EFFECTS OF TIME OF DAY AND SIGNAL FREQUENCY ON VIGILANCE PERFORMANCE

JIM LEARY

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Jim Leary

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Jim Leary
Memorial University of Newfoundland

ABSTRACT

Signal frequency in a visual vigilance task was increased at two different testing times, corresponding to a "low" and a "high point" in the diurnal cycle. Two methods were used to increase signal frequency. An increase solely in signal probability, with total event rate unaffected, improved detection performance mainly at the low point of the cycle. This improvement was accompanied by a decrease in values of the signal detection theory index, β. An increase in total event rate, at a fixed level of signal probability, had no significant effect on detection rates, but decreased false alarm rates at both testing times. The decrease was accompanied by increased values of d' and β. Performance temperature relationships were found only in the high event rate condition. Morning values of d' exhibited a relationship with degree of introversion. No relationship was found between introversion and daily temperature changes which casts some doubt on the generality of "changeover" theory.

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INTRODUCTION

That performance measures will vary according to the time in the normal waking day they have been taken has been known since the pioneering studies of Kleitman (reported in Kleitman, 1963). The magnitude and direction of this "time of day effect" depends upon the particular task being employed. Thus Blake (1967b) found a positive trend, a tendency for performance to improve as the day proceeded, in measures of serial reaction, vigilance, card sorting, letter cancellation and arithmetic calculations. In contrast, a negative trend was observed in a test of "digit span". This latter finding has been verified more recently by Baddeley, Hatter, Scott and Snashall (1970) using a similar paradigm. Typical of tasks in which positive trends occur is the vigilance task, which is of relatively long duration, repetitive, monotonous, and requires sustained attention for proper execution. This type of task is the focus of the present study.

In their review, Conroy and Mills (1970) have concluded that the circadian body temperature rhythm is endogenous, that is, it will persist in the absence of any normal "Zeitgeber", or periodic influences of the environment. Briefly, the shape of the daily curve in temperature can be described as a rapid rise early in the waking day, a levelling off to a peak in the evening, and a decline to a minimum in the early morning (Blake, 1967a). Changes in performance efficiency have been shown to closely follow this physiological rhythm, both in normal waking day studies (e.g., Kleitman,

1963) and in studies of varied work-rest schedules (Colquhoun, Blake and Edwards, 1968a, 1968b, 1969). Studies in which performance and body temperature have been measured synchronously; however, have sometimes reported the two rhythms to proceed out of phase with each other, the peak in performance lagging behind the peak in temperature (Alluisi and Chiles, 1967; Alluisi, 1972). It should also be noted that while the general level of each falls, diurnal cycling in both temperature (Murray, Williams and Lubin, 1958) and performance (Williams and Lubin, 1959) persist under conditions of sleep deprivation. It appears then, that while performance efficiency and temperature are generally at a lower level during sleep deprivation, they continue to change with basically the same circadian rhythm.

Although the relationship between body temperature and performance is very close, it is questionable whether the relationship between the two is a causal one; it seems rather that the two variables are reflecting changes in at least one underlying mechanism (for a discussion of this point see Colquhoun, 1971). A possible theory to account for performance and temperature changes during the day is that changes in arousal level underlie the rhythm.

One source of evidence arises from studies in the field of sleep deprivation. Wilkinson (1958) found that the usual performance decrement observed after loss of sleep was less prominent when the task situation became more complex, or contained greater incentive. It was noted, for example, that "knowledge of results" had an effect that paralleled the use of stimulant drugs in effectively restoring the efficiency of sleep-deprived subjects. This effect of knowledge of results was confirmed in a later study (Wilkinson, 1961), and was explained by the use of a model in which it was assumed that level of arousal and efficiency of performance were related according to an inverted - U function (Hebb, 1955). It was proposed that sleeplessness, as a lowered state of arousal, places one toward the ascending position of the curve. The arousing, or motivational, factor of knowledge of results can then cancel the effects of sleeplessness restoring one to a higher position along the inverted - U curve. Corcoran (1962b) and Wilkinson (1963) further showed that noise reduced the amount of performance deterioration produced by loss of sleep. This would be predicted by an arousal model, as the two stresses should produce their effects in opposite directions, noise as an arouser, and sleeplessness as a de-arouser. Increasing gross amount of stimulation in a visual vigilance task was also shown to reduce the effects of sleep loss (Corcoran, 1963).

Corcoran (1962a) advanced the rather parsimonious definition of arousal, or "activation", as being the "inverse probability of falling asleep". Assuming that sleep deprivation produces a deterioration in performance due to a lowered state of arousal, it might then be proposed that the circadian rhythm represents simply variations in sleepiness, or arousal level, which affect temperature and performance similarly.

Existing evidence favors such a proposal. The same type of task in which the time of day effect has been demonstrated is vulnerable to loss of sleep. Vigilance tasks were the first to be shown to be susceptible to the effects of sleep deprivation (Corcoran, 1962b, 1964; Wilkinson, 1960, 1964; Wilkinson, Edwards and Haines, 1966), the susceptibility of this type of task to time of day effects has already been mentioned. This may be due to what Hockey and Colquhoun (1972) term the "load" characteristic of vigilance, its requirement of sustained attention, making it less vulnerable to any process such as an increase in "effort" which could override the effects of sleep deprivation or time of day in shorter, and less repetitive tasks.

The effects of sleep deprivation, furthermore, are in the opposite direction to that observed with progression from lower to higher points in the circadian rhythm of body temperature. Wilkinson (1964), for example, found that the effect of sleep loss on vigilance first manifested itself as a deterioration in performance during the last half of the task, causing greater within-session decrement, before overall performance level was lowered by continued sleep loss. Blake (1971) when comparing vigilance performance scores between 0800 and 2100 hours during the normal waking day, concluded that the time of day effect on performance was greater in the second half of the test than in the first. Specifically, performance decrement during the task was observed at all earlier periods of the diurnal cycle, but was virtually absent at 2100 hours.

Hence it appears that sleep deprivation, by lowering the general level of arousal, has an adverse effect on the ability to sustain attention in vigilance tasks, while this ability increases during the waking day; due to an increase in arousal level.

Finally, it has already been mentioned that the tendency for body temperature and performance to follow a circadian rhythm persists, but at a generally lower level during sleep deprivation. This persistent diurnal cycling then appears to counteract the effects of sleep loss at some times and exaggerate it at others, causing performance to improve during what would be the 'normal' waking hours, as would be expected if arousal level were increasing.

In time of day studies, the additional factor of individual differences in the effect has emerged, associated with the personality dimension of introversion-extraversion. The conception has been held that introverts are generally at a higher level of arousal than extraverts (Corcoran, 1965). Support for this stems from studies in vigilance performance where it has been shown that extraverts benefit more from the addition of "arousing" factors than introverts (Bakan, 1959; Davies and Hockey, 1966). Extraverts have also demonstrated a preference for the addition of auditory stimulation during visual vigilance while introverts show a preference for its absence (Davies, Hockey and Taylor, 1969). There is also physiological evidence which agrees with the hypothesis (Corcoran, 1964b). These results are all consistent with an inverted - U relationship between arousal and performance, where introverts occupy a higher position along the arousal continuum than extraverts (Corcoran, 1965). Those factors which can be said to increase arousal would then be more beneficial to the performance of extraverts, as their position would be increased along the steep ascending portion of the inverted - U. Introverts, because of a position close to optimal, or the peak of the inverted - U, would show no such improvement. An increase in arousal would move them past the peak to a position on the descending portion of the curve, either cancelling the effects of arousing factors on perform- ance, or causing a performance decline in the case where the previous position along the arousal continuum was already at the optimum level.

An interaction has been demonstrated repeatedly between performance efficiency at different times of day and the per- sonality dimension of introversion-extraversion. Colquhoun (1960) and Colquhoun and Corcoran (1964) found a positive correlation between degree of introversion and performance efficiency in vigilance and a search task when testing was carried out in the morning, with introverts performing at a higher level than extraverts. The relationship was reversed, or ceased to exist, when individuals were tested in the afternoon. Blake (1967a) further related these findings to individual differences in the circadian rhythm of body temperature. The correlation between oral temperature and degree of introversion was found to change from significantly positive to significantly negative over the 'active' part of the waking day. Generally, introverted subjects showed a more rapid temperature rise in the early morning, reached their temperature peak earlier than extraverts, and their temperature began to fall at an earlier point in the evening. There was thus a phase advance in the introvert daily temperature curve, compared with the curve obtained for extraverts.

The relationship between introversion-extraversion and daily performance and temperature rhythms corresponds to the differentiation Kleitman (1963) made between "morning" and "evening" types, which he claimed was due to the existance of "two distinct types of body-temperature and efficiency curves, with the peak reached early in the waking period in one and later in the other." (p. 161). Thus Pátkai (1969), after classifying individuals as "morning workers" or "evening workers" on the basis of a questionnaire measuring opposite extremes in diurnal alertness patterns, found a significant difference between the scores of the two groups along a scale of Extraversion, her "morning workers" being more introverted and "evening workers" more extraverted.

The crossover in the daily performance and temperature curves, with introverts reaching their peak in both indices before extraverts, casts some doubt on the assumption that introverts are always at a higher level of arousal than extraverts (the "chronic arousal" theory). If temperature is taken as a valid index of an underlying state of arousal, it may be that extraverts are actually more aroused than introverts at later points in the diurnal cycle. Here the temperatures of introverts show a decline, while that of extraverts show a rise. Besides the support this proposal receives from the studies by Colquhoun (1960) and Colquhoun and Corcoran (1964), there is now evidence that the effect on individual differences in performance due to the introduction of an arousing factor to the task situation also varies with time of day. Blake (1971) used both knowledge of results and noise as arousing factors in a letter cancellation task. Greater performance improvement was found at earlier periods of the waking day by the addition of these factors, suggesting that individuals were lower in arousal at these times, and closer to the optimal level later in the day. As might be expected, the greatest effect was on extraverts, who showed considerably improved performance with the addition of noise or incentive early in the day. What was difficult for the early theory was the finding that extraverts showed an impairment later in the day. Neither effect was shown in introverts, who were therefore apparently unaffected by the additional "stressors". An arousal model which explained the differential performance improvement by extraverts early in the day in terms of their general low arousal would have to explain the impairment later in the day by assuming extraverts to be at a higher level of arousal at this period of the diurnal cycle, when the addition of an arousing factor would raise the arousal level of extraverts to post-optimal levels thereby causing a performance decline with the added "stress". This is of course postulating a changeover along the arousal continuum during the day as extraverts became more aroused than introverts, a view in conflict with the earlier notion that introverts were at all times higher in arousal than extraverts. However, the findings that introverts exhibited greater salivary output in Corcoran's (1964) salivation test at all times of day, and that preference for auditory stimulation was shown by extraverts regardless of time of day (Davies, Hockey and Taylor, 1969) pose serious problems for the "changeover" theory and support the "chronic arousal" theory. Thus neither theory can be considered adequate at present.

It is clear, however, that arousal level is intimately involved when subjects are without sleep, when they are at different stages of their circadian rhythms, and when they are introverted rather than extraverted. It is equally clear that there is not a complete identity of the functions underlying both extraversion and levels of sleepiness: perhaps more than one arousal system is involved. The existence of two separate, but functionally interdependent, systems may be a possible explanation. Arousal level would then be determined by one mechanism, while the other could control "arousability", or reactivity, at any particular level of arousal. "Chronic" theory would then be justified by proposing that at any particular level of arousal introverts may always be more reactive to external stimulation than extraverts. Thus it would not have to be assumed that they are always at a higher absolute arousal level. Both arousal systems are then involved. The "changeover" theory, according to this model, is therefore only relevant to that system responsible for gross arousal, or sensory activation, level.

Present Study. The present study was designed both as a test of the general arousal model of time of day effects, as well as try to detect whether a changeover in relative levels of arousal is actually occurring between introverts and extraverts during the day. Vigilance, it has been stressed, is quite sensitive to the effects of time of day. For this reason a type of visual vigilance task was employed. The frequency with which signals occurred in the task was increased at different periods of the waking day. Corcoran (1963) showed that by doubling signal frequency the adverse effects of sleep loss on performance in a visual vigilance task was reduced. Increasing the rate of signal presentation then appeared to have the same "arousing" effect as knowledge of results, or noise, on sleep-deprived subjects. Increasing signal frequency could be producing its effect through simply increased stimulation, as it appeared to be doing in Corcoran's (1963) study, or an increase in the probability that any event is a signal.

In a vigilance task using temporally regular discrete events two possible methods of increasing signal frequency are by either increasing the probability that any event is a signal by some desired factor, leaving event rate constant, or by increasing event rate (both signal and non-signal) by that same factor in order to leave signal probability at the same value. The resulting effect on performance has been shown to differ, depending upon which of these methods were used. When total event rate remains constant, superior vigilance performance results from increasing signal probability. This was first demonstrated by Colquhoun (1961) and is evident in the data of Jerison (1965). Superior performance with increasing signal probability seems to be due to a lowering in the subject's criterion (β) for reporting the presence of a signal as both detections and false alarms increase (Baddeley and Colquhoun, 1969). This is consistent with the Theory of Signal Detection, from which it follows that a lower criterion would be the sole result of an increase in the probability of a signal (Green and Swets, 1966).

When signal probability is kept constant, an increase in the total event rate has been shown to lead to poor performance (Colquhoun, 1969; Jerison, 1965, 1967; Loeb and Binford, 1968; Taub and Osborne, 1968). That is, although the temporal frequency of signals has been increased, the resulting effect is opposite to that when the probability that a given event is a signal is raised. For example, when a total of 1800 events were presented during an hour-long vigil, Jerison (1965) found superior performance under a high probability condition, where 75 of the events were signals, than under a low probability condition where there were 15 signals. However, when probability was kept constant superior performance was shown at the slower event rates. Thus, at the probability level of .04, higher detection rates were shown when 360 events (15 signals) an hour were presented, than with the presentation of 1800 events (75 signals). Although there were more signals in the second case, a greater signal "rate", percentage detections showed a decline.

A possible explanation may lie in the differences in the gross amount of sensory stimulation that the observer receives when exposed to an increase in signal rate due to an increase in signal probability, on the one hand, and an increase in the total event rate on the other. Jerison (1967) suggested that the deterioration shown in performance at high event rates might be due to "overstimulation" as a result of the greater number of events. Although this suggestion runs counter to the conception of a vigilance task as being generally boring, repetitive, and low in stimulation, it may well be able to explain the differing effects of increasing signal frequency. Increasing signal probability alone does not cause any increase in the gross amount of incoming sensory stimulation, but may be arousing in the sense that there are more signals to which an overt response is to be made. In this way, besides the change in the observer's criterion, level of arousal may be raised. Increasing the temporal frequency of signals by keeping probability constant, and increasing the total number of events, does produce an increase in the total amount of incoming sensory stimulation, as well as providing a larger number of events requiring overt responding. As performance declines here with an increase in stimulation, it could well be the case that the observer is overaroused, that is, that arousal has been moved past the post-optimal level. With regard to this proposition, it should be noted that Corcoran (1963) increased signal frequency by increasing the total number of events and keeping probability constant. Superior performance was shown in the high frequency condition only when subjects were very low in arousal due to prolonged sleep deprivation. Under normal sleep conditions there is some evidence that the increased stimulation may have raised arousal to a level that was too high for efficient performance. When arousal was at a very low level, due to sleep loss, the increased stimulation raised the level to an optimal for detection performance, while in the low frequency condition arousal was much less than optimal as only one half as much sensory stimulation was occurring here. This explanation, which we shall refer to as the "gross sensory input" theory, is, of course only tentative and was also tested in the following design.

Signal frequency was increased at two different times of day - in the morning, corresponding to the low-point during the normal waking day in performance and temperature rhythms, and again in the early evening, the period during which performance and temperature are usually at their highest (Hockey and Colquhoun, 1972). There were three different conditions of signal presentation rate: a low frequency - low probability condition (LF-LP), and two conditions with increased signal frequency. In the high frequency-high probability condition (HF-HP) frequency was increased by increasing signal probability and keeping event rate the same as the LF-LP condition. In the high frequency-low probability condition (HF-LP) frequency was increased by increasing the total event rate, keeping signal probability the same as the LF-LP condition while making signal frequency the same as the HF-HP condition. Thus one high-frequency condition differed from the LF-LP condition only in signal probability, the other high frequency condition in the rate at which all events occurred, but both had signals occurring at the same rate.

A number of predictions can be made based upon the previous discussion on the time of day effect, and the differences in performance between individuals at different times of day. If an increase in signal frequency by an increase in overall event rate has a deleterious effect on performance due to hyperarousal, this effect should be less when individuals are initially at a lower level of arousal, since a greater increase in arousal would then be required to move them to a post-optimal level of arousal. This would be the case in the morning test sessions in the present study. Furthermore, the effect of increasing signal frequency by this method should be less on extraverts at this time, if they are at lower levels of arousal early in the day. The study by Blake (1971) with noise and knowledge of results, which suggested a changeover in arousal during the day, would further predict the detrimental effect to be greater on extraverts later in the day, as they would at this time be more highly aroused than introverts. In overall analysis, if an increase in signal frequency by increasing event rate is over-arousing, superior performance should then occur in the morning sessions. If it is not over-arousing, the typical time of day effect on vigilance should occur, with superior performance in afternoon sessions. In both cases, however, performance should be at a lower level than in the low frequency condition. This prediction is effectively that high event rate will be similar in its effects to noise and knowledge of results.

With regard to increasing signal probability, superior performance in terms of detections can be predicted as a result of the lowering in the criterion used to report the presence of a signal. There is, in addition, the possible arousing factor of having more signals to which a response is required. This factor should have its greatest effect also in the morning sessions, when arousal is lowest. Again, the effect, if present, should be greater upon extraverts at this time of day, producing greater performance improvement. Later in the day extraverts should exhibit a performance decline, if Blake's (1971) study with noise and knowledge of results is used as an indicator.

Any differences between the effects of the two high frequency conditions can be attributed to the presence of non-signal events in the HF-LP condition, and would support a theory which emphasizes the effectiveness of gross sensory bombardment upon arousal level.

METHOD

Subjects. Thirty-three male graduate and undergraduate students at Memorial University were used as subjects. All subjects had normal, or corrected vision, and were paid at the rate of three dollars per session for their participation in the study. Each subject was assigned at random to one of the three experimental groups.

Selection of initial materials. Passages of prose from a number of books, thought to be fairly representative of those read by university students, were randomly selected and every seventh letter was checked. If it was a consonant (including 'y') it was recorded, if not, the procedure was continued. By this method a table of random consonants, occurring with the approximate frequency of their appearance in written prose, was prepared. Selecting letters from this table, 4x4 matrices of consonants were constructed and then typewritten, to be used as the "non-signal" stimuli. In addition, matrices were typewritten which contained one of the vowels, 'a', 'e', 'i', 'o', or 'u', in one of the 16 positions in the matrix. These were the "signal" stimuli. All letters were typewritten in lower case. The task was to detect the presence of one of the five vowels, 'a', 'e', 'i', 'o', or 'u', which could occur in any one of the 16 positions of a 4x4 display of consonants. An example of a display containing a signal is shown in Figure 1.

Apparatus. Video-tape recordings of the vigilance task were made using 35 mm. slides of the matrices. Twin

s	h	d	n
y	l	u	r
r	h	n	c
c	p	l	d

Kodak Carousel 800 H projectors with Gerbrands t-scope shutters (Model G1165) projected the slides onto a screen at a distance of 6 feet. "On" and "off" intervals were controlled by the use of a Lafayette 5040 B Timer. The tapes were prepared by recording the matrices as they appeared on the screen onto an Ampex VR5100 1-inch videotaping unit via an Ampex CC-324 camera with a Canon TV-16 Zoom lens, mounted behind the projectors at a distance of 7.5 feet from the screen. The matrices, when played back on videotape, created a 6-inch display on each of the six Conrac CVA 17 CRT monitors, over which the displays were presented.

Procedure. Three tapes were prepared for each of the three experimental conditions, each tape presented on one morning and one evening session. For example, if the tapes in any condition were labelled, A, B and C, the sequence of presentations over the six experimental sessions would have been ABCABC. A full-length practice tape was also prepared for each condition. Tapes were prepared according to the following design. In the low frequency-low probability (LF-LP) condition a display occurred once every 8 seconds and remained visible for 0.8 seconds ("on" time for the display was kept constant at 0.8 seconds for all conditions). A total of 320 displays were presented per session, of which 10 were signals; signal probability was therefore .03 and the mean time lapse between signals 256 seconds. In the high frequency-high probability (HF-HP) condition 320 displays were again presented, one every 8 seconds. There were, however, a total of 40 signals; signal probability was therefore .125 with a mean inter-signal time lapse of 64 seconds. In the high frequency-low probability (HF-LP) condition 1200 displays were presented, one every 2 seconds. As in the other high frequency condition there were 40 signals; signal probability was then the same as the LF-LP condition, .03, whilst the number of signals corresponded to the HF-HP condition and occurred at the same average inter-signal interval of 64 seconds. The task lasted for slightly less than 43 minutes in all conditions. The characteristics of the three conditions are recorded in Table 1.

Signals were presented quasi-randomly in all conditions in order to meet a number of constraints. Five signals occurred during each half of the test in the LF-LP condition, inter-signal intervals being limited to a range of from 64 to 448 seconds. In the two high frequency conditions 10 signals occurred during each quarter of the test, the range of inter-signal intervals being from 16 to 112 seconds. The positions at which signals occurred on the display were chosen at random. The 4x4 display was divided into four 2x2 quadrants. Each quadrant contained at least one signal during each half of a task in the LF-LP condition. In the high frequency conditions, where 20 signals occurred during each half of a session, each of the 16 positions on the display was tested at least once, and five signals occurred within each quadrant. In addition, each of the five vowels used as signals had the same probability of occurrence, each one being used twice per session in the LF-LP condition, and eight times in the high frequency conditions. Within these

TABLE 1

Characteristics of the Three Experimental Conditions

Condition	Number of events	Signals	Signal probality	Signal frequency
LF-LP	320	10	.03125	1 / 8 seconds
HF-HP	320	40	.125	1 / 8 seconds
HF-LP	1280	40	.03125	1 / 2 seconds

limits, the particular vowel used as a signal was chosen at random.

Identical signals occurred in the same temporal pattern across the two high frequency conditions, the only difference between them being that four times as many non-signal displays occurred between each signal in the HF-LP condition. In addition, 10 signals in each task in the high frequency conditions occurred at the same time, with the same vowel as a signal, and at the same position on the display, as the 10 signals used in the corresponding session in the LF-LP condition. There were then temporally-coincident signals across all conditions. In the high frequency conditions, all signals were spatially, physically, and temporally identical.

The videotapes were presented over six Convac CVA 17 CRT monitors, each mounted in a separate booth. During the 0.8 second "on" time the display was searched for the presence of any vowel (signal). On a panel below each monitor was mounted a button, to be pressed at the occurrence of a signal. Extending from this panel was a board which the subjects could use to rest their right arm, so it would not have to be moved in order to press the button. The buttons in each booth were connected to an Esterline Angus (Model A) 20 channel event recorder, for the collection of data.

There were 11 subjects in each experimental group. Each group was tested at only one level of signal frequency and probability. A full-length practice session was held on Monday afternoon, with signals occurring at the same frequency and probability as were experienced in subsequent experimental sessions. Thus there should have been no peculiar effect on performance due to being trained and tested at different levels of signal probability (Colquhoun and Baddeley, 1964, 1967). The subjects were never told exactly how many signals would be presented, nor the fact that each subsequent experimental session contained the same number of signals as the practice session.

In all sessions subjects were isolated, at an approximate distance of 2.5 feet at eye-level from the monitor over which the task was presented.

In the practice sessions subjects were "cued" prior to the onset of a signal by a buzzer broadcast to all booths, for the first half of the session. During the second half no cuing was given, but knowledge of results given instead by sounding the buzzer after a signal had appeared. Subjects were instructed to press the button if they actually detected the signal while the cuing buzzer was on. For the second half of the session they were instructed to attempt to detect any vowel that might appear on the screen. These were the only instructions given as to how to behave during the session. All subjects were given the Eysenck Personality Inventory (Form A) prior to the practice session on Monday.

Each experimental group was divided into two sub-groups, the individuals in each sub-group were then tested together as a group. Group A (n = 5 for the LF-LP condition, n = 6 for the HF-HP condition, n = 6 for the HF-LP condition) had experimental sessions on Tuesday, Wednesday and Thursday. Testing was carried out at 9 a.m. and 5 p.m. each day. The morning time was chosen as it seemed to be the earliest time at which all subjects could be run without any adverse effects due to partial sleep deprivation. Some preliminary research indicated that the afternoon temperature peaks of the University students used as subjects varied anywhere from 3 p.m. until quite late in the evening, indicative perhaps of vast differences in study and social habits. The 5 p.m. afternoon time was then picked both as an approximate modal time at which temperature peaks seemed to be occurring and as a reasonable time at which subjects could be expected to engage in the experiment for three successive days.

Group B (n=6 for the LF-LP condition, n=5 for the HF-HP condition, n=5 for the HF-LP condition) was also tested at 9 a.m. and 5 p.m., but had their first experimental session Tuesday afternoon and final session Friday morning. Practice effects were then roughly balanced across the morning and evening sessions. As each subject performed six times in all, twice for each tape, the experiment was in effect replicated three times.

Each subject used the same booth for each session in order to control for possible differences in viewing conditions between monitors. Watches were removed before entering the booths. Oral temperatures were taken before and after each experimental session, the mean of the two readings recorded as the temperature for that session. The only responses recorded were the button presses.

RESULTS

The data were summed across sessions before analysis. Non-parametric tests of significance were used exclusively, since most of the experimental data were not normally distributed.

Signal Frequency Effects

Detection and false alarm rates. Mean percentages of detections and false alarms across both testing times for each condition are shown in Table 2. A Kruskal-Wallis non-parametric analysis of variance indicated that differences in detection rates between the three conditions were not statistically significant ($p>.10$). Further analysis using the Mann-Whitney test revealed a significant increase in detection rates for the HF-HP condition relative to the LF-LP condition ($p=.02$), but nonsignificant increases in the HF-HP condition relative to the HF-LP condition ($p=.07$), and the HF-LP condition relative to the LF-LP condition ($p=.33$). The differences in false alarm rates between the three conditions were found to be significant by the Kruskal-Wallis test ($p=.001$). The differences between conditions, however, were mainly due to the large reduction in false alarm rates in the HF-LP condition. Mann-Whitney tests showed large differences between the HF-LP and LF-LP conditions ($p<.0005$) and between the HF-LP and HF-HP conditions ($p<.0001$). The difference in false alarm rates between the LF-LP and HF-HP conditions was not significant ($p=.11$).

Signal detection theory measures. The detection and false alarm data were converted into values of d' and β (Freeman, 1964), the indices used by the Theory Signal Detection (TSD).

TABLE 2

PERCENTAGES OF DETECTIONS AND FALSE ALARMS WITH CORRESPONDING TSD INDICES FOR EACH CONDITION

CONDITION	% DETECTIONS	% FALSE ALARMS	d'	BETA
LF-LP	.691	.0037	3.211	35.261
HF-HP	.768	.0052	3.296	20.500
HF-LP	.735	.0004	3.931	226.627

The equal-variance requirement necessary for the use of Freeman's tables was assumed, since it could not be tested on the data collected. The group values of d' and β are contained in Table 2. Differences between the conditions in both indices were significant by the Kruskal-Wallis test ($p=.001$ in both cases). Mann-Whitney tests revealed that the differences found between conditions in d'-values were again due to the large HF-LP differences. The differences in this index between the LF-LP and HF-HP conditions were not significant ($p=.22$), whereas there were significant differences between the HF-LP and LF-LP conditions ($p<.0005$) and the HF-LP and HF-HP conditions ($p<.0001$). Therefore d' showed a definite increase in the HF-LP conditions. The differences in β-values were all significant. A decrease in β was observed in the HF-HP condition relative to the LF-LP condition ($p=.02$) in contrast to a relative increase in the HF-LP condition ($p=.001$). The differences between the two high frequency conditions were then highly significant ($p<.0001$).

<u>Time of Day Effects</u>

<u>Detection and false alarm rates</u>. Morning and evening detection rates for each condition are plotted in Figure 2, and are also contained among the other performance measures in Table 3. Within each condition no significant differences were found between detection rates at the two testing times (Wilcoxon tests, $p>.25$ in all cases). Kruskal-Wallis analyses indicated no significant differences between the conditions on morning detection scores ($p>.1$) or evening scores ($p>.25$) implying no

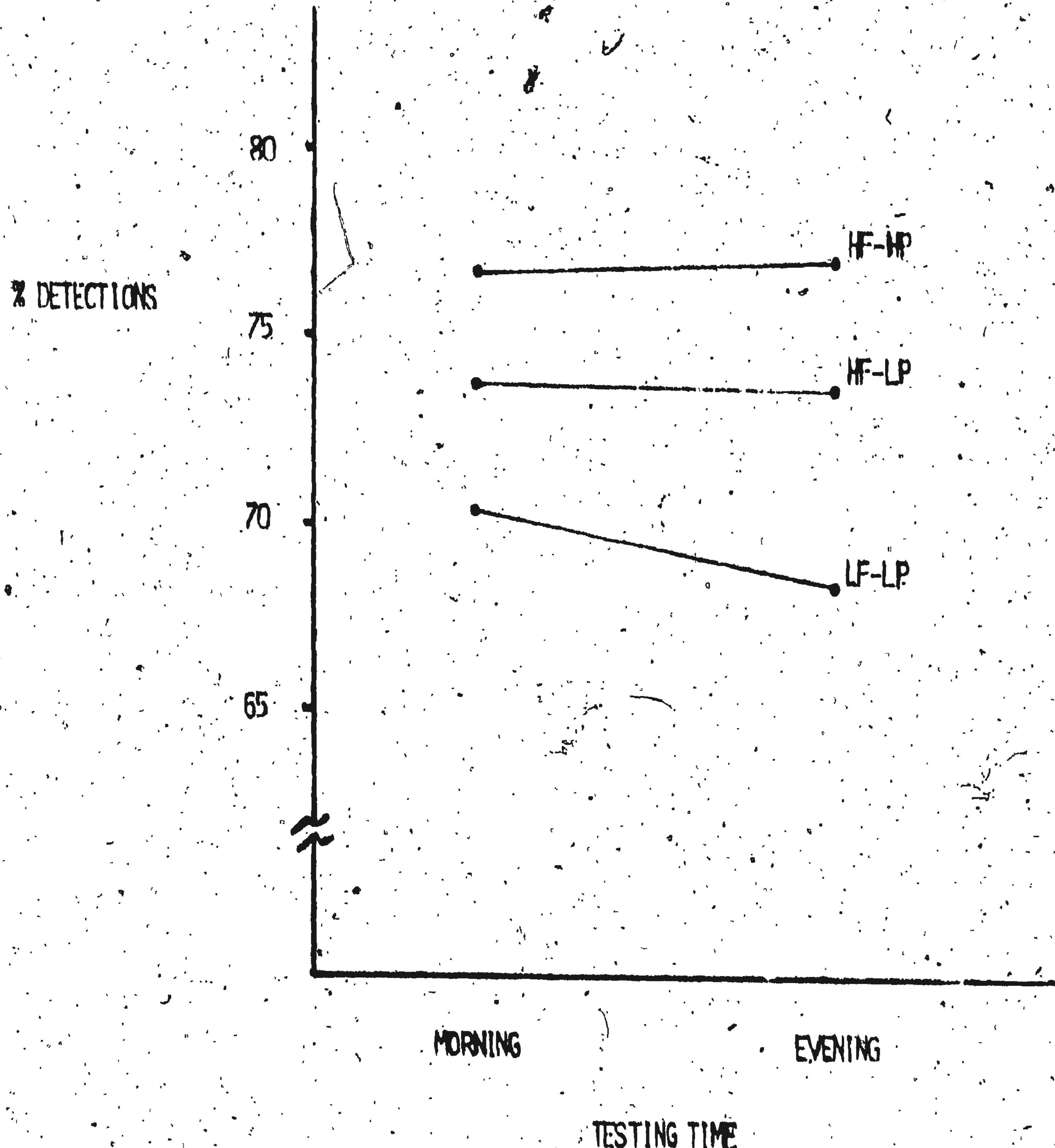
% DETECTIONS
80
75
70
65
HF-HP
HF-LP
LF-LP
MORNING
EVENING
TESTING TIME

TABLE 3

Morning Versus Evening Performance Measures For Each Condition

Condition	Testing Time	% Detections	% False Alarms	d'	Beta
LF-LP	Morning	.70	.002	3.38	50.06
	Evening	.68	.004	3.09	28.57
HF-HP	Morning	.77	.004	3.38	25.78
	Evening	.77	.006	3.25	17.04
HF-LP	Morning	.74	.0004	4.00	246.18
	Evening	.73	.0004	4.00	267.17

difference in the slopes of the daily performance curves of Figure 2. Analysis of change in detection rates over time of day (detection rate (p.m.) - detection rate (a.m.)) also failed to reveal any differences between the three experimental conditions (p .75).

Morning and evening detection rates for the two high frequency conditions were analyzed separately, relative to the LF-LP condition, with the use of Mann-Whitney tests. In the HF-HP condition a significant increase was found in morning detection rates (p .04). The increase in detection rates in the evening did not reach significance (p .08). In the HF-LP condition neither morning nor evening detection rates were found to differ from the LF-LP condition (p .18 and p .22, respectively).

Morning and evening false alarm rates for each condition are contained in Table 3. Wilcoxon tests indicated no difference between morning and evening false alarm rates in the LF-LP and HF-LP conditions (p .12 and p .42, respectively). The HF-HP condition, however, showed a significant increase in evening false responding (p .05). Kruskal-Wallis analyses revealed significant differences between the three conditions on both morning false alarm rates (p .005) and evening false alarm rates (p .01). Further analyses with Mann-Whitney tests indicated no difference between the LF-LP and HF-HP conditions for the morning or evening testing times (p=.08 and p .17, respectively). The HF-LP condition was found to have decreased false alarm rates relative to the LF-LP condition during both morning testing sessions ($p<.001$) and evening sessions ($p<.01$). Thus the differences found between conditions in false alarm rates persisted at both testing times.

Signal detection theory measures. The three experimental conditions were analyzed for differences between morning and evening values of the TSD indices. These values of d' and β are contained in Table 3. Within the two low probability conditions Wilcoxon tests revealed no differences between morning and evening values of either index ($p>.20$ in all cases). In the HF-HP condition there was a significant ($p=.02$) tendency for β to decrease with time of day, accompanied by a non-significant ($p=.06$) tendency for d' to decrease.

Kruskal-Wallis tests indicated that the three conditions differed significantly on both morning and evening values of d' ($p<.05$ and $p<.01$, respectively) and β ($p<.01$ and $p<.005$, respectively). Mann-Whitney tests showed no differences in the values of d' between the LF-LP and HF-HP conditions during either the morning ($p=.28$) or evening ($p=.32$) testing sessions. Both morning ($p=.04$) and evening ($p=.005$) values of d' in the HF-LP condition were higher than the LF-LP condition. While morning values of β were lower in the HF-HP condition than in the LF-LP condition ($p=.04$), there was no significant difference in the evening values of this index ($p=.08$). Again the HF-LP condition differed from the LF-LP condition during both morning ($p=.008$) and evening ($p=.005$) testing sessions. Therefore the tendency for both d' and β to increase in the HF-LP condition was not affected by time of day. The decrease in β in the HF-HP condition was significant only during the morning testing sessions.

Temperature and performance. Mean morning and evening temperatures were 97.7°F and 98.3°F, respectively. A simple sign test indicated that evening temperatures were in fact greater than morning temperatures (32 out of 33 cases, $p < .000001$). As temperature was only measured at two points of the diurnal cycle among all individuals, it is impossible to say whether evening temperatures were in any way near their peak values.

Within each condition Spearman rank correlation coefficients were calculated to determine whether there existed a relationship across time of day between oral temperature and the performance measures, detection rate, false alarm rate, d' and β. Indices of relative change for temperature and the performance measures were computed. The raw data for the measures within each condition were converted into Z scores. Degree of relative change was then defined by the index (Z p.m. - Z a.m.). The more positive this score, the greater the degree of positive change between morning and evening measures, relative to other individuals within that particular group of Z scores. This measure was used in all subsequent analyses of changes in temperature and performance across time of day.

The correlations between temperature and detection rate are contained in Table 4. The only significant results were the positive correlations between morning temperature and detection rate, and relative change in both these measures, in the HF-LP condition. Within this condition, then, those individuals

TABLE 4

CORRELATIONS BETWEEN TEMPERATURE AND DETECTION RATES

CONDITION	MORNING	EVENING	RELATIVE CHANGE
LF-LP	-.061	.327	-.309
HF-HP	.330	-.298	-.136
HF-LP	.705*	.177	.700*

*$p < .01$

who had the highest temperatures in the morning testing sessions tended to display superior detection performance at this time. The greatest increases in temperature between testing times was then associated with the largest improvements in detection performance.

The only significant result found with false alarm rates, as shown in Table 5, was again within the HF-LP condition. This was a negative correlation between relative changes shown in temperature and false alarm rates between testing times. Therefore the opposite trend occurred in the relationship between temperature change and false responding as was found between temperature and detection performance in the HF-LP condition. Whereas the greatest relative increases in temperature were associated with a tendency for detection rates to increase, they were also related to a tendency for false alarm rates to decline.

The two trends, superior detection performance accompanied by lower false alarm rates, suggest a relationship between temperature change and d'. Table 6 shows the correlations found between temperature and d'. Once more it was only in the HF-LP condition that a significant relationship was observed. This was a positive correlation between evening temperatures and evening values of d', so that higher temperatures in the evening were associated with higher values of d'. No relationship, however, was shown between the indices of relative change for the two measures. The other TSD index, β, showed no significant relationship with temperature in any condition, as can be seen from the correlations contained in Table 7. It should be noted

TABLE 5

Correlations Between Temperature and False Alarm Rates

Condition	Morning	Evening	Relative change
LF-LP	.282	.148	.073
HF-HP	.395	-.028	.402
HF-LP	-.070	-.014	-.693*

$^{*}p<.01$

TABLE 6

CORRELATIONS BETWEEN TEMPERATURE AND d'

CONDITION	MORNING	EVENING	RELATIVE CHANGE
LF-LP	-.333	.548	-.429
HF-HP	.071	-.536	-.214
HF-LP	.098	.688*	.107

*$p < .05$

TABLE 7

CORRELATIONS BETWEEN TEMPERATURE AND BETA

CONDITION	MORNING	EVENING	RELATIVE CHANGE
LF-LP	.000	.571	.143
HF-HP	-.142	.393	-.142
HF-LP	-.438	.509	-.071

here that although some of the correlations which appear in the Tables appear rather large, they are still nonsignificant due to the relatively small number of individuals used as subjects in the present study.

Individual Differences

It must be stated at the beginning of this section that it was originally intended to employ twice the number of subjects as were eventually tested. As a result of equipment failure it became impossible to replicate the experiment to two additional groups for each condition. The resultant small sample size made it quite improbable that anything of significance would emerge in the way of individual differences. The following analyses, however, were still performed because of the importance of this theoretical area. It was hoped that some significant findings might arise, even with the relatively small sample size.

Degree of introversion and performance measures. Within groups analyses were performed to test the relationship between degree of introversion and performance across time of day. Spearman rank correlation coefficients were calculated between degree of introversion and the values of the performance measures at both testing times, as well as relative change in, and the overall value of, those measures. The resulting correlations with detection performance, shown in Table 8, indicated no significant relationship in any condition between degree of introversion and the number of signals reported at either testing time or across time of day. Also, no relationship

TABLE 8

CORRELATIONS BETWEEN DEGREE OF INTROVERSION AND DETECTION RATES

CONDITION	MORNING	EVENING	RELATIVE CHANGE	OVERALL
LF-LP	-.134	-.171	.291	-.305
HF-HP	.271	.380	-.011	.220
HF-LP	-.113	-.382	-.186	-.232

emerged between change in detection performance across time of day and degree of introversion. The same lack of any relationship was observed with false responding. Table 9 contains the correlations between degree of introversion and false alarm rates, none of which approached significance.

Examination of the TSD indices yielded one significant finding, reported in Table 10. Introversion was discovered to be positively correlated with morning values of d', again in the HF-LP condition. It then appears that in this condition the more introverted subjects tended to have higher values of d' in the morning testing sessions. This relationship then broke down later in the day. Table 11 shows that none of the correlations between degree of introversion and values of β gave evidence for the existence of a relationship in any condition.

<u>Degree of introversion and temperature data.</u> This analysis was performed to test the relationship between introversion and daily temperature changes. Here, introversion would be expected to correlate positively with morning temperatures, and negatively with the degree of relative change in temperature between testing times, according to "changeover" theory. The actual correlations (across all experimental conditions) are reported in Table 12. All the correlations were positive and nonsignificant. However, it should be noted, the largest correlation was with morning temperatures, and smallest with relative change in temperature.

TABLE 9

CORRELATIONS BETWEEN DEGREE OF INTROVERSION AND FALSE ALARM RATES

CONDITION	MORNING	EVENING	RELATIVE CHANGE	OVERALL
LF-LP	-.268	.345	.241	.050
HF-HP	-.128	.002	.268	-.200
HF-LP	.193	.366	.157	.261

TABLE 10

CORRELATIONS BETWEEN DEGREE OF INTROVERSION AND d'

CONDITION	MORNING	EVENING	RELATIVE CHANGE	OVERALL
LF-LP	-.476	-.524	.143	-.232
HF-HP	.330	-.098	-.491	.298
HF-LP	.714*	-.321	-.007	-.206

*$p < .05$

TABLE 11

CORRELATIONS BETWEEN DEGREE OF INTROVERSION AND BETA

CONDITION	MORNING	EVENING	RELATIVE CHANGE	OVERALL
LE-LP	.619	-.024	-.476	.068
HE-HP	-.580	-.455	.063	.103
HE-LP	-.030	-.107	-.214	.001

TABLE 12

CORRELATIONS BETWEEN DEGREE OF INTROVERSION AND TEMPERATURE

Morning	Evening	Relative change
.171	.146	.033

DISCUSSION

Signal Frequency Effects

The results of the present study indicate that the main effects of an increase in signal frequency are almost entirely dependent upon the particular experimental procedure employed. An increase in signal frequency due to an increase in signal probability alone, with total event rate unaffected, led to an increase in detection rates. This increase was accompanied by a decrease in the TSD index, β. An increase in total event rate, leaving signal probability at a constant value, resulted in a decrease in false alarms rates. Both d' and β were increased by this latter method.

It was originally hypothesized that an increase in the signal's probability alone would be beneficial to vigilance performance. This would be due to a lowering of the observer's criterion for reporting the presence of a signal. In agreement with this was the significant increase in detection rates in the HF-HP condition relative to the LF-LP condition. Although false alarm rates were not significantly affected, there emerged the expected decrease in β-values and no significant effect on d' in the HF-HP condition, consistent with the predictions of the Theory of Signal Detection. Thus it appears that an increase in signal probability improves detection performance as the result of a decrease in caution, as reflected by a lowered β.

It was also proposed that there might emerge the possible "arousing" factor of having more signals to which a response was required in the HF-HP condition. The greatest effect here was expected in the morning testing sessions, as individuals would then be at lower levels of activation. When morning and evening detection rates in this condition were compared separately with the LF-LP condition, this was in fact verified. There was a significant increase in detection rates in the morning sessions. The increase in detection rates in the afternoon testing sessions failed to reach significance. The same trend was observed in the tendency for β to decrease in the HF-HP condition. The decrease was only significant in the morning sessions. Therefore it appears that there is another important factor to take into account when signal probability is raised besides the effect on the observer's criterion predicted by the Theory of Signal Detection.

An increase in the total event rate, with signal probability held constant, was expected to lead to poorer detection performance. This was not found to be the case. An increase in signal probability was not significantly more effective in increasing detection rates than was an increase in gross event rate, where a nonsignificant increase in detection rates occurred. While detection performance did not differ significantly in the HF-LP condition relative to the LF-LP condition, there was a significant decrease in false positive responding. This result supports these studies in which false alarm rates were found to be inversely related to event rate, at a fixed signal probability level (e.g. Taub and Osborne, 1968). Signal detection theory analysis revealed that both d' and β increased with increased event rate. The direct relationship between β and event rate was expected, as a result of the effect on false alarm rates. The relationship with d' was not anticipated, as it was originally proposed that there would be a decline in detection rates to accompany the decrease in false alarm rates. This expectation then assumed that the distributions of noise and signal-plus-noise would remain a constant distance apart. The observer's criterion would then move toward the right along the sensory continuum, producing the increase in β. This would result in a decline in both detections and false alarms as the criterion moved upward along the signal-plus-noise distribution. However, it was found that detection rates did not decline and d'-values increased.

An increase in gross event rate now appears to have two important main effects. One is opposite to that which is observed when signal probability alone is increased. This is an increase in degree of caution, or β, when gross event rate increases, as can be observed by a decline in false alarm rates. The other main effect is an increase in d', or sensitivity. That is, the increase in the total number of events appears to be making the signal more discriminable. Hence the decline in false alarm rates is not accompanied by declining detection performance. The most parsimonious explanation of the effect would be to propose that the ability to discriminate between signal and non-signal events improves as a result of the increased practice the observer receives in matching the two events when the total number of events is increased.

Within the perspective of the Theory of Signal Detection the effects of the two methods for increasing signal frequency would be conceptualized as follows: An increase in signal probability, at constant event rate, does not effect the distance between the means of the noise and signal-plus-noise distributions. That is, d' will remain unaffected. Detection performance will be improved due to the observer's criterion moving toward the left along the signal-plus-noise distribution. This effect would be the result of a lowered maximum likelihood ratio because of an increase in the probability of a signal's occurrence. Consequently there would be a decrease in β. However, if signal frequency is increased by increasing gross event rate, leaving signal probability at a fixed value, the distance between the two distributions is increased. Here d' increases and the signal becomes more discriminable, probably because of the greater amount of decision-making that is involved. That is, there is much more matching of signal to non-signal events, with the result that the observer acquires a better "image" of the signal. As signal probability has not changed, the observer might retain the same cutoff for his criterion along the signal-plus-noise distribution. This would leave detection rates unaffected. As this distribution has moved farther away from the noise distribution there would be a decrease in false responding and an increase in β.

"Gross input theory" no longer appears practicable to account for the performance changes observed when total event rate is increased. This theory would predict a deterioration in performance at higher activation levels, as overstimulation is seen as the causal factor of those performance changes which accompany an increase in event rate. However, significant positive correlations were observed in the HF-LP condition between morning temperatures and morning detection rates, and between the Z score measures of relative change across time of day in both measures. Therefore, the individuals who showed the greatest temperature change between testing times also exhibited the greatest improvement in detection performance. Performance then improved with increases in activation level, as reflected by oral temperature changes across time of day. Hyperarousal, then, does not appear to be the important factor in determining performance when signal frequency is increased by an increase in gross event rate.

Time of Day Effects

The HF-LP condition was the only one in which relationships were observed between temperature and performance changes across time of day. These were the correlations between temperature and detection rates mentioned above, a negative correlation between relative changes across time of day in temperature and false alarm rates, and a positive correlation between afternoon temperature and afternoon values of d'. Thus it appears that there is a tendency for detections to increase and false alarms to decrease at higher activation levels later in the diurnal cycle. This is consistent with an increase in d', which Colquhoun, Blake and Edwards (1968a, 1968b, 1969) consider a change in "true" efficiency, rather than a change in motivational state, at higher levels of arousal. Although there was no relationship observed between changes in temperature and d' across time of day, there was the positive correlation between afternoon temperature and d'-values in support of this notion.

As mentioned, there were no temperature-performance relationships observed in the LF-LP and HF-HP conditions. It should be stressed here that the HF-LP condition was the most "typical" of the three conditions. That is, the requirement of sustained attention was greatest in this condition, where events requiring visual analysis occurred at four times the rate of the other conditions. Thus the "load" characteristic of vigilance (Hockey and Colquhoun, 1972) was most satisfied in the condition. As a result it would be more sensitive to subtle time of day effects, as would be related to relative changes in temperature. It then appears that the presence of the non-signal events in the HF-LP condition relative to the other high frequency condition performed two important functions. The one was to increase discriminability of the signal, as measured by d', and the other was to increase the sensitivity of the task to fluctuations in arousal level.

The expected time of day effect did not occur in the LF-LP condition, that is, superior afternoon performance. This is probably due to the lax requirement of sustained attention in the condition. Because of the "breaks" the observer experienced between events the effects of time of day may have been cancelled. The existence of temperature-performance relationships only in the HF-LP condition indicates the superior sensitivity of a task that employs events occurring at a relatively rapid rate. Further support for the argument stems from the time of day effect on detection rates and β-values in the HF-HP condition relative to the LF-LP condition. This effect, superior detection performance and lower β in the HF-HP condition only during the morning testing sessions, when arousal would be at its lowest, argues for the need of an additional "arousing" factor in order for a time of day effect to emerge. This is because the HF-HP condition, where an increment in arousal can be inferred relative to the LF-LP condition, as a result of the above effect, did exhibit a substantial time of day effect. This was the apparent decrease in caution from morning to evening testing sessions in the HF-HP condition. False alarm rates increased and values of β declined in the afternoon testing sessions. It appears here that high arousal reduces the observer's criterion in the decision system, so that less evidence is now needed for a signal to result in a "signal" response. This is somewhat in contrast to the findings of the HF-LP condition. Here higher arousal, if temperature is indeed a valid index, was associated with greater detectability of the signal, as measured by d'. That is, a "signal" response was the result of more evidence arising from the signal itself.

Perhaps the states of two different systems are being measured. The one would be responsible for the individual's level of "true" efficiency (Colquhoun et al., 1968a, 1968b, 1969), or sensitivity, which increases at higher activation levels. It is this level which was probably reflected as the temperature-performance relationships shown in the HF-LP condition. The other system could be involved with the individual's level of motivation. Hence, even though a signal is not inherently more discriminable, it may be detected more readily at higher activation levels since less evidence is now required to give rise to the report of its presence. That is, criterion has been lowered. This is the effect that appears to have emerged in the HF-HP condition.

Individual Differences

The number of individuals within each condition (n=11) was rather small to expect any within-groups patterns to emerge. However, it is still puzzling that no individual differences were found in the main effects of increased signal frequency. These would have been reflected as relationships between degree of introversion and the overall performance measures of the three conditions. In particular, "chronic" theory would propose that the "arousing" aspects of an increase in signal frequency should be beneficial to the vigilance performance of extraverts, with little, or a deleterious, effect on the performance of introverts (Bakan, 1959; Davies and Hockey, 1966). Also, lower false alarm rates, and a higher β, have been associated with introversion (Tune, 1966).

The only individual differences found in any effect appeared in the HF-LP condition, as a positive correlation between degree of introversion and morning values of d'. If this relationship is valid there is an important implication for "changeover" theory. The d' measure of sensitivity, or as it has been called, "true" efficiency, could be a crucial index to explain performance differences observed during the diurnal cycling of introverts and extraverts. The superior performance of introverts early in the diurnal cycle would be the result of higher sensory discriminability rather than any motivational variable at this time. The system that was proposed responsible for level of sensory efficiency would then be the one which shows the differing diurnal patterns between introverts and extraverts. What has been termed the "motivational" system may be the one that is responsible for the differences that are the concern of "chronic" theory. Such a proposal, of course, requires more evidence.

Despite the small number of subjects used, trends should have been evident in between-groups analyses, particularly in daily temperature rhythms. According to Blake's (1967a) findings there should be a negative correlation between degree of introversion and relative change in temperature across time of day. Instead a slightly positive, but very nonsignificant ($p>.4$), correlation was found. Although this may have been due to "hitting between the peaks" at the afternoon testing time, there was also no relationship found between morning temperature and introversion. These findings may be the result of the particular population, University students, from which subjects were drawn for the present study. Pátkai's (1969) study, and those of the M.R.C. Applied Psychology Unit (e.g., Blake, 1967a, 1967b; Colquhoun, 1960; Colquhoun and Corcoran, 1964) used as subjects individuals who followed basically the same work schedule. Therefore, they were controlled for differences in work-activity patterns. Differences in social behavior, of course, were not controlled. These differences might then have been reflected as the differences which emerged in daily temperature and performance rhythms. That is, extraverts, due to a more active social routine, might be expected to perform at a lower level early in the day. Then, because of a greater amount of social activity later in the day, they would reach their performance and hence, temperature, peak at a later point in the circadian rhythm.

The performance and temperature rhythms of students, with a greater uncontrolled amount of variance in work patterns, would not be as dependent solely on social patterns. Much greater variance in their circadian rhythms would be expected. Therefore, it may be the case that arousal level at different points of the diurnal cycle is the reflection of daily activity patterns. This level can be measured physiologically as body temperature. As suggested earlier, performance may vary with arousal level because of the relationship with the d' index of sensitivity. That is, arousal level may be affecting a system responsible for the level of sensory efficiency. The diurnal patterns of this "efficiency system" are then a reflection of <u>absolute level</u> of arousal. It is this diurnal cycling which has been the concern of "changeover" theory.

"Chronic" theory, with its physiological evidence, then appears the most plausible and general theory to account for introversion-extraversion differences. This would be in the sense of a second system which determines arousability, or reactivity, at any particular level of arousal, rather than absolute level of arousal itself. The "motivational system" previously mentioned may be the one of concern here.

CONCLUSION

The differences in the effects of the two high frequency conditions support a theory that emphasizes the effectiveness of gross sensory bombardment upon arousal level. The prime effect of an increase in total event rate was to increase the d' measure of sensitivity, or "efficiency". Increased signal probability, however, also seemed to be associated with changes in arousal. The main effect here, a decrease in caution, or β, was most evident at earlier stages of a diurnal cycle, when individuals were at lower levels of arousal. Further, within the high probability condition, β was also found to decline later in the day when arousal level could be assumed to be highest. These results might help to incorporate both "changeover" and "chronic" arousal models into a single theoretical framework. Such a model would propose the existence of two distinct, but interdependent, arousal systems.

The first system has been called the "efficiency" system. Changes within this system are reflected as changes in the TSD index of sensitivity, or d'. An increase in gross event rate, and hence of gross sensory bombardment, was found to increase sensitivity. Thus, as individuals were stimulated in this fashion, their sensitivity to the task increased. Also in the HF-LP condition, it appeared that as temperature increased across time of day, performance improved, due to an increase in d'. Diurnal cycling in temperature then appears to be associated with changes in sensitivity. Thus, gross arousal level, as measured by body temperature, may determine level of sensory efficiency. "Changeover" theory is concerned with the functioning within this system. This theory proposes that Introverts are at higher levels of arousal early in the diurnal cycle. Hence, a positive relationship emerged between morning values of d' and Introversion.

A second system, referred to above as a "motivational" system, seems responsible for performance differences found between Introverts and Extraverts, regardless of the phase of the diurnal cycle under observation. "Chronic" theory would then be concerned with the functioning of this system. Motivation level may determine the probabilities adopted within the decision system, and hence the value of β. This level probably follows a circadian rhythm, but individuals might differ in this index of arousal at all points of the circadian cycle. That is, although β may change during the diurnal cycle, it might at all times show a higher value among Introverts (e.g., Tune, 1966). Thus an increase in signal probability improved performance mainly at the early point of the diurnal cycle. This implies increased arousal. When analyzed, this increase was due to a decrease in caution, or β. Further, β itself showed a decrease with time of day in the high probability condition. That is, as arousal level increased, degree of caution decreased. Changes in β, on the other hand, showed no relationship with the body temperature index of arousal.

Two arousal systems then appear to be functioning during the circadian cycle. One system, as indicated by sensory efficiency, appears to show differences associated with degree of introversion only according to the phase of the diurnal cycle. The other system might be responsible for differences observed between Introverts and Extraverts, regardless of diurnal cycling. The function of this latter system probably follows a circadian rhythm itself. That is, its level of functioning at any time may be a reflection of gross arousal level. However, the level of functioning is at all times different for Introverts and Extraverts. For example, although degree of caution may vary according to a circadian rhythm, Introverts may always react with a higher degree of caution than Extraverts. On the d' measure of sensitivity, it may be the case that Introverts will show greater values of this index only early in the diurnal cycle.

REFERENCES

Alluisi, E.A. Influence of work-rest scheduling and sleep loss on sustained performance. In W.P. Colquhoun (Ed.), Aspects of Human Efficiency. London: England Universities Press, 1972.

Alluisi, E.A. and Chiles, W.D. Sustained performance, work-rest scheduling and diurnal rhythms in man. In A.F. Sanders (Ed.), Attention and Performance. Amsterdam: North Holland, 1967.

Baddeley, A.D. and Colquhoun, W.P. Signal probability and vigilance: A reappraisal of the 'signal-rate' effect. British Journal of Psychology, 1969, 60, 169-178.

Baddeley, A.D., Hatter, J.E., Scott, D., and Snashall, A. Memory and time of day. Quarterly Journal of Experimental Psychology, 1970, 22, 605-609.

Bakan, P. Extraversion-introversion and improvement in an auditory vigilance task. British Journal of Psychology, 1959, 50, 325-332.

Blake, M.J.F. Relationship between circadian rhythm of body temperature and introversion-extraversion. Nature, 1967, 215, 896-897. (a).

Blake, M.J.F. Time of day effects on performance in a range of tasks. Psychonomic Science, 1967, 9, 349-350.

Blake, M.J.F. Temperament and time of day. In W.P. Colquhoun (Ed.) Biological rhythms and human performance. London:

Academic Press, 1971.

Colquhoun, W.P. Temperament, inspection efficiency, and time of day. Ergonomics, 1960, 3, 377-378.

Colquhoun, W.P. The effect of "unwanted" signals on performance in a vigilance task. Ergonomics, 1961, 4, 41-51.

Colquhoun, W.P. Effects of raised ambient temperature and event rate on vigilance performance. Aerospace Medicine, 1969, 40, 413-417.

Colquhoun, W.P. Circadian variations in mental efficiency. In W.P. Colquhoun (Ed.), Biological rhythms and human performance. London: Academic Press, 1971.

Colquhoun, W.P. and Baddeley, A.D. Role of pretest expectancy in vigilance decrement. Journal of Experimental Psychology, 1964, 68, 156-160.

Colquhoun, W.P. and Baddeley, A.D. Influence of signal probability during pretraining on vigilance decrement. Journal of Experimental Psychology, 1967, 73, 153-155.

Colquhoun, W.P., Blake, M.J.F., and Edwards, R.S. Experimental studies of shift-work I: A comparison of 'rotating' and 'stabilized' 4-hour shift systems. Ergonomics, 1968, 11, 437-453. (a).

Colquhoun, W.P., Blake, M.J.F., and Edwards, R.S. Experimental studies of shift-work II: Stabilized 8-hour shift systems. Ergonomics, 1968, 11, 527-546. (b).

Colquhoun, W.P., Blake, M.J.F., and Edwards, R.S. Experimental studies of shift-work III: Stabilized 12-hour shift systems. Ergonomics, 1969, 12, 865-882.

Colquhoun, W.P. and Corcoran, D.W.J. The effects of time of day and social isolation on the relationship between temperament and performance. British Journal of Social and Clinical Psychology, 1964, 3, 226-231.

Conroy, R.T.W.L. and Mills, J.N. Human circadian rhythms. London: Churchille, 1970.

Corcoran, D.W.J. Individual differences in performance after loss of sleep. Unpublished Ph.D. thesis, University of Cambridge, 1962. (a).

Corcoran, D.W.J. Noise and loss of sleep. Quarterly Journal of Experimental Psychology, 1962, 14, 178-182. (b).

Corcoran, D.W.J. Doubling the rate of signal presentation in a vigilance task during sleep deprivation. Journal of Applied Psychology, 1963, 47, 412-415.

Corcoran, D.W.J. Changes in heart rate and performance as a result of loss of sleep. British Journal of Psychology, 1964, 55, 307-314. (a).

Corcoran, D.W.J. The relationship between introversion and salivation. The American Journal of Psychology, 1964, 77, 298-300. (b)

Corcoran, D.W.J. Personality and the inverted-U relation. British Journal of Psychology, 1965, 56, 267-273.

Davies, D.R. and Hockey, G.R.J. The effects of noise and doubling the signal frequency on individual differences in visual vigilance performance. British Journal of Psychology, 1966, 57, 381-389.

Davies, D.R., Hockey, G.R.J., and Taylor, A. Varied auditory stimulation, temperament differences and vigilance performance. British Journal of Psychology, 1969, 60, 453-457.

Freeman, P.R. Table of d' and β. Medical Research Council Applied Psychology Research Unit, No. 529, November, 1964.

Green, D.M. and Swets, J.A. Signal detection theory and psychophysics. New York: Wiley and Sons, 1966.

Hebb, D.O. Drives and the CNS (conceptual nervous system). Psychological Review, 1955, 62, 243-254.

Hockey, G.R.J. and Colquhoun, W.P. Diurnal variation in human performance: A review. In W.P. Colquhoun (Ed.), Aspects of human efficiency. London: University Press, 1972.

Jerison, H.J. Human and animal vigilance. Perceptual and Motor Skills, 1965, 21, 580-582.

Jerison, H.J. Activation and long term performance. In A. F. Sanders (Ed.), Attention and performance. Amsterdam: North Holland, 1967.

Kleitman, N. Sleep and Wakefulness. Chicago: The University of Chicago Press, 1963.

Loeb, M. and Binford, J.R. Variation in performance on auditory and visual monitoring as a function of signal and stimulus frequencies. Perception and Psychophysics, 1968, 4, 361-367.

Murray, E.J., Williams, H.R. and Lubin, A. Body temperature and psychological ratings during sleep deprivation. Journal of Experimental Psychology, 1958, 56, 271-273.

Pátkai, P. Interindividual differences in diurnal variations in alertness, performance, and adrenaline excretion. Reports from the Psychological Laboratories University of Stockholm, No. 273, March, 1969.

Taub, H.A. and Osborne, F.H. Effects of signal and stimulus rates on vigilance performance. Journal of Applied Psychology, 1968, 52, 133-138.

Tune, G.S. Errors of commission as a function of age and temperament in a type of vigilance task. Quarterly Journal of Experimental Psychology, 1966, 18, 358-361.

Wilkinson, R.T. The effects of sleep loss on performance. Medical Research Council Applied Psychology Research Unit Report, Cambridge, No. 323, April, 1958.

Wilkinson, R.T. The effect of lack of sleep on visual watch-keeping. Quarterly Journal of Experimental Psychology, 1960, 12, 36-40.

Wilkinson, R.T. Interaction of lack of sleep with knowledge of results, repeated testing, and individual differences.

Journal of Experimental Psychology, 1961, *62*, 263-271.

Wilkinson, R.T. Interaction of noise with knowledge of results and sleep deprivation. *Journal of Experimental Psychology*, 1963, *66*, 332-337.

Wilkinson, R.T. Effects of up to 60 hours sleep deprivation on different types of work. *Ergonomics*, *7*, 175-186.

Wilkinson, R.T., Edwards, R.S., and Haines, E. Performance following a night of reduced sleep. *Psychonomic Science*, 1966, *5*, 471-472.

Williams, H.L., Lubin, A., and Goodnow, J.J. Impaired performance with acute sleep loss. *Psychological Monographs*, 1959, 73 (Whole No. 484).