

Subject	Pre-vigilance threshold (linelength)	# trials	Post-vigilance threshold	# trials
1	3.69	128	3.74	200
2	3.82	150	3.82	94
3	3.96	87	3.91	99
4	3.77	136	3.82	170
5	3.69	205	3.80	240
6	3.88	191	3.91	164
7	4.00	77	3.96	125
8	3.82	119	3.82	101
9	3.91	214	3.80	176
10	3.82	122	3.88	140

Group II

Hits:

Subject	Time Period 1	2	3	4
1	3	2	2	0
2	4	2	1	2
3	2	3	3	1
4	1	3	2	2
5	2	4	1	3
6	4	3	3	2
7	3	3	2	1
8	3	2	0	1
9	4	3	2	3
10	3	2	1	1

False Alarms:

Subject	Time Period 1	2	3	4
1	22	20	14	8
2	18	15	9	4
3	12	18	13	9
4	24	16	10	5
5	15	11	7	5
6	6	7	4	5
7	12	9	4	1
8	14	10	6	3
9	22	13	9	7
10	25	23	12	4

Group 2

Subject	Pre-vigilance threshold	# trials	Post-vigilance threshold	# trials
1	3.25	241	3.27	150
2	3.55	94	3.41	83
3	3.49	183	3.27	200
4	3.44	106	3.44	82
5	3.49	204	3.55	198
6	3.49	172	3.44	105
7	3.27	93	3.33	102
8	3.44	105	3.44	93
9	3.49	140	3.44	120
10	3.44	138	2.38	157

Group III

Hits:

Subject	Time Period 1	2	3	4
1	2	1	0	1
2	2	2	2	3
3	1	0	0	0
4	3	2	1	2
5	2	0	1	2
6	2	2	1	2
7	2	3	2	0
8	1	1	2	1
9	3	2	1	2
10	1	2	0	1

False Alarms:

Subject	Time Period 1	2	3	4
1	30	33	18	14
2	25	22	20	23
3	39	42	30	22
4	19	14	12	9
5	27	25	28	21
6	34	20	18	16
7	25	27	25	23
8	31	22	17	19
9	26	14	11	8
10	16	18	12	7

Group 3

Subject	Pre-vigilance threshold	# trials	Post-vigilance threshold	# trials
1	3.22	109	3.33	82
2	3.16	205	3.27	147
3	3.22	133	3.22	156
4	3.19	179	3.22	164
5	3.22	76	3.30	98
6	3.27	102	3.33	127
7	3.30	203	3.27	184
8	3.19	96	3.22	87
9	3.27	172	3.38	151
10	3.22	133	3.27	149

APPENDIX II

β values for Experiments I, II, and III, calculated as the distance in standard deviation units between the criterion and the mean of the noise distribution.

Experiment I

β*

Time Period	Control - .012 signal probability	Control - .021 signal probability
1	2.03	2.04
2	2.19	2.10
3	2.27	2.20
4	2.42	2.19
5	2.30	2.25
6	2.48	2.32

Time Period	Experimental - .012 signal probability	Experimental - .021 signal probability
1	1.98	1.97
2	2.08	1.98
3	2.20	2.07
4	2.21	2.11
5	2.21	2.16
6	2.22	2.10

* These β values represent average values for 5 days' performance.

Experiment II

β

Time Period	Group 1	Group 2	Group 3
1	1.37	1.68	1.64
2	1.50	1.72	1.71
3	1.71	1.74	1.74
4	1.96	1.77	1.73

Experiment III

β

Time Period	Group 1	Group 2	Group 3
1	2.00	1.61	1.37
2	2.17	1.70	1.44
3	2.29	1.91	1.56
4	2.37	2.15	1.64

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