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Productivity on a weekly rotating shift system: circadian adjustment and sleep deprivation effects?

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There is little doubt that productivity and safety can be impaired on the night shift. Two main factors have been identified that may be responsible for this. On the one hand, the circadian rhythm in performance on at least simple tasks is at a low ebb at night, and adjusts only slowly over a span of night shifts. On the other, the day sleeps of shift workers taken between night shifts are of a reduced duration, and thus a cumulative sleep debt may accrue over successive night shifts. The former thus predicts that productivity should improve over a span of night duty, while the latter predicts that it should decline. We have examined the productivity of 53 female shift workers, and the sleeping habits of a sub-sample of 30 of them, on a weekly rotating shift system in order to assess the relative contribution of these two factors. Our results suggest that circadian adjustment to night work is the dominant factor for the first three or four successive nights shifts, but that sleep deprivation effects may then result in a decrease in productivity over subsequent nights. They also indicate that sleep deprivation, but not circadian adjustment, may affect the productivity of some workers when on the morning shift.

1. Introduction

Approximately 20% of those employed in manufacturing industries work on some form of shift system (Kogi 1985). This can result in a variety of problems for both the individuals and their employers, ranging from impoverished health and social life to impaired productivity and safety. Although these problems have been fairly extensively studied (Folkard and Monk 1985), there is still considerable uncertainty as to the effects of shift work, and especially night work, on productivity.

Relatively few studies have successfully obtained uncontaminated measures of 'real job' performance on different shifts. There are a number of reasons for this, including, for example, the fact that in many cases the maintenance of machinery is confined to the day, while qualitatively different tasks are often performed on the different shifts. Nevertheless, studies that have overcome these problems, with one notable exception (see below), have found that various measures of productivity and/or safety are lower at night (Folkard and Monk 1979). Unfortunately, the nature of these studies has been such that it has not proved possible to determine why this should be the case, and hence how to alleviate this problem.

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With a view to rectifying this, a number of authors have either conducted 'simulated shiftwork studies' in which (typically naïve) subjects are put on shift work in the laboratory, or have taken interpolated performance measures from experienced shiftworkers at their normal place of work (see review by Monk and Folkard 1985). The findings from these studies suggest that lowered night shift productivity is a result of two main factors. Firstly, the day sleeps of shift workers taken between night shifts are typically 1–4 hours shorter than normal sleeps (Akerstedt 1985). This can result in a cumulative 'sleep debt' over successive night shifts, and consequently in a progressive impairment of performance (Tepas *et al.* 1981, Tilley *et al.* 1982). Secondly, performance efficiency on a range of tasks has been found to exhibit a circadian (around 24 hour) rhythm, and such rhythms show a phase adjustment over successive night shifts (Colquhoun *et al.* 1968). Performance on any given night shift will thus be affected by the phase of the circadian rhythm in the task concerned.

In the case of complex cognitive performance, involving a high short-term memory load, the available evidence suggests that the phase of the unadjusted circadian rhythm is such that performance will be good at night, but will deteriorate over successive night shifts as the rhythm adjusts (Folkard and Monk 1979). Thus, for this type of task, both the sleep deprivation and circadian rhythm factors will result in a progressive impairment of performance over successive night shifts, suggesting that very rapidly rotating shift systems may be preferable. Indeed, the sole 'real job' study to have found superior night shift performance concerned computer operators performing a cognitive task on this type of system (Monk and Embrey 1981).

In contrast, the performance of more simple, non-memory loaded tasks is relatively poor at night when the circadian rhythm is unadjusted, and improves over successive night shifts as the rhythm adjusts (Colquhoun *et al.* 1968). Thus, while both the sleep deprivation and circadian rhythm factors agree that this type of performance will, on average, be lower on the night shift, they disagree as to the trend over successive night shifts and hence as to how to minimize this problem. From the sleep deprivation point of view, performance will deteriorate over successive nights and thus rapidly rotating shift systems are preferable. From circadian rhythm considerations, performance will improve over successive nights and thus permanent, or slowly rotating, shift systems are preferable. In view of this conflicting intelligence, the present study examined productivity on a simple perceptual-motor job over successive night shifts, compared to successive morning and afternoon shifts, with a view to determining the actual trend in an industrial context.

2. Procedure

The study was conducted in an electronics component factory where a total of 186 female shift workers were employed in manufacturing (winding-up) capacitors. They worked on a weekly rotating shift system involving five successive work days (Monday to Friday) followed by two rest days, on each of the morning (06.00–14.00), afternoon (14.00–22.00) and night (22.00–06.00) shifts. The shifts rotated in the order of mornings–nights–afternoons, and a complete cycle of the system took place every 3 weeks.

An individual piece-rate incentive plan was in operation such that the workers were paid a fixed amount for each capacitor of a given type that they produced. This amount was 20% higher on the night shift than on the morning or afternoon shifts. The workers were not penalized for rejected capacitors since their incidence was extremely low. A number of different types of capacitor were produced on the same machines in

various run lengths. The work demanded a high level of perceptual-motor coordination and manual dexterity, but was very monotonous. The average operation cycle time was about 31 s.

The productivity of all the shift workers engaged in producing capacitors was monitored, without their knowledge, over a 4 month period. During this period, 53 of them produced one of four main types of capacitor over complete weeks on each of the morning, afternoon, and night shifts, and their productivity over these weeks was thus selected for analysis. These 3 weeks were not necessarily consecutive ones, but the order in which the different shifts occurred was approximately balanced over the different shift workers. The type of capacitor produced during these 3 weeks differed between shift workers, but was constant for each individual.

These 53 shift workers had a mean age of 25.1 years (range, 18-39 years) and had been employed in this capacity for an average of 4.0 years (range, 1-16 years). Thirty-three of them were married, and 15 had children living at home with them. Following the monitoring of their productivity, a representative sample of 30 completed a questionnaire concerning their normal sleeping habits on the different shifts.

3. Results and analyses

3.1. Sleep patterns

The mean number of hours slept between successive shifts is shown in the table. A fairly normal pattern was observed when the results from the whole group were considered. The shift workers slept the longest between afternoon shifts and an average of about 2 hours less between successive morning or night shifts. However, these figures conceal rather different patterns for the single and married workers. Both groups slept the longest between afternoon shifts, but while the married workers slept the shortest between successive night shifts, the single shift workers slept the shortest between successive morning shifts. Thus a sleep deprivation account of impaired productivity might make rather different predictions for these two groups.

3.2. Productivity

The main results are shown in figure 1, with the mean number of capacitors produced plotted for each day and shift. From this figure it is clear that while morning and afternoon shift productivity was relatively constant over the week, night shift productivity varied quite considerably.

Preliminary analyses indicated that there were no reliable differences associated with the type of capacitor produced ($F(3,49) = 2.18; p > 0.10$), and this factor was thus

The mean (and standard deviation) number of hours slept between successive morning, afternoon and night shifts.

	Morning shift	Afternoon shift	Night shift
Overall sample ($N=30$)	6.77 (0.79)	8.67 (1.58)	6.59 (3.11)
Single shift workers ($N=12$)	7.11 (0.84)	9.88 (1.40)	8.68 (3.41)
Married shift workers ($N=18$)	6.54 (0.69)	7.86 (1.13)	5.19 (1.96)

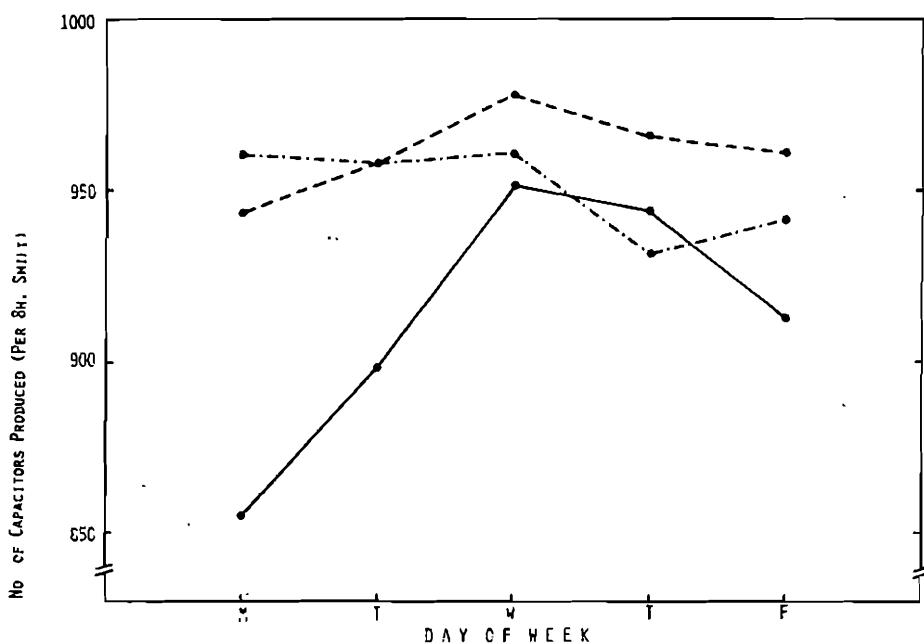


Figure 1. The trend in productivity over a week of morning (●—●—●), afternoon (□—□—□) and night (○—○—○) shifts ($N=53$).

ignored in the subsequent analyses. In view of the different sleeping pattern of the single and married shift workers, a three factor, mixed design analysis of variance was based on the productivity scores. This examined the between-subject factor of single versus married, and the within-subject factors of type of shift (morning, afternoon and night) and day of the week (Monday to Friday).

The productivity of the married shift workers (mean = 964) was somewhat higher than that of the single ones (mean = 904), although this difference was not reliable ($F(1,51) = 3.52; 0.05 < p < 0.10$). There was a highly significant main effect of type of shift ($F(2,102) = 12.82; p < 0.001$), with productivity being highest on the afternoon shift (mean = 962) and lowest at night (mean = 912). Mean productivity also varied with the day of the week ($F(4,204) = 5.07; p < 0.05$), being low on Monday (mean = 919), increasing to a maximum on Wednesday (mean = 963), and then showing a slight decrease to Friday (mean = 939). However, inspection of figure 1 suggests that this day of the week effect was largely confined to the night shift and indeed there was a reliable 'type of shift \times day of the week' interaction ($F(8,408) = 3.44; p < 0.001$). There was no evidence for either a 'groups \times type of shift' ($F(2,102) = 0.84$) or a 'groups \times day of the week' ($F(4,204) = 0.90$) interaction, but there was a reliable 'groups \times type of shift \times day of week' interaction ($F(8,408) = 2.56; p < 0.01$).

This latter interaction was explored by means of separate analyses based on the data from each shift. These confirmed that there was no reliable main effect of the day of the week on the afternoon ($F(4,204) = 0.89$) or morning ($F(4,204) = 1.34$) shifts, but a highly reliable one on the night shift ($F(4,204) = 9.50; p < 0.001$). In contrast, there was no reliable 'groups \times day of the week' interaction on the afternoon ($F(4,204) = 1.04$) or night ($F(4,204) = 0.99$) shifts, but a reliable one on the morning shift ($F(4,204) = 4.76; p < 0.01$). This interaction is shown in figure 2. The productivity of the married shift workers was clearly relatively constant over the week of morning

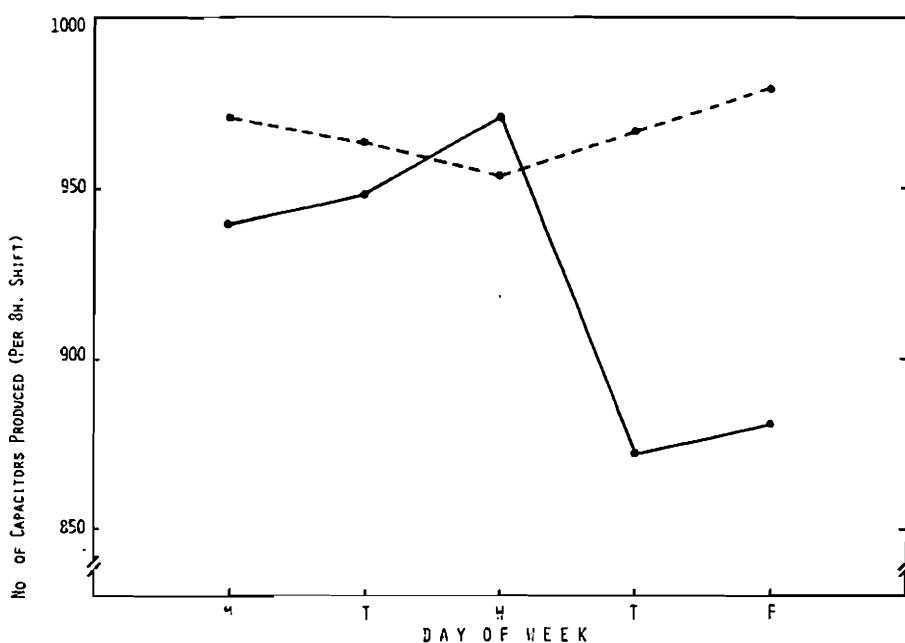


Figure 2. The trend in productivity over a week of morning shifts shown separately for the married ($N=33$) (---●---) and single ($N=20$) (●—●) shift workers.

shifts while that of the single shift workers fell considerably on the last 2 days.

The question arises as to whether these differences between the single and married shift workers are attributable to differences in their age and experience, rather than to their marital status *per se*. Thus the mean age of the single workers was somewhat less than that of the married ones (single, 23.3; married, 26.2), as was their mean years of experience (single, 2.9; married, 4.6). In order to check on these potentially confounding factors, further analyses of variance were performed comparing young and old, and inexperienced and experienced, shift workers. In both cases these were based on a median split.

The analysis based on age yielded a significant main effect of age ($F(1,51)=4.09$; $p<0.05$), but no evidence of any interaction with the type of shift or day of the week ($F<1$ in all cases). Indeed, even the main effect of age was probably due to confounding with experience. Thus the analysis based on experience indicated that experienced workers were significantly more productive than inexperienced ones ($F(1,51)=6.67$; $p<0.025$; experienced mean, 986; inexperienced mean, 908). Again, however, there was no evidence of any interactive effect involving experience ($F<1$ in all cases). In view of this pattern of results it would appear that whereas the slight difference in overall productivity between single and married shift workers may well be due to confounding with experience, there is no evidence to suggest any confounding in the interactions with type of shift and day of the week.

4. Discussion

Two main points emerge from consideration of these results. The first is that both circadian and sleep deprivation factors would appear to play a role in determining the productivity of shift workers. Thus it seems unlikely that the trend observed for the night shift reflected a weekly industrial work curve (Murrell 1971), since such an

interpretation would predict a similar trend for all three shifts. Rather, the productivity trend found over the week of nights suggests that circadian adjustment played the major role for the first three nights, but that sleep deprivation effects subsequently dominated. However, it is unclear whether there was residual circadian adjustment after the first three nights that was masked by cumulative sleep deprivation effects, or whether complete circadian adjustment had occurred by this point. The literature on circadian adjustment to night work suggests that it is extremely unlikely that the present shift workers' temperature rhythms would have adjusted by this point (e.g. Colquhoun *et al.* 1968), but this need not necessarily imply that their perceptual-motor speed rhythm had not done so. There is evidence both that perceptual-motor speed does not parallel changes in body temperature over the normal day (Monk and Leng 1982) and that performance rhythms can run independently of the temperature rhythm (Folkard *et al.* 1983).

The second major point to emerge from this study is that social factors such as family commitments can have an influence on productivity curves. In the present study this was largely confined to the morning shift when single, but not married, shiftworkers showed a decrease in productivity on the fourth and fifth morning shifts. However the reason for this difference is unclear. Although it is true that single workers slept least when on the morning shift, in absolute terms they still got a little (about 35 min.) more sleep than married workers. If this decrease in productivity is to be interpreted as reflecting sleep deprivation, then relative rather than absolute sleep duration must be assumed to be the important factor. Thus the single workers' sleep between morning shifts was reduced by 28%, but that of the married workers by only 13%, relative to the duration of their sleeps when working on the afternoon shift. Whether or not this productivity decrease is indeed due to relative sleep deprivation, these results emphasize that it is not only the night shift that can pose problems for shift workers. Although relatively little disruption of circadian rhythms is likely to occur on the morning shift, the requirement to get up early together with social pressures to retire at a normal time may result in a substantial sleep deficit (Dahlgren 1981).

Finally, it should be emphasized that the available literature suggests that a rather different pattern of results might have emerged had the shift workers been performing a more memory-loaded task (Folkard and Monk 1979). Nevertheless, the present results indicate that a weekly rotating shift system may be a relatively good one from the point of view of simple perceptual-motor productivity on the night shift. More rapidly rotating shift systems might fail to capitalize on the beneficial effects of circadian adjustment, while more slowly rotating or permanent systems might exacerbate the detrimental effects of sleep deprivation.

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On s'accorde sur le fait que le rendement et la sécurité sont détériorés au cours de la période de travail de nuit. On a identifié deux facteurs principaux qui pourraient en être responsables. D'une part, le rythme circadien de la performance à des tâches simples atteint un niveau bas au cours de la nuit et ne s'ajuste que lentement durant une période assez longue de postes de nuit. D'autre part, les périodes des sommeil diurne que les ouvriers postés prennent entre deux postes de nuit ont une durée courte et peuvent être à l'origine d'une dette cumulée de sommeil. Le premier facteur permettrait donc de prédire une amélioration du rendement durant une période

étendue de travail de nuit, alors que le deuxième facteur prédirait plutôt le contraire. On a examiné le rendement de 53 ouvrières postées, ainsi que les habitudes de sommeil de 30 d'entre elles, au cours d'un système de rotation hebdomadaire, afin d'étudier la contribution relative de ces deux facteurs. Nos résultats suggèrent que l'ajustement circadien au travail de nuit est le facteur qui domine durant les trois à quatre premières nuits de travail successives, mais que les effets de la privation de sommeil peuvent ensuite survenir et faire décliner le rendement au cours des nuits qui suivent. Ces résultats montrent également que la privation de sommeil, mais non l'ajustement circadien, peut affecter le rendement de certains ouvriers lorsqu'ils sont au poste du matin.

Produktivität und Sicherheit können sich in der Nachschicht zweifellos vermindern. Zwei Hauptfaktoren, die hierfür verantwortlich sein könnten, wurden ermittelt. Zum einen ist die circadianrhythmische Leistungsfähigkeit, auch für einfache Aufgaben, nachts auf einem niedrigen Niveau und steigt nur langsam über mehrere Nachschichten an. Zum anderen ist der Tagschlaf der Schichtarbeiter, zwischen den Nachschichten genommen, von verminderter Dauer, so daß eine cumulative Schlafschuld bei aufeinanderfolgenden Nachschichten entstehen kann. Aus ersterem läßt sich folgern, daß die Leistungsfähigkeit bei aufeinanderfolgenden Nachschichten zunehmen könnte, während letzteres nahelegt, daß sie abnimmt. Wir untersuchten die Leistungsfähigkeit von 53 Schichtarbeiterinnen und die Schlafgewohnheiten eines Teilkollektivs von 30 Frauen, bei einem wöchentlich rotierenden Schichtsystem, um den relativen Beitrag dieser beiden Faktoren zu ermitteln. Unsere Ergebnisse legen nahe, daß die circadiane Anpassung an die Nacharbeit in den ersten 3 oder 4 aufeinanderfolgenden Nachschichten dominant, das Schlafdefizit in weiteren Nächten jedoch zu einer Abnahme führt. Die Ergebnisse zeigen auch, daß das Schlafdefizit, nicht die circadiane Anpassung, die Leistungsfähigkeit einiger Arbeitspersonen in der Frühschicht beeinflußt.

生産性と安全性が夜勤では損なはれるのは殆ど疑いがない。この原因と思われる2つの要因が明らかにされた。1つは、少なくとも簡単な作業での成績の概日リズムで、これは夜間では退潮期にあり夜勤を続けるうちにゆっくりとしか調整されない。もう1つは、夜勤と夜勤と間の交替作業者の昼間睡眠で、この睡眠は短く、従って夜勤を続けるうちに睡眠負債が累積する。夜勤継続時の生産性は、前者では向上し、後者では低下すると予測される。一週間交替制の53名の女性交替作業者の生産性とそのうちの30名の睡眠習慣を調査し、2つの要因の相対的貢献度を評価した。その結果によると、夜勤に対する概日調整は最初の3、4晩の夜勤における主要因であるが、断睡効果はその後の夜勤で減少する。朝勤の作業者の生産性は概日調整ではなく断睡に影響されていることも示されている。

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