SHIFTWORK AND PERFORMANCE

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The technological advances that have resulted in a doubling of the incidence of shiftwork over the past 20 or 30 years (Walker, 1978), have also produced a change in the type of task on which the shiftworker is typically engaged. In the past, the shiftworker's job was usually of a predominantly manual or perceptual nature (Wojtczak-Jaroszowa, 1977), and placed little reliance on higher cognitive processes. This, however, has changed with the advent of continuous industrial processes and costly complex machinery, like computers, that for economic reasons have to be run continuously. Today, many shiftworkers are required to perform complex cognitive jobs that tap very different information processing capabilities to those demanded by more manual tasks. This is also true in the social services sector where the demand for 'round the clock' services has produced a similar increase in the incidence of shiftwork.

The purpose of the present paper is to show how this change in the nature of the shiftworker's job may affect the optimal type of shift system in terms of maintaining adequate levels of productivity and safety. It is clear that in many situations, e.g., the control room of a large chemical plant, the cost of an error to society may be such that it is essential to maintain high levels of performance efficiency. Unfortunately, there is a paucity of data relating production efficiency and/or accident rate to different types of shift system, and what data there is is difficult to classify in terms of the cognitive load involved in the task. Thus, as Colquhoun (1976) points out we are forced to rely on evidence from laboratory studies, and hope that in the future we will be able to substantiate our conclusions from field studies.

Field Studies

The field studies that have been carried out do at least indicate that there is a problem of impaired efficiency on the night shift. Six of these studies have obtained relatively continuous (i.e., hourly or two hourly) measures of performance, and their findings are summarized in Figure 1. The studies have been ordered chronologically from the earliest (top) to the latest (bottom) study of which the author is aware. Arbitrary scales have been used and these have been chosen to approximately equate the amplitude of the six curves. Some of the curves have been inverted such that for all the curves, the lower the reading the worse was the performance.

In the earliest study, Browne (1949) examined the speed with which switchboard operators answered calls at different times of day or night. The data has been corrected by Browne to take account of the number of calls at any given time of day. Performance speed improved in a fairly linear-manner from 0800 to 1800, and dropped sharply after about 2200 such that it was slower during the night than at any other time of day. The trend in the frequency of making errors when reading meters (Bjerner & Swensson, 1953) shows a rather different trend over the normal waking day, performance decreasing over most of this period and there being evidence of a slight 'post-lunch dip'

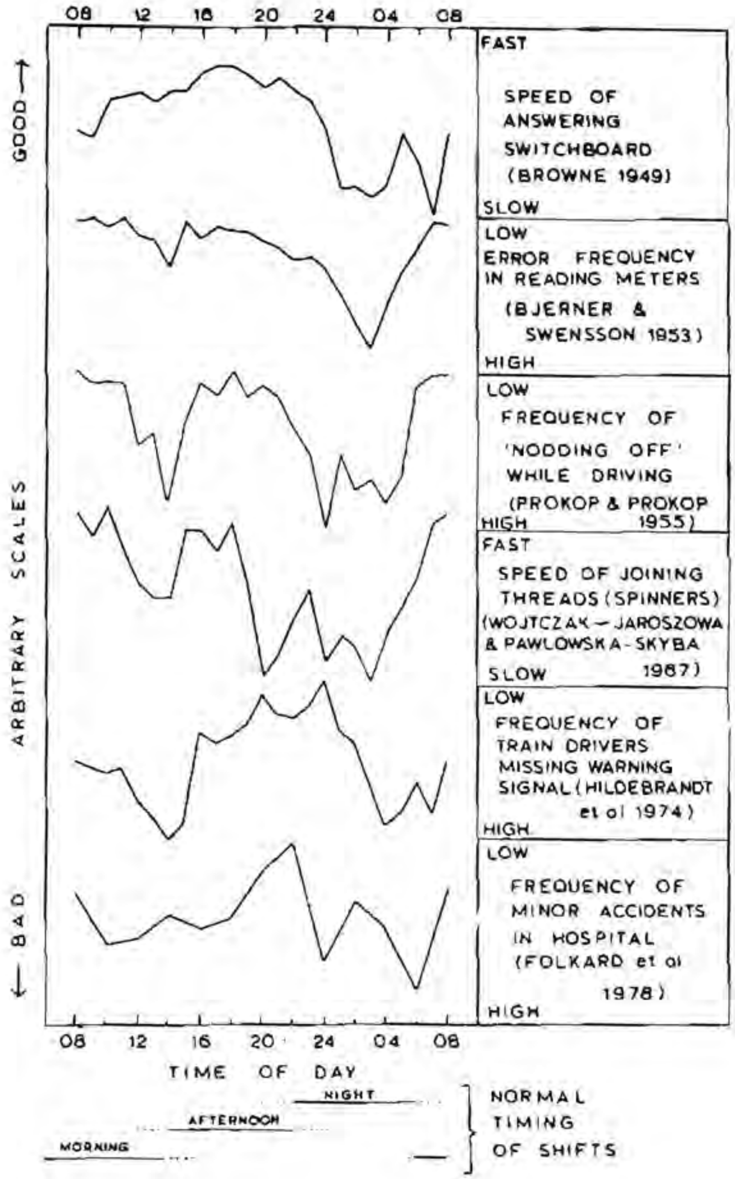

Figure 1. 24-hour performance curves from field studies of shiftwork (From Folkard & Monk, 1979).

(Colquhoun, 1971) in performance. However, again there was a fairly sharp drop in accuracy after about 2200, and performance reached its minimum level during the night hours. The difference in the trend over the normal waking period has apparently been ignored in the past, but may reflect the rather different nature of the task being performed.

The third panel down shows the frequency with which professional drivers reported having 'nodded off' while driving at different times of day (Prokop & Prokop, 1955). In this data the 'post-lunch dip' is even more apparent, with the frequency of 'nodding off' being almost as high at 1500 as during the night period. The reason for this is uncertain, although it has been suggested that the post-lunch dip is more marked in people who are relatively sleep deprived (Hildebrandt, Rohmert, & Rutenfranz, 1974). Again, however, there was clear evidence of an impairment during the night hours. This was also the case in the study of Wojtczak-Jaroszowa & Pawlowska-Skyba (1967) who examined the speed with which five spinners joined broken threads. This study was a particularly detailed one, with about 5,000 measurements being taken in all. The shiftworkers studies had all been on shiftwork for at least 10 years, and were highly proficient at their task. They were studied on the morning (0530 to 1330), afternoon (1330 to 2130) and night (2130 to 0530) shifts, although it is unclear how rapidly they rotated through these shifts. In Figure 1 the data from these three shifts had been combined to give a continuous 24 hour curve. As the authors point out, performance speed was about 10% slower on the night shift than on either the morning or afternoon shift.

The results of another detailed study are shown in the next panel. In this study (Hildebrandt, Rohmert, & Rutenfranz, 1974), automatic recording devices were fitted to the cabs of ten locomotives. Approximately every twenty minutes a warning light appeared for 2.5 seconds, followed by an auditory warning signal for a further 2.5 seconds. If neither of these signals were heeded, there was a thirty second sounding of the hooter in which the driver had to operate the safety gear to avoid an automatic braking of the locomotive. Hildebrandt et al. were able to record a total of 2,238 occurences of the hooter sounding, that indicated that neither of the warning signals had been responded to. Despite the fact that the warning light was more visible at night, more warning signals were missed, i.e., hooters sounded, during the night than in the day, apart from the period immediately after lunch.

The final panel of Figure 1 shows the frequency with which patients incurred minor accidents during their stay in hospital (Folkard, Monk, & Lobban, 1978). In this study, the records of a large modern hospital were examined for a five year period. A total of 1,854 'unusual incidents' occurred during this period, of which 1,576 were minor accidents involving a patient, and for which there was a clear indication of the time of occurrence. Only 30% of these accidents resulted in any injury to the patient, and in the majority of these cases (80%) only minor scratches or bruises were sustained. As can be seen from Figure 1, the frequency of these incidents tended to decrease over the normal waking period, and to increase over the night, despite the fact that most patients are asleep during the night hours. The two 'peaks' at 2200 and 0800 appeared to be due to the patients need to 'pass water' before going to sleep at night and on awakening in the morning.

In this last study it is, of course, unclear whether the data represents variations in patients 'accident proneness', or variations in the 'vigilance' of the nursing staff. Nevertheless, taken together the results shown in Figure 1 suggest that there is a problem of impaired efficiency and reduced levels of safety during the night. This conclusion is supported by the results of other studies that have examined performance efficiency on different shifts but have been unable to extract relatively continuous data. Thus, for example accidents on the night shift have been found to be more serious but, for some reason in this study, less frequent than on the morning or afternoon shift (Andlauer & Metz, 1967), while production quality has been found to be poorer at night (Meers, 1975). However, in many of these studies, and in those summarized in Figure 1, there are a large number of potentially confounding factors. Thus, for example, Meers (1975) not only reports lowered production quality at night from a sugar refinery and wire pulling factory, but also notes that there was less adequate maintenance of the machinery at night. It is therefore unclear as to whether the lowered quality was due to the impaired efficiency of the shiftworkers themselves or to that of the machinery they operated.

Experimental Studies

In order to overcome the potential contamination of performance measures by other factors, a number of researchers have conducted experimental studies, often using naive shiftworkers in laboratory settings. These experimental shiftwork studies have examined the disruption of the subjects' circadian (around 24 hours) rhythms in performance efficiency on various tasks. Before considering the results of these studies, and their implications for the optimal scheduling of shift systems, it is necessary to consider the evidence for circadian rhythms in the performance of different types of task.

Circadian Rhythms in Performance

Since it is impossible to obtain performance measures from individuals when they are asleep, most studies in this area have only examined performance efficiency over the course of the "normal working" day. Nevertheless, there is a marked tendency to consider the "time of day effect" or 'diurnal variation' observed as reflecting an underlying circadian (i.e., 24 hour) rhythm in performance efficiency. Many of the earlier studies were reviewed by Freeman and Hovland (1934) and Kleitman (1939). More recent general reviews have also appeared, e.g., Kleitman (2nd edition, 1963), Colquhoun (1971), Hockey and Colquhoun (1972), Broughton (1975), as well as more specialized reviews that have considered only particular types of performance, e.g., Monk (1979), Folkard (in press). The purpose here is not to duplicate these reviews but to summarize their conclusions and to draw attention to certain points that seem to have important implications for shiftwork.

Perceptual-motor performance. Many of the studies reviewed by Freeman and Hovland (1934) examined performance on relatively simple perceptual-(or sensory-)motor performance. Freeman and Hovland classified the studies they reviewed in terms of the trend in performance over the day and concluded that "the balance of evidence apparently favours an afternoon superiority for sensory and motor performance" (p 786). Thus, for example, in one of the better of the early studies Gates (1916a) found performance on letter cancellation and maze tracing tasks to improve fairly steadily over the whole of the school day. A similar conclusion was reached by Kleitman (1939), although he failed to distinguish between different types of task; an omission which has had serious consequences on subsequent research and theory in this area.

Kleitman (1939) ignored the fact that many studies had found certain types of performance to deteriorate over the day. He emphasised those studies of a perceptual-motor kind that had found performance to improve over the day, and drew attention to the parallelism between such diurnal variations in performance, and the circadian rhythm in body temperature. Indeed, Kleitman argued for a causal relationship between these two, suggesting that "either (a) mental processes represent chemical reactions in themselves or (b) the speed of thinking depends upon the level of metabolic activity of the cells of the cerebral cortex, and, by raising the latter through an increase in body temperature, one indirectly speeds up the thought process" (Kleitman, 2nd Ed., 1963, p160). Thus both body temperature and performance efficiency were held to be low immediately after awakening in the morning, and to improve over the day to reach a maximum in the afternoon.

The most direct evidence that Kleitman presents to support his view of a causal relationship between temperature and performance is correlational data between spontaneous changes in body temperature associated with time of day, and the corresponding changes in simple reaction time. This data, representing 120 pairs of readings from a single subject, confounds changes in temperature due to the circadian rhythm with other spontaneous changes mediated by both endogenous and exogenous factors. Subsequently, Rutenfranz, Aschoff and Mann (1972) have controlled for circadian changes, by summing over the different times of day, and have failed to find any relationship between day to day changes in temperature and corresponding changes in reaction time. This suggests that there is no causal relationship between temperature and performance, and that the correlation observed by Kleitman (1939) was due to independent circadian rhythms in temperature and performance that happend to be 'in phase' with one another. As Rutenfranz et al. (1972) point out, such synchronization could well result from the two variables being under the control of the same 'Zeitgebers' or enviromental 'time givers'.

Colquhoun (1971) also rejected the idea of a causal relationship between the circadian rhythm in body temperature and that in performance efficiency. However, like Gates (1916b) he argued that both may reflect a circadian rhythm 'sleepiness'. Evidence to support this argument was gleaned from the finding that circadian rhythms in performance are more pronounced in relatively sleep deprived subjects. Colquhoun interpreted this finding in terms of an inverted-U shaped relationship between arousal level and performance efficiency. In view of this postulated relationship, a given change in arousal level may improve, have no effect, or even degrade performance depending on the 'starting' level' of arousal. Sleep deprived subjects were seen as suffering from a lowered 'starting level' of arousal and thus showed a greater effect on performance of circadian variations in arousal level. Colquhoun (1971) therefore supported the idea of a parallelism between the circadian rhythm in temperature and that in performance efficiency, although rejecting the idea of a causal relationship between the two.

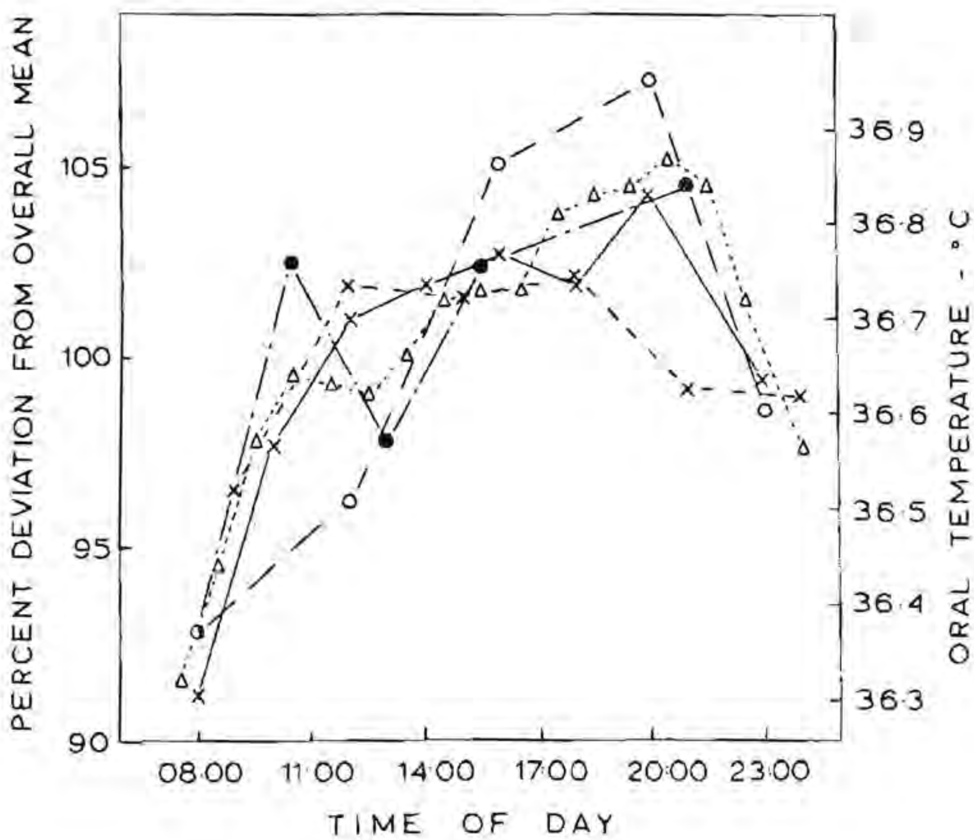

Figure 2. The trend over the day in visual search speed after Blake, 1967 (●---●), Fort & Mills, 1976 (x— —x), Hughes & Folkard, 1976 (o— — o) and Klein et al., 1972 (x- - - -x), together with the trend in oral temperature after Colquhoun et al., 1968a (Δ- - - -Δ)(From Folkard, 1980).

The best evidence for a parallelism between temperature and performance changes over the day comes from studies of visual search performance. These studies have all involved subjects searching through alphanumeric characters to find particular 'targets'. The precise nature of the 'targets' appears to be relatively unimportant, and has varied from tilted 'O's embedded in a background of upright ones (Hughes & Folkard, 1976) to the successive occurrence of a particular alphabetic character in random lines of such characters (Fort & Mills, 1976). The results of these studies, in terms of the speed with which subjects searched through the characters, are shown in Figure 2 together with the results of similar studies by Blake (1967) and Klein, Wegmann, and Hunt (1972). Also shown is the normal trend over the day in oral temperature after Colquhoun, Blake, and Edwards (1968a).

Two main points should be noted from this figure. First, these studies of visual search performance agree fairly well with one another that performance is low first thing in the morning, and improves over the day to reach a maximum at about 2000. Secondly, this trend over the day in visual search speed parallels fairly closely the trend in oral temperature. Unfortunately, this latter point does not hold true for other measures of perceptual-motor performance. Thus, for example, Klein, Wegmann, and Hunt (1972) report that reaction time was fastest at 0900 while temperature reached its maximum at 2100. Similarly, Buck (1976) found response speed to reach a maximum considerably earlier than the normal peak in body temperature. Against this, it should be noted that Blake (1967) found fairly similar trends over the day on a range of different perceptual-motor tasks, with performance on these tasks reaching a maximum at 2100, the latest time tested. It is unclear why these different studies have yielded inconsistent results. However, it seems probable that the precise information processing demands of the task employed may influence the phase of the circadian rhythm.

Cognitive performance. The best evidence that the information processing demands of a task may determine the phase of the circadian rhythm in performance comes from studies of more complex, cognitive performance efficiency. In their review, Freeman and Hovland (1934) recognized the need to classify studies according to the type of performance measure taken, but concluded that "...there is little agreement as to the time when complicated mental work can be done most efficiently" (p. 786). Subsequently, the effects of task demands have been largely ignored by reviewers in this area (e.g., Kleitmen, 1963; Broughton, 1975) although Hockey and Colquhoun (1972) noted that performance on memory tasks may show a rather different trend over the day to that for other tasks. Detailed examination of this area suggests that this is indeed the case.

In one of the early studies, Gates (1916a) noted that although performance on simple perceptual-motor tasks improved over the whole of the school day, that on two tests of short-term memory reached a maximum at about 1100 and then decreased over the remaining times tested. Gates (1916b) found a similar function for college students tested over a greater range of different times of day. As a result, he suggested that "in general the forenoon is the best time for strictly mental work" (Gates, 1916a, p. 149).

While there is some cause to doubt the generality of this conclusion (see below), subsequent studies of short-term memory (e.g., Blake, 1967; Baddeley,

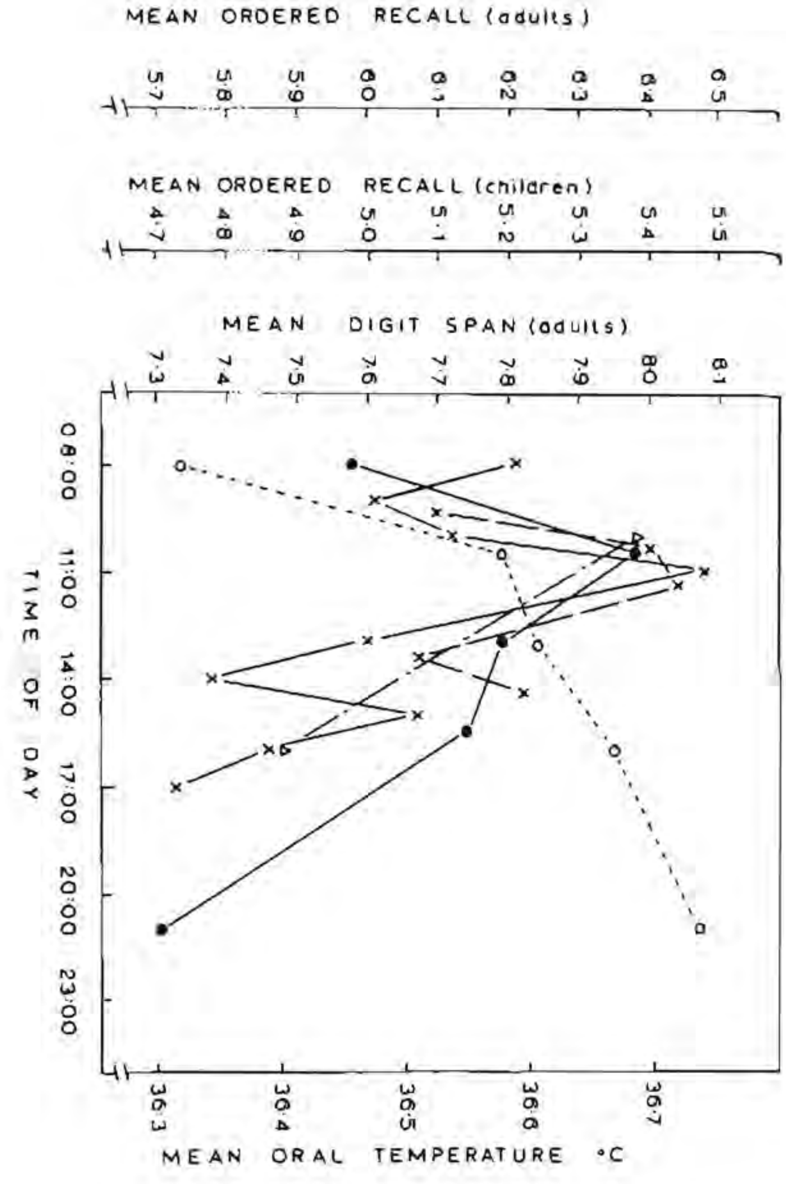

Figure 3. Digit span/sequence performance as a function of time of day after Baddeley et al., 1970 (Δ- - -Δ), Blake, 1967 (●——●), Gates, 1916a (x——x) and Gates, 1916b (x— —x), together with the trend in oral temperature after Blake, 1971 (o- - - -o)(From Folkard, 1980).

Hatter, Scott, & Snashall, 1970) have found very similar trends over the day. These findings are summarized in Figure 3, together with the temperature readings from Blake's (1967) study of short-term memory. There is considerable agreement between these studies as to the trend in short-term memory over the day. In addition, there is no evidence for Blake's (1967) results that the mid-morning peak in short-term memory was due to the testing of an atypical sample of subjects, since their temperature readings reached a maximum in the evening.

Other studies, e.g., Laird (1925), Folkard and Monk (in press) have examined the immediate memory for information presented in prose. In both studies university or college students were given a scientific article or short passage to read, and then either gave a verbatim written recall, or completed a multiple-choice questionnaire. The results from these two studies show considerable agreement with one another, although the trend over the day differed somewhat to that shown in Figure 3. Immediate memory for information in prose fails to show the initial improvement from early to mid-morning apparent in this figure, and decreased from the earliest time tested, namely 0800 (see Folkard, 1980, for a fuller review).

Further studies have examined the delayed retention of information presented at different times of day and, unlike immediate memory, have found it to be superior following the original presentation of the material in the afternoon or evening (e.g., Folkard, Monk, Bradbury, & Rosenthall, 1977; Folkard & Monk, in press). These findings have also been interpreted as reflecting an increase in arousal over the day. This follows from the finding of a number of studies, using a variety of methods of manipulating arousal level, that high arousal at presentation benefits delayed retention, despite the fact that it sometimes impairs immediate recall (see Craik & Blankstein, 1975; Eysenck, 1977, for reviews of this literature).

More importantly, from the present viewpoint, the short-term memory or storage load involved in the performance of a task has been found to have a substantial effect on the trend in performance over the day. A number of the early studies in this area (e.g., Laird, 1925) examined performance on various mental arithmetic tasks as a function of time of day. Recently, interest in this area has been re-stimulated by the 'working memory' model of Baddeley and Hitch (1974). These authors draw attention to the fact that many 'cognitive' tasks, while not of a 'pure memory' nature, involve the short-term storage of information. Such tasks include reading or listening to prose, as well as verbal reasoning. Often the measures of performance on these types of task of speed, rather than the accuracy measures that predominate in the memory literature. It thus seems reasonable to assume that these tasks involve information processing capacities similar to those tapped by the perceptual-motor tasks described earlier, but in addition involve short-term storage capacities. In view of this one might expect performance on this type of task to show a compromise between the increasing trend over the day found for many perceptual-motor tasks, and the decrease found for short-term memory. Indeed, the precise nature of this trend might be expected to vary systematically with the size of the short-term storage load involved.

The results shown in Figure 4 confirm that performance on memory-loaded 'cognitive' tasks shows a compromise function between that found for percep-

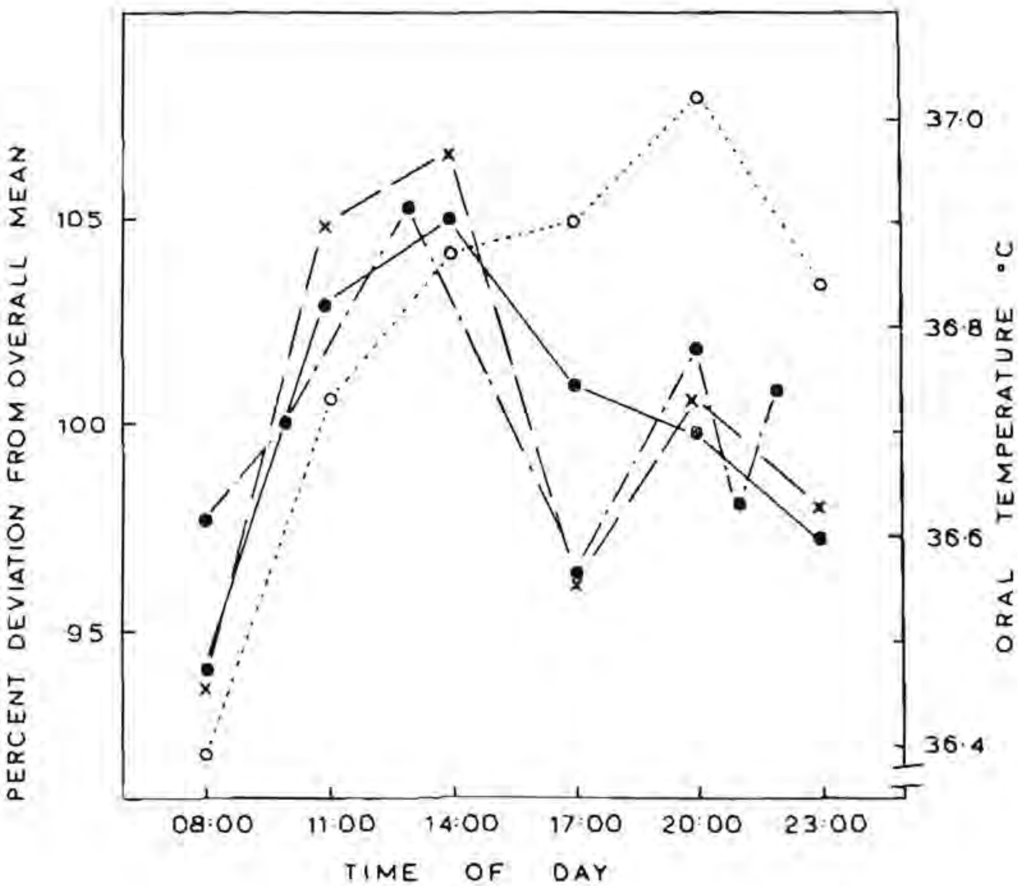

Figure 4. Performance speed on tasks involving 'working memory' as a function of time of day after Folkard, 1975 (x— —x and •— •) and Laird, 1925 (•—·—•), together with the trend in oral temperature after Folkard, 1975 (o----o)(From Folkard, 1980).

tual-motor performance and that found for short-term memory. In this figure is shown performance speed, on double digit addition (Laird, 1925) and two verbal reasoning tasks (Folkard, 1975). Also shown is the trend in oral temperature for Folkard's subjects. Performance speed on this type of task clearly reaches a maximum considerably earlier than the peak found for visual search (see Figure 2), but somewhat later than that found for short-term memory (see Figure 3).

More direct evidence for the influence of short-term memory load in determining the phase of the circadian rhythm in performance was obtained by Folkard, Knauth, Monk, and Rutenfranz (1976). These authors used a visual search task in which the memory load could be systematically varied by varying the number of alphabetic characters defining the target. Two subjects on an experimental rapidly rotating (2-2-2) shift system performed low (2-target), medium (4-target) and high (6-target) memory load versions of this 'Memory and Search Task' (MAST) every 2 hours 40 minutes while on-shift. Since there was little evidence of any disruption of the circadian rhythm in body temperature, the results from the three shifts were combined to give relatively continuous 24-hour curves. These are shown in Figure 5, together with the circadian rhythm in body temperature. The correlation between temperature and performance changed from being significantly positive for the 2-target version, through being effectively zero on the 4-target version, to being significantly _negative_ on the high memory loaded 6-target version.

Laboratory studies of circadian rhythms in performance have thus shown that there is _not_ a single circadian rhythm in performance efficiency. Rather, the phase of the circadian rhythm in performance would appear to depend on the information processing demands of the task under consideration. There is a clear need for further systematic research in this area to isolate all the important characteristics of the task in determining the phase of the rhythm, although there is already ample evidence that the short-term memory load does so. Indeed, this latter finding would appear to be of prime importance in the shiftwork context in view of the increasingly cognitive nature of the shiftworker's task. The next section thus considers the adjustment of performance rhythms to shiftwork, and the influence of task demands in determining such adjustment.

Shiftwork and Performance

A number of experimental shiftwork studies have included measures of performance efficiency. Most of these studies have used tasks of perceptual-motor performance, and have found the adjustment of the rhythm in performance to follow that of body temperature fairly closely. For example, Kleitman and Jackson (1950) examined performance on choice reaction, colour naming and 'flight simulation' tasks on a rapidly rotating (4-day cycle) shift system, and observed a marked parallelism between colour naming speed and body temperature. Indeed, this parallelism was such that the authors argued that performance efficiency could be assessed indirectly by the measurement of body temperature.

More recently, Colquhoun, Blake, and Edwards (1968a, 1968b, 1969) compared 'permanent' and 'rotating' shift systems and found a similar parallelism between the circadian rhythm in body temperature and that in certain of their measures of performance. This parallelism persisted even though there was evidence of partial adjustment of the tempreature rhythm over successive night shifts on the 'permanent' system. However, there was no evidence of complete adjustment of the subjects' circadian rhythms even after twelve successive nights. Indeed, other studies (Knauth & Rutenfranz, 1976) indicate that it can take up to three weeks for the circadian rhythm in body temperature to completely adjust to night work.

The implication of these findings is that night-shift performance is low for two reasons. First, the phase of the circadian rhythm in the performance of perceptual-motor tasks is such that performance on these tasks is usually at a low ebb at night. Secondly, this circadian rhythm adjusts very slowly to night work, and thus shows little adjustment over the span of 4 to 6 successive nights that is typical of even 'permanent' night workers. It should, however, be noted that these studies have used naive shiftworkers as subjects, and that rather better adjustment might be expected in more experienced shiftworkers (see below).

However, perhaps the most striking prediction to be derived from the studies reviewed in the previous section is that night shift performance of memory loaded cognitive tasks might be expected to be relatively good (see, for example, Figure 5). This prediction is difficult to reconcile with the consistently poor night shift performance found in the 'real life' studies shown in Figure 1. It is, of course, possible that none of the tasks performed in these studies involved a high memory load, although this seems unlikely in the case of, for example, the meter reading study of Bjerner and Swensson (1953). Indeed, the tendency for performance on this task to deteriorate over the normal day is consistent with the view that it involved a fairly high memory load. How then can this apparent contradiction be resolved?

The answer would appear to be that although performance on memory loaded tasks may normally be high at night, the circadian rhythm in such performance adjusts very rapidly to night work, resulting in a <u>deterioration</u> of night shift performance. As far as the author is aware, the first evidence suggesting this rapid adjustment of cognitive performance rhythms was obtained by Hughes and Folkard (1976). They examined the adjustment of the circadian rhythm in body temperature and performance on four different tasks to an experimental 10-day period of an 8-hour phase delay in <u>both</u> the sleep/wake and work/rest cycles. All the measures were taken at 4-hourly intervals (0800, 1200, etc.) while the six subjects were awake for two days prior to the experimental period, and for the last two days of it. Two perceptual-motor (visual search and manual dexterity) and two 'cognitive' memory loaded (double digit addition and verbal reasoning) performance tasks were used.

Hughes and Folkard (1976) analyzed the data in terms of the 'time since getting up effect' which should be identical before, and at the end of, the experimental period if complete adjustment had occurred. Subsequently the author has re-analyzed this data using a novel statistical procedure based on analysis of variance. Briefly, this involves extracting a normal trend over the day for the 'pre-shift' data. The mean score at each time of day is expressed as a difference from the overall mean. These difference scores clearly sum to zero, and can be used as coefficients of orthogonal polynomials in extracting the pre-shift 'time since getting up' trend from the post-shift data (see Winer, 1970, pp. 70-77 for a discussion of trend analysis). The significance of the 'pre-shift trend' in the post-shift data can be assessed by an F test, and the proportion of the variance it accounts for can also be calculated. Finally, the significance of any deviation of the post-shift data from the pre-shift trend can be estimated. It should be noted, however, that this procedure (1) tests only the shape of the trend, not its amplitude and (2) assumes the pre-shift trend to be a perfect estimate of the normal trend over the day. Since this assumption is never valid, the technique will under-estimate the degree of adjustment.

The results of this re-analysis of the Hughes and Folkard (1976) data are shown in Figure 6. Clearly all five measures showed considerable adjustment to the 8-hour shift, and the pre-shift trend accounted for a significant proportion of the variance for all measures. However, there was also significant deviation from perfect adjustment (i.e., from the 'preshift' trend) in the case of temperature, visual search, and manual dexterity, but not for either double digit addition or verbal reasoning. Thus, on the last two days of a ten-day phase shift of 8 hours, performance on two memory loaded cognitive tasks showed better adjustment than that on two perceptual-motor tasks.

Further evidence that the rate of adjustment of performance rhythms to night work is affected by memory load was obtained by Monk, Knauth, Folkark, and Rutenfranz (1978, Experiment II) using 2- and 6-target versions of the MAST test described in the previous section. In this study 2 naive shift-workers took part in an experimental shift work study involving 21 successive night shifts. The two versions of the MAST test were given every four hours throughout the study. In analyzing the results, 24 hour cosine curves were fitted to successive four day windows. The phase estimates were then expressed as deviations (in hours) from perfect adjustment. The results, averaged over the two subjects, are shown in Figure 7.

The most striking finding shown in this figure is that even on the first four-night window the phase of the circadian rhythm in 6-target (high memory load) MAST performance was within 2 hours of perfect adjustment. Indeed this rhythm was perfectly adjusted, in terms of phase, by the tenth night. The performance rhythm on the 2-target (low memory load) version of MAST adjusted more slowly, as did rectal temperature, with both measures achieving complete adjustment only after 16 nights. As in the Hughes and Folkard (1976) study, the conclusion to be drawn from these results is that the performance rhythm for cognitive, memory loaded tasks adjusts more rapidly to night work than either that for simple perceptual-motor tasks, or the circadian rhythm in body temperature.

Both the Hughes and Folkard (1976) and the Monk et al. (1978) studies used naive shift workers, interpolated measures of performance, and relatively small numbers of subjects. It is therefore unclear whether their findings can be generalized to experienced shift workers and more realistic tasks. An opportunity to remedy these problems arose as part of a large scale shiftwork study (Folkard & Monk, in press).

Fifty nurses were shown an 'in-service' training film on the use of Radium therapy at 2030 or at 0400. Their memory for the information presented was tested both immediately, and after a period of 28 days. In addition, two-

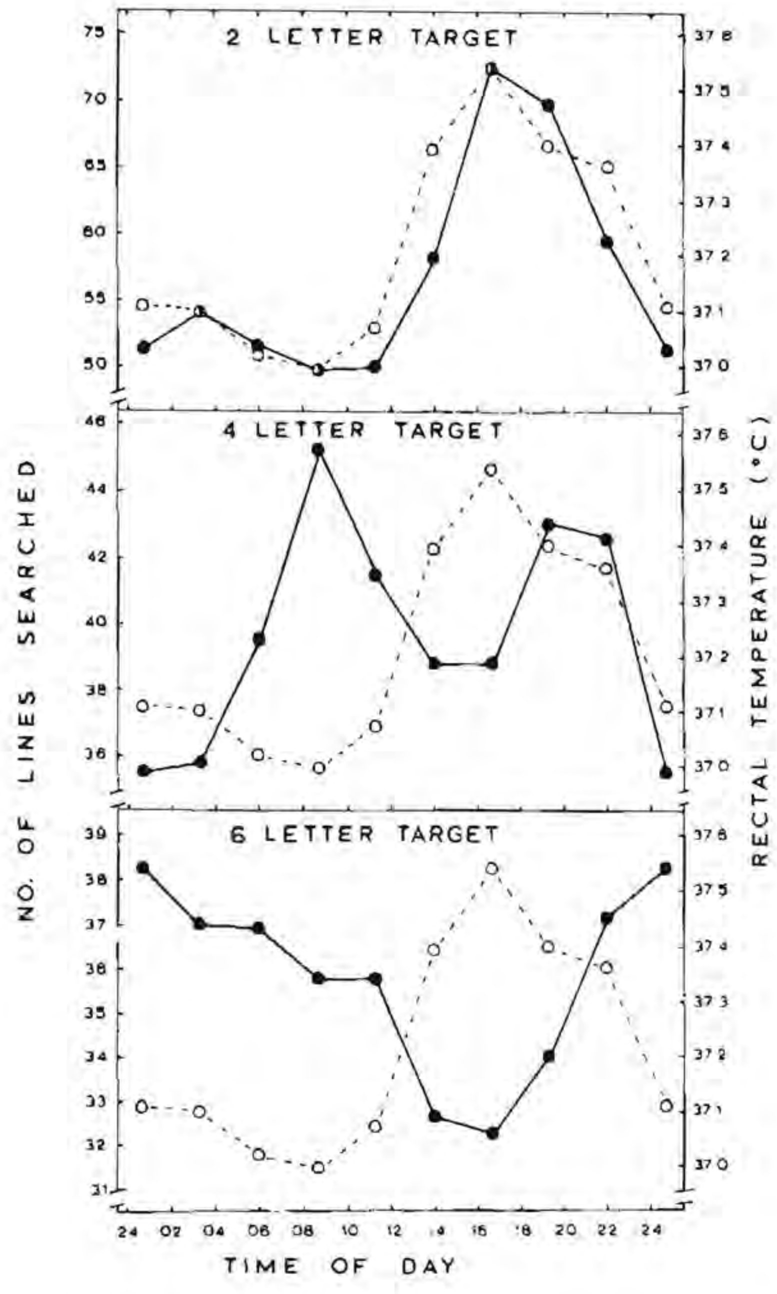

Figure 5. Performance speed on low (2-letter target), medium (4-letter target) and high (6-letter target) memory load versions of a visual search task as a function of time day, together with the trend in rectal temperature, after Folkard et al., 1976 (From Folkard & Monk, 1979).

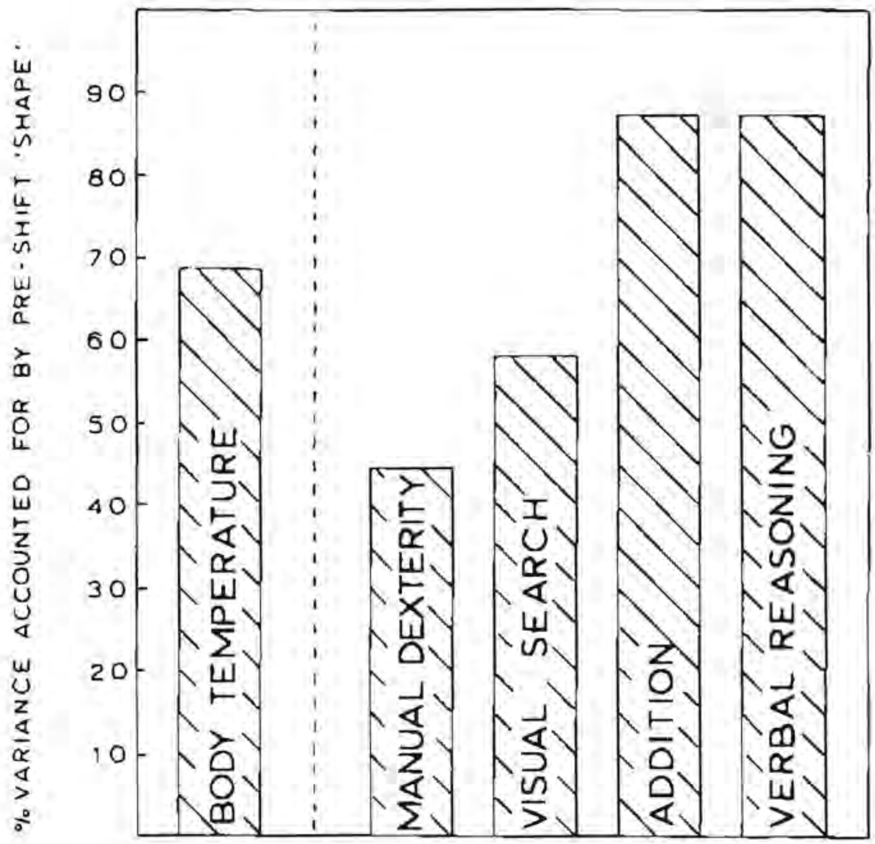

Figure 6. The degree of adjustment of the time of day effect in body temperature and four performance measures at the end of a ten-day period of an 8-hour shift in living routine after Hughes & Folkard, 1976 (From Folkard & Monk, 1979).

hourly measures of temperature and affective state were obtained over the course of the night shift on which the film was shown. All the nurses were 'permanent' night workers, half of them being full-timers who worked four nights a week, and the other half part-timers, who worked only two nights a week. The film was shown on the first or second night of any given nurse's span of successive night shifts.

The immediate memory results were scored simply in terms of the number of questions correctly answered (out of 20). Each nurse's 28-day delayed score was expressed as a percentage of her immediate score in order to provide an index of delayed retention that was unbiased by the level of immediate memory. The slope of the best fitting straight line to each nurse's temperature scores on the night she saw the film was taken as an index of adjustment to night work. These adjustment scores were used to divide the nurses into those showing 'good' adjustment and those showing 'poor' adjustment (on the basis of a median split) when they saw the film. The results are shown in Figure 8.

As predicted, the group showing poor adjustment had higher immediate memory scores at 0400 than at 2030, but the reverse was true for those showing good adjustment. In contrast, delayed retention appeared to be unaffected by the level of adjustment. Clearly these results confirm that the circadian rhythm in immediate memory adjusts particularly rapidly to night work. Thus, while the immediate memory scores of the good adjusters seemed to show complete adjustment, this was not the case for their temperature rhythms. These results also indicate that the circadian oscillator responsible for the effect of time of presentation on delayed retention differs from that responsible for immediate memory. Finally, it should be noted that the 'good' adjusters showed far better adjustment of their temperature rhythm than might be expected from experimental shiftwork studies (e.g., Colquhoun, Blake, & Edwards, 1968b, 1969; Knauth & Rutenfranz, 1976) given that the nurses were on only the first or second of a period of successive night shifts.

It seems clear that recommendations based on studies using simple perceptual-motor tasks cannot be generalized to situations where the shiftworker performs a more 'cognitive' memory-loaded job. Whereas poor nightshift performance on perceptual-motor tasks is due to the lack of adjustment of performance rhythms, on more cognitive tasks it would appear to be due to this very adjustment. Thus performance on cognitive tasks appears to be relatively good during the night provided people's rhythms are unadjusted. However, as adjustment occurs, so performance deteriorates. Indeed, this deterioration with increased adjustment is rather more rapid than the improvement found for perceptual-motor tasks. In view of this, the 'permanent' shift systems that may be best for maintaining adequate levels of perceptual-motor performance would seem to be far from ideal for more cognitive tasks. For these types of task rapidly rotating shift systems (e.g., 2-2-2) are probably better since they result in minimal disruption of the shiftworker's circadian rhythms (see Knauth & Rutenfranz, 1976; Smith, 1979).

Other Factors Affecting On-Shift Performance

It is clear from the results reviewed in the previous section that, whatever the nature of the shiftworker's task, his on-shift performance will be largely determined by the extent to which his circadian rhythms adjust to

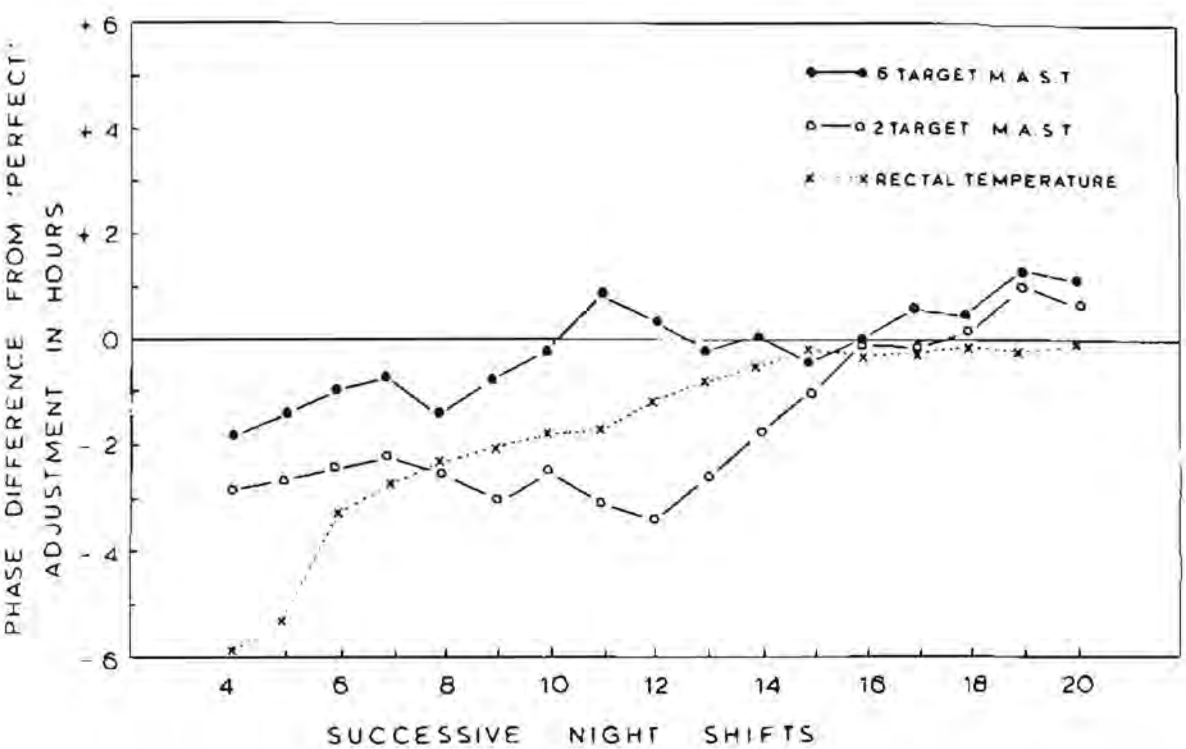

Figure 7. The adjustment of the phase of the circadian rhythm in performance on low (2-target MAST) and high (6-target MAST) memory load versions of a visual search task, and in rectal temperature after Monk et al., 1978 (From Folkard & Monk, 1979).

shiftwork. For simple perceptual-motor tasks any adjustment will result in improved night shift performance, while for more cognitive, memory-loaded tasks, adjustment might be expected to result in an impairment of night shift performance. The degree to which an individual's circadian rhythms adjust to night work will in turn depend on a number of factors, perhaps the most important of which are the type of shift system, and the 'type' of individual, i.e. individual differences. This section thus briefly considers the influence of these factors in determining the degree of adjustment of the shiftworker's circadian rhythms.

Shift System

As indicated above, Colquhoun et al. (1968b, 1969) found people's circadian rhythms to gradually adjust over a period of successive night shifts, although complete adjustment did not occur within the twelve-day period studied. This finding is typical of experimental shiftwork studies that have examined adjustment to permanent night work (e.g., Van Loon, 1963; Knauth & Rutenfranz, 1976). In general, these studies agree in showing that adjustment to 'permanent' night work takes place rather slowly over successive night shifts, but that re-adjustment to a diurnal pattern of life on rest days is very rapid (e.g., Van Loon, 1963). These experimental studies thus suggest that 'permanent' night work results in the shiftworker's circadian rhythms being in a continuous state of flux. In contrast, the available evidence suggests that rapidly rotating shift systems result in very little disruption/ adjustment of the shiftworker's circadian rhythms (e.g., Knauth & Rutenfranz, 1976).

However, since these experimental shiftwork studies have used naive shiftworkers, they have been unable to examine potential 'long-term adjustment'. It has long been argued that such adjustment may occur as a result of prolonged experience of a particular shift system, and that it may enhance the 'short term' adjustment that occurs over a period of successive night shifts. Such enhancement might result in a permanent inversion, or at least a flattening, of the night worker's circadian rhythms. Alternatively, long-term adjustment may not affect the normal rhythm, but simply result in a speeding-up of short-term adjustment over successive night shifts.

Several authors have attempted to demonstrate the potential for long-term adjustment, although there are immense practical problems in doing so. Ideally it involves finding two groups of shiftworkers, one 'permanent' and one 'rapidly rotating', who are employed in the same section of a single institution/ company, have the same timing of shifts, the same experience, and perform identical jobs. In practice, no-one has yet managed to achieve this. Nevertheless, Smith (1972, 1979) was able to compare rapidly (2 or 3 successive nights) and slowly (5 successive nights) rotating shiftworkers, while Åkerstedt, Patkai, and Dahlgren (1977) compared 'permanent' nightworkers with weekly rotating shiftworkers. Their findings suggest that rotating shiftworkers do not show any evidence of long-term adjustment. Indeed, Smith (1979) suggests that his subjects showed little evidence of any adjustment to night work. In contrast, permanent night workers did show some long-term adjustment relative to weekly rotating shiftworkers (Patkai, Åkerstedt, & Pettersson, 1977; Åkerstedt et al., 1977).

These studies were unable to determine whether long-term adjustment resulted in permanent changes to the circadian rhythm, or simply more rapid short-term adjustment. Some evidence that the latter is the case was obtained by Folkard, Monk, and Lobban (1978), who compared the adjustment of full- (4 nights per week) and part- (2 nights per week) time permanent night nurses in two separate studies. In the first of these studies clear evidence was obtained that the full-time staff showed better adjustment on the average than the part-time staff, even when the potential for short-term adjustment has been controlled for. In the second study, no difference was found between the groups in their normal circadian rhythms on a rest day, but the full-time nurses showed better adjustment on the first of a period of successive night shifts. Indeed, as in the Smith (1979) study, there was little evidence of any adjustment at all in the part-time staff. Thus long-term adjustment would appear to only occur in full-time 'permanent' night workers, and to take the form of a speeding-up or facilitation of short-term adjustment rather than a permanent flattening or inversion of the rhythm. It has been suggested that it occurs because of the relative stability of night-oriented synchronizers in permanent night staff (Åkerstedt et al., 1977), and that the scheduling of day sleeps may be particularly important in this respect (Folkard et al., 1978).

The implications of these various findings for on-shift performance are clear, although long-term adjustment of performance rhythms has yet to be demonstrated. In situations where adjustment is desirable, e.g., for perceptual-motor tasks, the optimal shift system may be a full-time permanent one that maximizes the potential for both short- and long-term adjustment. In concontrast, when such adjustment results in impaired performance, as would appear to be the case for cognitive, memory-loaded tasks, rotating shift systems may be preferable since they appear to result in little disruption of the normal circadian rhythms. Indeed, it has been argued that the more rapid the rotation of a shift system, the less disruption occurs (e.g., Knauth & Rutenfranz, 1976).

Individual Differences

The second important factor in determining the level of adjustment of circadian rhythms to night work is that of individual differences. It has long been recognized that individuals differ from one another in both their 'circadian type' and the degree to which their circadian rhythms adjust to night work (e.g., Kleitman, 1939; Åkerstedt & Fröberg, 1976). From a practical point of view it is clearly desirable to be able to predict these individual differences on the basis of questionnaire scores. Many of the attempts to do this have been excellently reviewed by Åkerstedt and Fröberg (1976). In this section the earlier studies will thus be very briefly mentioned, and some recent developments will be noted.

As Åkerstedt and Fröberg (1976) point out, most of the research in this area has concentrated on differences in the phase of people's circadian rhythms, despite the fact that the amplitude and stability of these rhythms may also be important. Kleitman (1939) distinguished between 'Morning types' (M-types) and 'Evening types' (E-types) on the basis of phase differences in the circadian rhythm of body temperature, and found similar differences in perceptual-motor performance. Subsequently a number of questionnaires have been developed to distinguish between M- and E-types (e.g., Horne & Östberg,

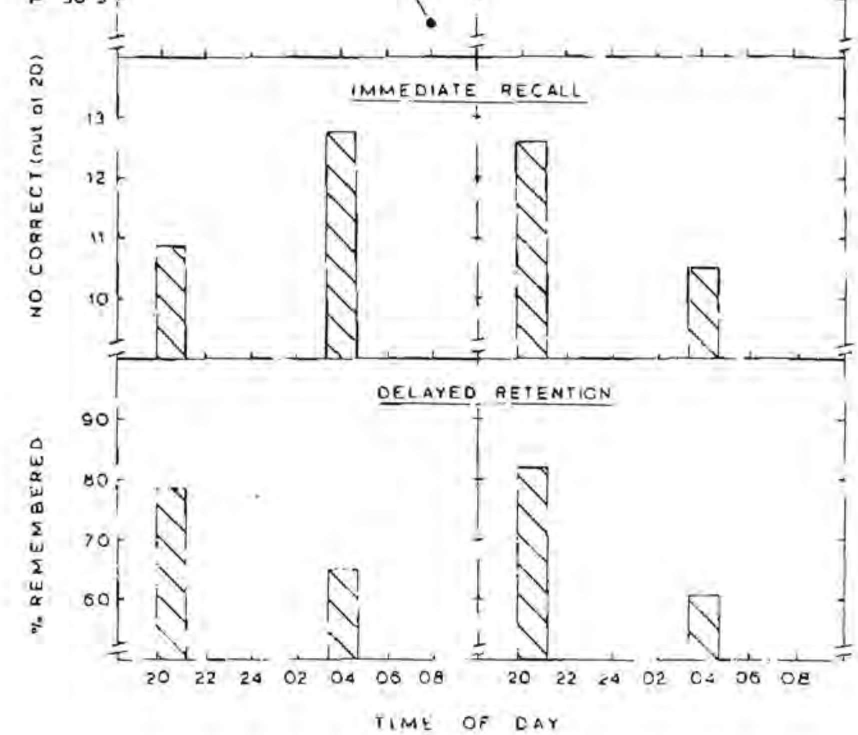

Figure 8. Immediate and delayed retention of the information presented in a film at 2030 or 0400, shown separately for nurses showing 'poor' or 'good' adjustment of their circadian rhythm in oral temperature to night work. (From Folkard & Monk, 1980).

1976) and it has been suggested that E-types should adjust more readily to night work. However, as Åkerstedt and Fröberg (1976) note, early attempts to demonstrate this met with only limited success.

Since the review by Åkerstedt and Fröberg, a number of promising studies have been reported that suggest that it may prove feasible to predict adjustment to night work from questionnaire results. Thus, for example, Breithaupt, Hildebrandt, Dohre, Josch, Sieber, and Werner (1978) have reported fairly substantial relationships between scores on a morningness questionnaire and various characteristics of sleeps taken at unusual times. In addition, adjustment to night work has been shown to be better in 'neurotic extraverts' than in 'neurotic introverts' (Colquhoun & Folkard, 1978), and better in individuals with low amplitude rhythms than those with higher amplitudes (Reinberg, Vieux, Ghata, Chaumont, & Laporte, 1978). Adjustment to time zone transitions has been found to be more rapid in individuals whose normal rhythms show a late phase (Colquhoun, 1979), and an attempt has been made to develop a 'circadian type questionnaire' (CTQ) that taps aspects of the circadian rhythm other than that of phase (Folkard, Monk, & Lobban, 1979). Scores on this questionnaire have been found to correlate with various measures of adjustment to night work (Folkard et al., 1979) and have successfully predicted adjustment to the one-hour time-zone change involved in 'daylight saving' schemes (Monk & Aplin, in press).

In sum, there is good evidence that individuals differ in the degree to which their circadian rhythms adjust to night work, and some progress has been made towards being able to predict these differences from questionnaire results. It is, however, unclear whether these differences reflect differences in short- or long-term adjustment, and there is a clear need for further research in this area. In the future it may prove possible to select people whose rhythms adjust easily to shift work to man permanent shift systems in order to maximize the benefits of such systems for perceptual-motor performance. In addition, people whose rhythms show minimal disruption might be selected for rotating shift systems apparently desirable for more cognitive, memory-loaded tasks.

Conclusions

The main conclusion to be drawn from the studies reviewed in this paper is that there is no single 'optimal' shift system for ensuring adequate levels of productivity and safety. Rather it would appear that the universally low night shift performance observed in field studies may be due to rather different combinations of various factors. Of these factors, the demands of the shiftworker's task, the type of shift system, and differences between individuals would seem to be particularly important. These factors can be viewed as interacting with one another, via the shiftworker's various circadian rhythms, in determining 'on shift' performance. This is illustrated in Figure 9 in which the solid lines represent known connections, and the dashed lines probable ones.

Task demands may influence on-shift performance by (1) determining the phase of the normal circadian rhythm in performance and (2) affecting the rate at which this rhythm adjusts to night work. Rate of adjustment will also be affected by the type of shift system, and hence potential for short- and long-

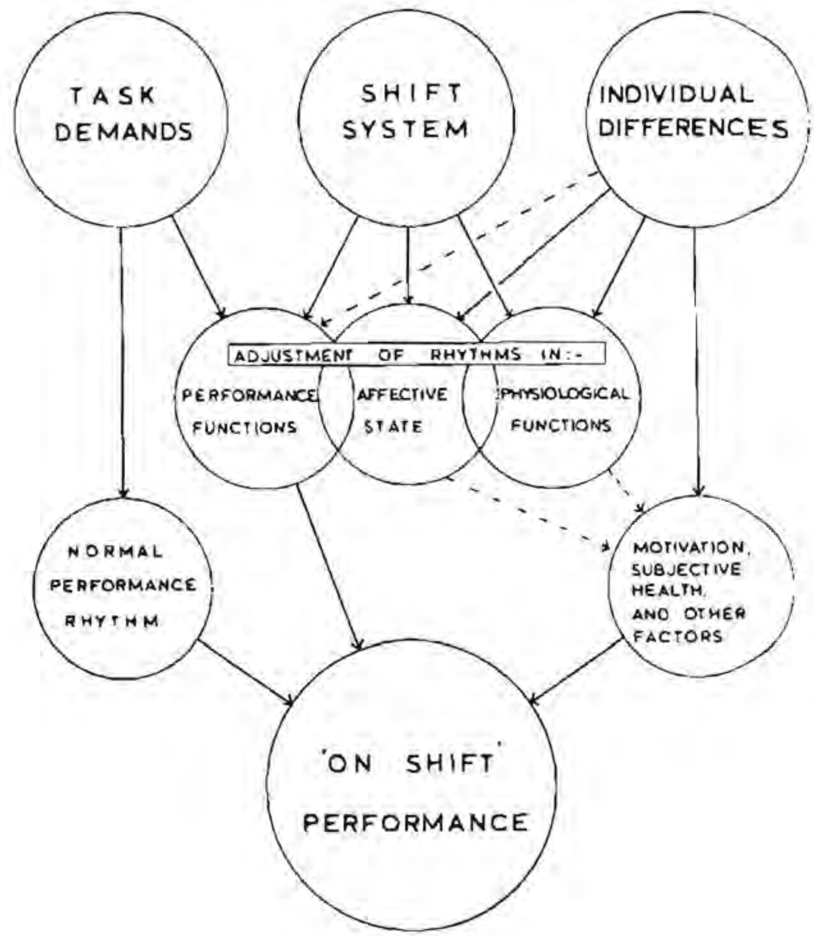

Figure 9. A descriptive model showing how 'On shift' performance may be affected by task demands, shift systems, and individual differences with these factors interacting via the shiftwork in circadian rhythms (From Folkard & Monk, 1979).

term adjustment, and by individual differences in such adjustment. In addition, the degree to which an individual adjusts to night work will affect his on-shift performance indirectly via his subjective health, and motivational level. As yet, little, if any, research has been done on this indirect effect of shiftwork on performance, although subjective health and motivation are clearly important factors in their own right (see, for example, Åkerstedt & Fröberg, 1976; Harrington, 1978; Walker, 1978).

Finally, there clearly are situations where high levels of performance efficiency and safety have to be maintained on the night shift. If all other factors are equal, the results reviewed in this paper favour 'permanent' systems for simple perceptual-motor tasks, but rapidly rotating ones for more cognitive, memory-loaded tasks. However, these conclusions must be regarded as extremely tentative. There is a clear need for further experimental and field studies of shiftwork that recognize the potential interaction of the various factors shown in Figure 9, and that take account of the influence of the effects of shiftwork on other factors such as subjective health and motivation that may also affect 'on-shift' performance. At this stage all that can be concluded with certainty is that the problem of impaired night shift performance is far more complex than has been recognized in the past.

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