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Shift Work: Circadian Rhythm Disruption and Beyond

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Shift work is an indispensable part of modern life. It is scheduling of work, in a rotating or a continuous or a discontinuous fashion, in which a group of workers succeed each other at the same workstations in shifts. It has been indisputably accepted that shift work produces a number of detrimental effects on human health. It induces disruption of circadian rhythm and causes several sleep-related and social problems. It also retards performance and increases the chance for the occurrence of major industrial accidents. This article provides an overview of the literature on shift-work research and underlines the cost of shift work that prominently includes disruption of circadian rhythms and impairment of sleep. The article also focuses on the possible ways that may lessen the impacts of shift work, by way of minimizing occupational health hazards among shift workers and augmenting workplace safety and productivity.

Key Words: Shift work, Circadian rhythm disruption, Sleep disorder, Psychosocial problem, Clinical problem, Performance impairment, Chronotype, Shift-work optimization.

Introduction

Nearly one fifth of the total global work force works in shifts. Working shift is no longer a choice rather is a necessity of employment in organizations like hospitals, the police, the military, the transport industries and several factories. Recently, in India, the BPO (Business Process Outsourcing) and call centers have become extremely popular and recruit youngsters in large number (BPO India.org 2004). Mostly employees of these centers work in the night. The population of shift workers is growing steadily everywhere and the shift work has become an indispensable part of modern life.

The term shift work defined as an arrangement of work hours that uses two or more teams (shifts) of workers in order to extend the hours of operation of the work environment, beyond that of the conventional office hours. The varieties of shift work include stable/permanently displaced work hours in which the work schedule used does not require a person to normally work more than one shift (including night work), rotating shift work in which an individual is normally required to work more than one shift, changing from one shift to another and unscheduled work hours. On call shift is also a special form of shift work, where in case of emergency the particular group of workers are called for their duties. The most widespread shift system is when production is organized in eight-hour shifts, called morning, evening and night shifts (Knutsson 1989).

Humans exhibit overt rhythms in several physiological and behavioural variables, including core body temperature, neuroendocrine secretion, sleep organization and propensity, subjective alertness and cognitive performance (Ahasan et al. 2001). All these rhythms have endogenous circadian component and remain in synchrony with the light dark cycle and other oscillatory components of the environment (Aschoff 1960, 1981, Cardinali 2000). This phenomenon is called external synchronization. Shift work and rapid travel across several time zones (jet lag) are the best-known situations when synchronization breaks down and internal rhythms no longer oscillate with frequencies similar to the environmental cycles. In this state internal bodily rhythms are termed externally desynchronized (Aschoff et al. 1975). However, there are instances when many bodily rhythms

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despite being externally desynchronized remain internally synchronized. Here, internal rhythms run with similar yet non-circadian frequencies. However, in shift workers, complete temporal disorder characterized by both external as well as internal desynchronization has been reported (Reinberg et al. 1984, Pati & Saini 1991, Scott 2000, Kuhn 2001).

Consequences of Shift Work

Disruption of Circadian Rhythm

There is persuasive evidence to prove that shift work compromise human health and safety by disrupting the circadian rhythm. The later leads to reduced alertness and numerous alterations in behaviour and physiology of the subject. There are large numbers of research papers that depict disruption of the circadian rhythm in a wide array of variables among shift workers (Folkard et al. 1983, Reinberg et al. 1984, 1988, 1989, Motohashi 1990, Pati & Saini 1991, Gupta & Pati 1993, 1994a, Gupta et al. 1997). This phenomenon has been documented in various physiological rhythms, namely axillary temperature or oral temperature (**figure 1**) or skin temperature, heart rate, subjective fatigue, attention and drowsiness, peak expiratory flow and grip strength of both hands in shift workers from oil refinery, steel manufacturing, chemical engineering, photographic film manufacturing and cement industries (**figure 2**) (Reinberg et al. 1984, 1988, 1989, Motohashi et al. 1987, Chandrawanshi & Pati 2000). Further, the same has been reported for circadian rhythm in oral temperature, drowsiness, heart rate and performance in shift working Indian nurses (Pati & Saini 1991, Gupta & Pati 1994a, Gupta et al. 1997). Disruption of circadian rhythm in estimation/ judgment of short-interval time duration (TE_{10sec}) has also been documented among shift workers (Pati & Gupta 1994). Time estimation is an ability in humans to perceive the passage of time, as they perceive space, differently at different time of the day. The impairment of this ability in shift workers may produce number of detrimental effects both at the levels of individuals' performance, and safety and productivity of the organization.

The disruption of circadian rhythm in any given variable essentially reflects a change in its frequency (f) or period (τ). In this case τ (internal period of the rhythm under investigation) is not equal to the T (period of the *zeitgeber*, the external time giver). However, alteration in the period may accompany with the changes in three other important parameters of circadian rhythm, such as its phase (the timing of the highest value), amplitude (half the difference between the highest and the lowest value) and 24-hour average (rhythm-adjusted mean). But, mere alterations in the latter three parameters not necessarily mean that there is a desynchronization. This implies that one can have a rhythm with a frequency/ period similar to the *zeitgeber* but with altered phase and/or amplitude and/or 24-h average.

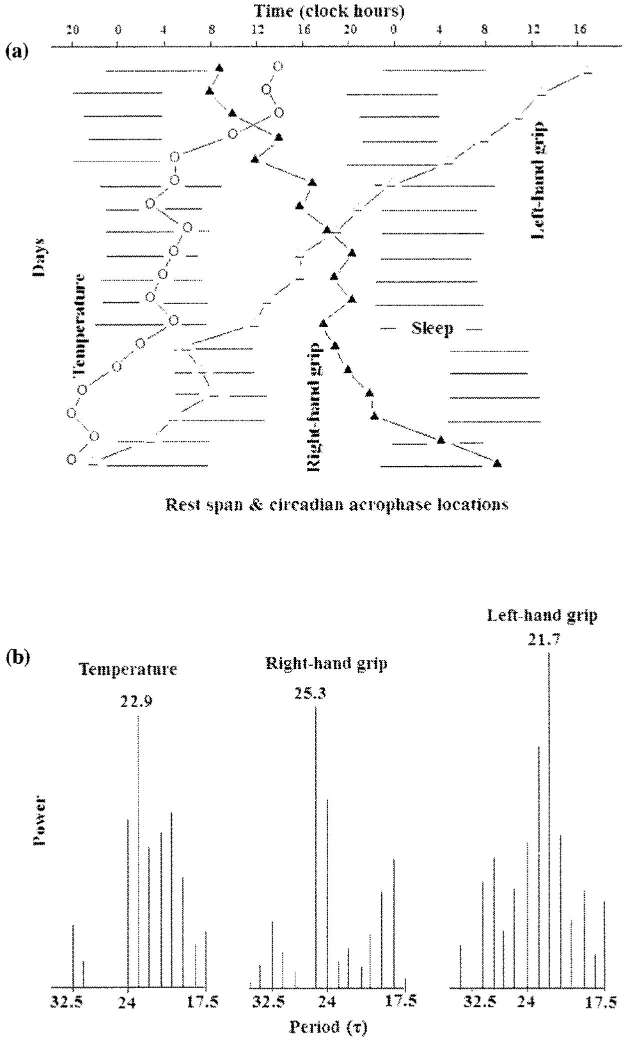


Figure 1 a, Rest span and circadian acrophase locations of three variables in a subject. Horizontal bar, Double plot of hours of rest span (from lights-out to lights-on). O, Acrophase location of oral temperature; ▲ , right- and D, left-hand grip strength. **b,** power spectra of the same variables. The tallest of the lines of any spectrum and the figure at 1a corresponds to the prominent period of that variable.

Subject: oil refinery operator; right handed; age, 31 years; shift working for 3 years; very poor tolerance to shift work (From Reinberg et al. 1988).

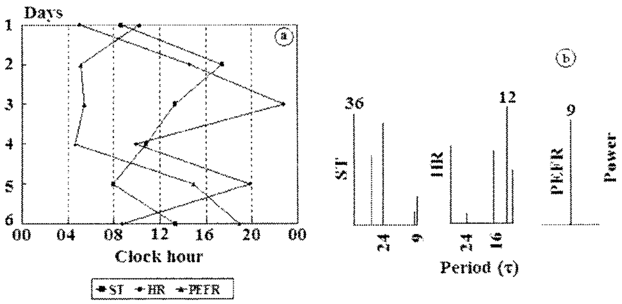


Figure 2 a, Day-to-day changes in acrophase of skin temperature (ST), heart rate (HR) and peak expiratory flow rate (PEFR) in a shift worker (SW#04) from a cement factory. All three rhythms exhibit external desynchronization. **b,** Power spectra of the same variables. The prominent periods differ from 24 h in all variables (Based on Chandrawanshi & Pati 2000).

Phase

Shift workers commonly experience a phase shift in circadian rhythm, i.e., the peak of the rhythmic function exhibits either advancement or a delay in its occurrence. This has been impressively demonstrated in case of body temperature rhythm (Aschoff 1978, Reinberg et al. 1984, Matsumoto & Morita 1987, Härmä et al. 1990). An illustrative example in **figure 3** demonstrates a phase shift in oral temperature rhythm of a steel plant worker (Gupta 1992). The subject exhibited the peak in its circadian rhythm in oral temperature at about 16:00 while he was working in the night shift. An advancement of about 8 hours in the peak of the same rhythm was registered when the subject worked in the afternoon shift thereafter. Similar phase shifts in the body temperature rhythm have been reported in older shift workers following night duty (Matsumoto & Morita 1987). Härmä et al. (1990) obtained comparable results in the oral temperature and sleepiness rhythms of the shift workers, irrespective of age, following their transition from the morning to the night shift. The magnitude of phase shift is influenced by several factors. The most crucial among others are their exposure to the type of work schedule and natural time cues (Arendt et al. 1995). The major effect of shift work involves a phase shift of the circadian rhythm resulting as consequence to a shift in the *zeitgeber*. Reinberg & Smolensky (1992) and Reinberg et al. (1984, 1988) observed an interesting relationship: the larger the phase shift the smaller is the amplitude.

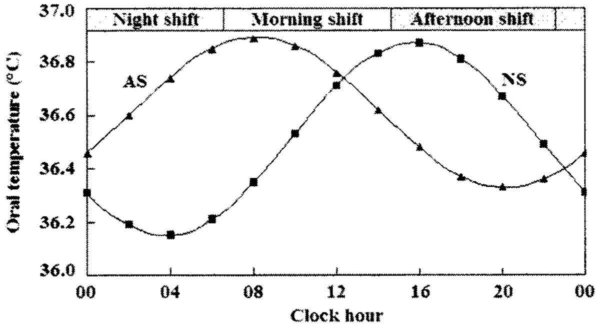


Figure 3. An illustrative example of phase shift in oral temperature (ºC) of a shift worker from a steel plant. A phase advance of the body temperature occurred in shift worker following night shift. AS, afternoon shift; NS, night shift.

Amplitude

The magnitude of alteration in the amplitude of circadian rhythm is more pronounced in shift workers as compared with those of the diurnal workers, when a longitudinal time series is under consideration. But, this phenomenon can be best viewed when the time series is sufficiently long. In short time series the day-to-day variability may mask the changes in amplitude. This aspect has been extensively studied in shift workers (Touitou et al. 1990; Reinberg et al. 1988). The former have documented smaller and larger circadian amplitudes respectively of serum cortisol and melatonin rhythms in shift workers than in controls. They also reported alteration in the amplitudes of prolactin and testosterone rhythms in shift workers with a fast rotating shift system. The latter group suggested that changes in the amplitude of circadian rhythm could be used as indices to determine the magnitude of rhythm desynchronization.

Chandrawanshi & Pati (2000) studied the circadian time structure of shift workers, from a cement plant, in two different spells. There was a lag of about 16 months between two spells. During this period the factory remained almost closed for nearly 8 months with moderate to low profile activities in the remaining months. At the time of the study in the first spell the shift workers had already experienced about 14 months of industrial slough. However, when the same shift workers were reexamined in the second spell after about 16 months they experienced about 30 months of cumulative industrial slumber that accompanied 8 months of near complete closure. However, during this period, shift workers were assigned shift duties, irrespective of the workload and activity of the factory. Despite on rotational shift duties, whenever there was no workload, they slept at their work places. In other words, they behaved reasonably like day workers with nocturnal sleep during the period between two spells of studies. Therefore, in the shift workers of the cement factory the once desynchronized rhythms in several variables became resynchronized. The process of resynchronization also accompanied an increase in the circadian amplitudes of these rhythms (Chandrawanshi & Pati 2000).

24-hour average

The 24-h average of a given rhythm may undergo a change when a shift worker is shifted from one work schedule to another. The magnitude of this change may also depend upon the direction of schedule rotation, for example clockwise versus counterclockwise rotation. Härmä et al. (1990) observed that the 24-h average of the oral temperature rhythm decreased slightly and that of the sleepiness rhythm increased highly significantly from morning to the second night shift in various age groups. The 24-h averages of several circadian rhythms have been shown to alter in shift workers. The 24-hour average of the random number addition speed (RNAS) rhythm increased in shift workers as compared to control subjects (Pati & Saini 1991, Gupta & Pati 1994a). RNAS reflects mental processing ability of an individual and varies as function of time of the day. An increase in the 24-h average in RNAS rhythm reveals a decrease in the mental processing ability. This suggests that shift workers took longer time than their day working counterparts to sum fifty pairs of random numbers (**figure 4**).

Consequences on sleep

Sleep disorder

Shift workers suffer from sleep disorder classified as *Shift Work Sleep Disorder* and placed under *Circadian Rhythm Sleep Disorders* as per the ICSD diagnostic and coding manual (Culebras 1992, Labyak 2002, Reid et al. 2004). Insomnia like sleep disorder is one of the major causes of concern among the shift workers (Czeisler et al. 1982, Tepas & Mahan 1989, Ohayon et al. 2002, Åkerstedt 2003). This abnormality is characterized by difficulty in falling and staying asleep. The rotating shift workers and night shift workers demand sleep during the day and stay in conflict with the periodic *zeitgeber*, specially light-dark cycle. In addition, these workers find it difficult to sleep during daytime due to noises at home and in the residential community (Åkerstedt 1988). The other reason is the displacement of the circadian wakefulness to trough timing where the sleep-promoting properties of the circadian rhythm are at their maximum (Åkerstedt 1987, 1995).

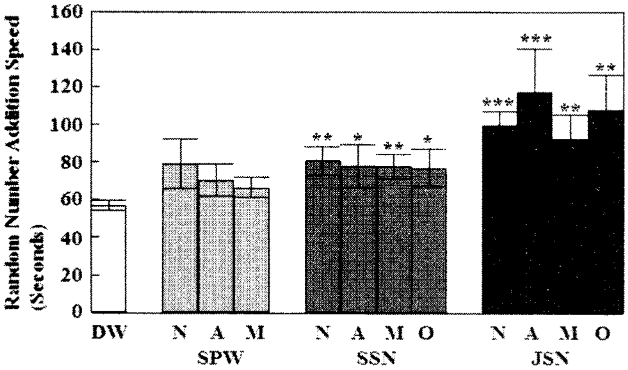


Figure 4. Twenty-four hour average ± 1 SE of random number addition speed (in seconds) in day workers and various groups of shift workers during different shifts. DW, day workers; SPW, shift workers from a steel plant; SSN, senior shift working nurses; JSN, junior shift working nurses; N, night shift; A, afternoon shift; M, morning shift; O, off day. $*p<0.05$; $**p<0.01$; $***p<0.001$ (Based on data from Gupta & Pati 1994a).

Shift work in the night leads to acute partial sleep deprivation, impairment in alertness and decreased productivity. What effect does sleep deprivation produce on circadian rhythm? Fröberg et al. (1975) have reported that a 72-hour sleep deprivation does not obliterate circadian rhythms in adrenaline excretion and fatigue ratings. However, noradrenaline and performance rhythms were found to be irregular. Continuous work in the night shift may lead to chronic partial sleep deprivation. Glenville et al. (1978) have shown that one night sleep deprivation impairs performance in both choice reaction time (CRT) and simple reaction time (SRT). The former is an indicator of sensorimotor performance, whereas the latter assesses the alertness of the subject, the ability to concentrate and to react to an expected event. In addition to performance decrements, chronic sleep deprivation, may lead to many other clinical complications. It has been reported that total sleep deprivation may lead to fatal/devastating consequences, such as death as reported in non-human primates (Rechtschaffen et al. 1983). The association between shift work and sleep disruption results in adverse medical and psychological consequences (Phillips et al. 1991). A majority of shift workers admit to having experienced involuntary sleep on the night shift, whereas this is rare on day-oriented shifts (Åkerstedt et al. 1983, Coleman & Dement 1986).

The proportion of shift workers suffering from sleep disturbances is usually above 50% compared to 5-20% for day workers (Åkerstedt 1984). The sleep disturbances reported by shift workers are both qualitative and quantitative and may lead to increased use of alcohol and hypnotics (Phillips et al. 1991). A number of studies demonstrated that compared to the permanent day workers, sleep quality and quantity seem to be poorer for the rotating shift workers (Regestein & Monk 1991, Siebenaler & McGovern 1991, Chang et al. 1993). Tilley et al. (1982) and Fischer et al. (1997) suggested that the quantity and quality of sleep are degraded and deteriorated as a result of working at night.

Sleepiness

Sleepiness has been defined as a drive towards sleep (Dement & Carskadon 1982) and is traditionally expressed in subjective terms, although there are clearly pronounced behavioural and physiological expressions. Poor sleep, both quantitative and qualitative, induces sleepiness. It has been documented that the main causes of sleepiness in workers working in irregular work hours are, the alteration in the peaks of circadian rhythms (Folkard & Åkerstedt 1992, Åkerstedt 1995), the amount of prior wakefulness (Folkard & Åkerstedt 1992), the length of work shift (Rosa et al. 1989), and the speed of rotation of work shift (Knauth 1993).

A significant circadian rhythm has been documented in subjective drowsiness/sleepiness in apparently healthy human subjects (Reinberg et al. 1989, Gupta & Pati 1994a, b). Chandrawanshi (1998) demonstrated drowsiness rhythm in 8 day-active subjects with a peak located between 22.8 h and 00.2 h (**figure 5**). Czeisler et al. (1980) and Zulley et al. (1981) demonstrated that in subjects, who have the option to select their own preferred sleep/wake pattern, under total isolation from external time cues, exhibit circadian rhythm of sleep. Dijk & Czeisler (1994) suggested that a natural disposition of circadian rhythm in sleep seems to consolidate sleep and wakefulness. In case of shift workers, rhythm in sleepiness desynchronizes externally as well as internally (Reinberg et al. 1989, Gupta & Pati 1994a).

Shift workers do have problems with sleep management specially because they attempt to have sleep at chronobiologically unsuitable time of the day. The problems include difficulty in initiating sleep and staying asleep. According to Czeisler et al. (1980) sleep is very difficult at the peak (maximum) of the body temperature rhythm and very easy at its nadir (minimum). Shift work disrupts the normal relation between rest/activity and the circadian regulation of bodily functions (Åkerstedt 1985). Among the most obvious effects of this disruption are disturbed sleep and increased sleepiness (Rutenfranz et al. 1981, Åkerstedt 1984). Åkerstedt (1992) reported sleepiness peak during the early morning in between 04.00 and 07.00 in night shift workers. A secondary peak has also been observed in sleepiness in the afternoon (Åkerstedt & Gillberg 1982). Lavie (1985) has documented a 24-h rhythm in sleep propensity function (SPF). A 7-minute sleep trial is applied every 20 minutes around the clock. The amount of sleep obtained in each trial, plotted as function of time, results in SPF. The largest peak occurs at night (around 04.00 h) while a second peak, smaller than the night one, occurs in the afternoon (around 16.00 h).

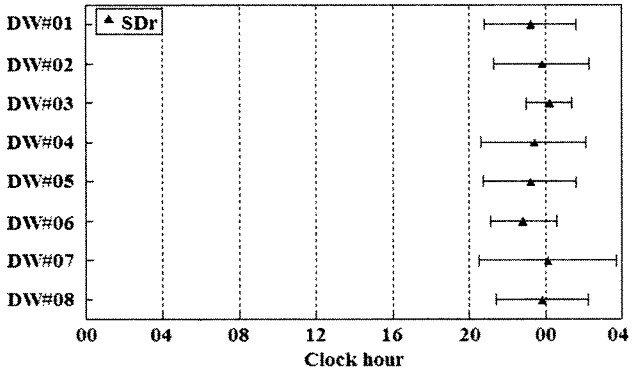


Figure 5. Acrophase map for subjective drowsiness (SDr) rhythm in eight day-active subjects. Each point represents the estimated maximum (acrophase, Ø) of each subject over a 24-h time scale, with midnight as phase reference. The horizontal line defines the 95% confidence limits of acrophase. Acrophase located between 22.8 h and 00.2 h.

It has been suggested that the majority of shift workers experience sleepiness during the night-shift work, whereas day work is associated with no or marginal sleepiness (Åkerstedt 1995, Czeisler & Dijk 1995). Usually, the relation of subjective sleepiness with performance is a close one, with major performance lapses occurring at the higher levels of sleepiness (Gillberg et al. 1994). Åkerstedt (1995) emphasized that not only sleepiness is experienced during the night shift, a considerable increase in sleepiness has also been observed in workers while they return to day work soon after the night shift. Furthermore, when the starting time of the morning shift is advanced, more sleepiness is experienced during the day (Kecklund et al. 1994). This also decreases sleep length and sleep quality (Moors 1990). An early start of morning shift at around 0600 has particularly deleterious effects upon alertness (Tucker et al. 1998).

Sleep length

In humans, the basic amount of sleep need, notwithstanding large inter-individual differences, is about six hours per night (Ferrara & De Gennaro 2001). Shift work in the night decreases sleep length and may result in an increase in sleep complaints (Tilley et al. 1982, Barak et al. 1995). The reduction in sleep length is perhaps one of the most important problems that night shift workers often encounter. According to Kripke et al. (1979) short sleep lengths may lead to decreased life expectancy. However, recent evidence shows that habitual sleep duration greater than seven hours is associated with increased rates of mortality (Grandner & Kripke 2004). This aspect needs further attention to have a generalization. Tepas & Carvalhais (1990) reported that permanent night shift workers sleep longer on their days off, but they still sleep almost 4 hours less per week than the day workers do. Similar results have been reported in plenty (Tilley et al. 1982, Tepas & Mahan 1989, Folkard et al. 1990, Tepas & Carvalhais 1990, Totterdell & Folkard 1990). Dahlgren (1981) has found that sleep length reduces to 4.5 h on the first night shift, but increases again over six consecutive night shifts to reach a level of 5.7 h. It has also been reported that sleep length decreased during morning and night shifts than all other workdays and days off (Fischer et al. 1997, Gupta et al. 1997). Further, it has been documented that workers on the afternoon/evening shifts sleep the longest, workers on the day shift sleep slightly less, and night shift workers sleep the least (Åkerstedt & Torsvall 1981, Williamson & Sanderson 1986, Tepas & Carvalhais 1990). Workers exposed to *on call shift work* have also shorter sleeping time (Imbernon et al. 1993). It has been shown that sleep duration is dependent on the time of sleep onset (Czeisler et al. 1980, Zulley et al. 1981). It has been found to be the shortest among shift workers if it is started some hours after the circadian trough in activity/ body temperature (?) rhythm, whereas sleep started close to the trough is somewhat longer (Foret & Lantin 1972). This conclusion is also supported by field studies that show a decrease in sleep duration when sleep onset is delayed after the night shift (Knauth & Rutenfranz 1981). Sleep on morning shift days can also be shortened, especially if work starts early in the morning (Radosevic-Vidacek & Vidacek 1994). Reduction in sleep length is associated with decrements in performance (Fröberg et al. 1975, Gillberg & Åkerstedt 1994), decreased alertness (Carskadon & Dement 1982), and higher incidence of accidents and increased probability of precipitation of health problems among/ by night workers (Tepas & Mahan 1989, Tepas et al. 1993). Changes in mood state, increased feelings of fatigue, sleepiness and irritability, inability to concentrate, and periods of misperception also occur on account of reductions in sleep length in night shift workers (Williamson & Sanderson 1986, Tepas & Carvalhais 1990).

It has been demonstrated that rotational shift workers report more fatigue than do day workers (Fröberg et al. 1975, Åkerstedt 1988, Alfredsson et al. 1991). Usually, the fatigue is particularly widespread on the night shift, hardly appears in the afternoon shift, and is intermediate on the morning shift (Gupta & Pati 1993). Kecklund et al. (1994) suggested that morning shifts (starting between 04.00 and 07.00) is usually perceived as extremely fatigue inducing. Rosa and Colligan (1987) demonstrated that the 12-h night shift produces higher ratings of fatigue than 8-h night shifts.

Sleep as function of sex and age

Female shift workers have been reported to experience more sleep disturbances than men. They suffer from drowsiness more frequently during work (Rotenberg et al. 1998). The problems of drowsiness become severe when they work in the morning shift (Rotenberg et al. 1998). Sleep length was reported to be shorter in case of female night shift workers. The added responsibilities of looking after the home and children may aggravate sleep problems and tiredness in female shift workers, thus adversely affecting their health (Gadbois 1981, Tepas et al. 1993, Chan 1994). In addition, female shift workers had higher complaint rates at every age (Marquie et al. 1999). A positive correlation between the magnitude of sleep problems and age is a natural phenomenon (Marquie & Foret 1999, Marquie et al. 1999, Neubauer 1999). These authors reported that more is the age poorer is the sleep quality. Normally, aging is associated with earlier awakening and decreased sleep consolidation at the end of the night (Duffy & Czeisler 2002). Humans at the age of 50 and above tend to use hypnotics frequently to get rid of their sleep problems (Marquie & Foret 1999). The problems of sleep are usually magnified if aged subject happens to be a shift worker (Foret et al. 1981, Heslegrave & Rhodes 1997, Marquie & Foret 1999). According to Marquie et al. (1999) sleep quality becomes poorer in shift workers at 32- and 42-years of age. Middle-aged shift workers have been shown to experience more superficial sleep (Torsvall et al. 1981). The cause of the poor adjustment of the older shift workers to shift work has been attributed to the greater amount of sleep disturbances (Foret et al. 1981). Sleep length may decline with age and the rate of decline has been shown to be the largest among the night workers (Åkerstedt & Torsvall 1981, Pavard et al. 1982).

Psychosocial/psychophysiological problems

Shift work has been known to influence family and social life significantly. Shift workers experience a number of psychological disturbances and family dysfunctions (Åkerstedt 1990, Chang et al. 1993). The irregular work hours affect the whole family: the worker, his/her spouse and children. The displacement of the shift worker in time and space can result in domestic inconvenience both for the individual and spouse, as well as other members of the family, to the extent that it could have detrimental effects on family relationships (Walker 1985). The difficulties in social life are mainly due to an inharmonious relationship between work schedules of shift workers and those of other day workers. Thus it is difficult for shift workers to participate in regular meetings and in other social events/activities, which are usually scheduled in the evening or on weekends (Carpentier & Cazamian 1977).

Although there is no evidence that shift work is related to manifestation of psychiatric ailments, reduced sleep length and sleeping less than seven hours per night has been reported to be associated with minor psychiatric disorders in medical students of Brazil (Hidalgo & Caumo 2002). Therefore, it would be difficult to rule out a possible association between shift work and psychiatric disorders especially since shift workers have decreased sleep length. It has been documented that various psychosomatic and psychoneurotic complaints are more common among shift workers (Koller et al. 1978, Oginska et al. 1993). Shift workers also complain about depression, helplessness and stress more frequently. Healy and Williams (1988) and Healy et al. (1993) proposed that the psychosocial disruptions leading to depression, may produce a state of circadian disrhythmia and consequently it is likely to lead to helplessness type of cognition as a result of disturbances in neurovegetative functions. A relationship between shift work and anxiety, and between shift work and depression has been established (Healy et al. 1993). Costa et al. (1981) in a group of male textile workers, found that 72% of workers who gave up permanent night work did so as a result of neurotic troubles. In addition, neurotic disorders were five and 16 times more likely to occur in three-shift workers and permanent night workers, respectively, than in day workers. There are also common core complaints in shift work and depression, such as disturbed sleep, disturbed appetite, lethargy, apathy, poor concentration and neuroticism (Healy & Waterhouse 1991). Thus, it seems clear that the depression-induced psychosocial dislocations, brings about dysrhythmia (Tsujimoto et al. 1990, Souetre et al. 1991).

According to Frese & Semmer (1986) stress at work is an important predictor of ill health, independent of shift work. They argue that the impact of stress at work (working conditions), other than shift work itself, on ill health deserves more concern than what is being considered so far. Kandolin (1993) reported that female nurses in three-shift work experience more stress symptoms and often this leads to less enjoyment in their work than women in two-shift work. Male nurses reportedly have the same amount of burnout and stress in both two- and three-shift work. It has also been noted that the early start of the shift puts the nurses under considerable stress (Bauer 1993). An important relationship has been detected between night shift dose (the actual number of remunerated night shifts) and psychosocial stress (Cervinka 1993). Taking into account the worker's well-being and health, the result suggests that psychosocial and environmental stress factors at work act independently from shift-related stress factors. He also found a moderate correlation between night shift dose and other variables, such as stress at work, job satisfaction, and unspecific complaints.

Of the profile on mood states, the scores for depression and fatigue have been found to be significantly higher after a night on call (Engel et al. 1987). Similarly, a decline in reaction time, and a deleterious change in mood scales have been reported after a night of emergency admission call (Deary & Tait 1987, Orton & Gruzelier 1989). Of the mental health, it has been reported that I-shift workers enjoy more degree of positive mental health than the II- and III-shift workers. Further, positive mental health is better in II-shift workers than III-shift workers (Kumar 1995). However, Kumar (1995) did not specify the timings of various shifts and probably ignored the fact that subjects involved in his study are rotational shift workers. Now question arises: does the mental health status keep on oscillating as the shift workers move from one shift to another at weekly intervals? This perhaps seems unlikely and Kumar's work needs to be reinterpreted. Also, positive mood ratings have been noted to be the lowest and negative mood ratings the highest on the night shift in firefighters and that the opposite are true on the afternoon/evening shift (Paley & Tepas 1994).

We examined the effects of three-shift work schedules of shift workers on anxiety and mental health of their day active spouses and children. The levels of anxiety were found to be significantly higher in spouses and children of shift workers as compared with their counterparts sampled in the family of day workers (**figure 6**). Also the status of mental health was significantly low among spouses of shift workers as compared with their day working counterparts (Pati & Chandrawanshi 2001). This indicates that disturbed daily schedules of shift workers may modulate anxiety and mental health in their spouses and children.

A model proposed by Rutenfranz et al. (1976) suggests that the major disease mechanism is brought about by disturbed circadian rhythmicity, which leads to stress. The stress reaction is responsible for complaints, such as lowering of well-being and probably adverse health states. The intervening variables, such as housing standards, sleeping conditions, the family situation, personality, and psychological adaptability are also responsible for such complaints. These intervening factors determine whether a particular person is able to

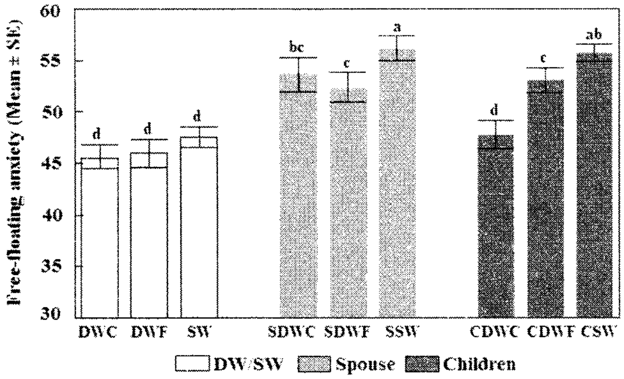


Figure 6. Average levels of free-floating anxiety in various groups of workers and their spouses and children. DWC, day workers from city; DWF, day workers from factory; SW, shift workers; SDWC, spouses of day workers from city; SDWF, spouses of day workers from factory; SSW, spouses of shift workers; CDWC, children of day workers from city; CDWF, children of day workers from factory; CSW, children of shift workers. Bars having similar alphabets are not statistically significant from each other at $p<0.05$ (Based on Duncan's multiple-range test).

cope with shift work successfully (Rutenfranz et al. 1981). Social environment may also play a key role in an independent pathway, from shift work to disease (Haider et al. 1988).

Shift worker's opportunities are restricted from full participation in the social activities, which are designed mostly for daytime work. Aschoff et al. (1971) have documented that social cues are of primary importance for retention of the circadian rhythms. Giedke et al. (1974) have also suggested that the social *zeitgebers* are capable of sustaining human circadian rhythms. According to Barton et al. (1994) the change from a delaying to an advancing system results in an increase in sleep difficulties, but a decrease in social disruption. The decrease in social disruption has been thought to result from the specific sequence of the shifts and the discontinuous nature of the shift system, particularly, the long weekend off every third week. Chan (1994) has reported that about 20% of those who start shift work eventually find it difficult to continue because of social rather than medical reasons. Workers exposed to on-call shift work have also disturbed psychological equilibrium and family and social life (Imbernon et al. 1993). Åkerstedt (1990) indicated that shift work that involves night shifts strongly influences the psychology and psychophysiology of the individual.

Clinical problems

Desynchronization of circadian rhythms, attributed to shift work, may lead to several clinical complications. It may produce disastrous chronopharmacologic effects, such as impaired metabolism and impaired responsiveness to medications (Phillips et al. 1991). It has also been reported that it may make shift workers more prone to sufferings notably myocardial infarction, exacerbation of insulin-dependent diabetes, epilepsy, and neuropsychiatric disorders (Brief & Scala 1986, Phillips et al. 1991, Fischer et al. 2002). Phillips & Brown (1992) have documented that disrupted circadian rhythms and fatigue from rotating shifts have been implicated as a cause of traumatic injuries. According to Monk (1988) desynchronization of circadian system affects the mental and physical health, longevity of the worker as well as public safety. However, there has been no categorical proof to suggest that prolonged shift work may alter longevity of shift workers. Michel-Briand et al. (1981) documented more cases of depression and affective illness in retired shift workers than in retired day workers, in whom cardiovascular and locomotor problems have been reported to be more predominant.

The health problems associated with shift work can broadly be classified as: disturbances of sleep, and impaired physical and psychological health. The detrimental effects of shift work are usually magnified with the age, the critical age being on an average 40-50 years (Koller et al. 1978, Åkerstedt & Torsvall 1981, Foret et al. 1981). Our studies reported a statistically significant age–related decline in peak expiratory flow rate (one of the important measures of the pulmonary functions) in shift workers as compared to day workers (Chandrawanshi & Pati 1996, Gangopadhyay et al. 1998). Deterioration in health has also been noticed after many years of shift work in some shift workers (Angersbach et al. 1980, Costa et al. 1981). In addition, occurrence of the health problems was found to be earlier in shift workers as compared with their day working counterparts (Koller 1983). Costa et al. (2001) reported a significant increase of low back pain, gastritis, headache and haemorrhoids in bus drivers working in a fast rotating 4-shift system. Further, an increased risk of cancer has also been documented in shift workers. A moderate increase in breast cancer risk among the female shift workers was associated with the length of shift work experience (Schenhammer et al. 2001). They reported that the risk was further increased among women who have experience of more than 30 years of shift working. Exposure to light at night may be associated with the risk of developing breast cancer (Davis et al. 2001). Light during nighttime suppresses the nocturnal production of melatonin, which in turn could increase the release of estrogen by ovaries that may lead to the risk of breast cancer. In addition, shift work has also been found to be associated with menstrual irregularities, reproductive disturbances, risk of adverse pregnancy outcome and sleep disturbances (Nurminen 1998, Labyak et al. 2002).

Cardiovascular complications

In industrialized countries, one of the most common causes of death is cardiovascular disease that includes myocardial infarctions (Muller et al. 1985), angina pectoris (Valle et al. 1988), sudden cardiac death (Willich et al. 1987) and stroke (Tsementzis et al. 1985). A circadian variation in the incidence of heart attack with a major peak in the morning hours and a minor peak in the late-evening hours have been observed by these authors. These findings strengthen the hypothesis that an increase in the coronary tone or spasm in the morning could be attributed to the early morning incidence of acute symptoms of coronary heart disease (CHD) (Muller et al. 1985).

Shift work has been reported as a risk factor for cardiovascular diseases (Knutsson 1989, Boggild & Knutsson 1999, Knutsson et al. 1999, Knutsson & Boggild 2000, Ha et al. 2001, Munakata et al. 2001). The risk of CHD was found to be approximately 1.5 times higher in night shift workers as compared to day workers (Morgan et al. 2003). Similarly, Angersbach & co-workers (1980) have found a slight but nonsignificant excess of cardiovascular disease (CVD) morbidity among shift workers (16.8%) as compared with their day working counterparts (14.8%). Holmes et al. (2001) demonstrated that shift work has direct and unfavorable effects on cardiac sympathetic and parasympathetic activity. This might be a possible factor that accentuates cardiovascular risk. In addition, Koller et al. (1978) reported statistically significant difference between shift workers (20%) and day workers (7%) for morbidity due to diseases of the circulatory system.

Further, a dose-response relationship has been witnessed between length of shift work experience and cardiovascular disease in oil refinery workers (Koller 1983). Knutsson et al. (1986) reported the same phenomenon at least during the first two decades of shift working. The relative risk of ischaemic heart disease (IHD) has been noticed to fall sharply after twenty years of shift work. In case of female shift workers an increased risk of coronary heart disease has been documented after exposure to 6 or more years of shift work (Kawachi et al. 1995).

There are several factors that may increase the risk of developing cardiovascular diseases. Knutsson & Zamore (1982) and Koller et al. (1978) have demonstrated an increased prevalence of risk factors for CHD in shift workers. Knutsson & Boggild (2000) proposed a model that depicts social problems, behavioral change, and disturbed circadian rhythm as the main shift work pathways to CHD.

Shift work is associated with certain disturbances in the social environment, which might lead to stress that in turn causes the development of cardiovascular disease. Study conducted in Swedish men documented that high stress was associated with risk factors, such as hypertension and atherogenic lipids, for CHD (Peter et al. 1999, Peter & Siegrist 2000). An association between hypertension and rotational and/or permanent night work has been established (Knutsson and Zamore 1982, Kitamura et al. 2002). Ohira et al. (2000) found an increased level of systolic blood pressure among Japanese shift workers. An increasing trend of systolic and diastolic blood pressure has been associated with the duration of shift work (Ha et al. 2001). In contrast, several studies do not show any relationship between blood pressure and shift work (Knutsson 1989, Boggild and Knutsson 1999).

The most common behavioral problems associated with shift work are smoking and unhealthy food habits. Numerous studies have shown that shift work is associated with smoking behaviour (Rosen et al. 1987, Knutsson 1989, Knutsson & Boggild 2000). Shift workers exhibit a predilection for a smoke thus making them vulnerable to CHD (Williamson & Sanderson 1986). It has been categorically demonstrated that an increase in the frequency of smoking might increase the relative cardiovascular risk by 10% if this behaviour is retained constantly for about 20 years (van Amelsvoort 2000). The type of work and industry may play important role in the development of smoke addiction. For example, a boring task (e.g. mail sorting, watching screen with "nothing" to do) may favour smoking, while in plants of high-risk industries (e.g. Oil refinery) smoking is strictly forbidden. Therefore, behavioural problems among shift workers cannot be generalized easily.

Lennernäs (1993) demonstrated a difference between shift and day workers with regard to meal frequency and the timing of meal intake. In addition, dietary intake has been reported to be lower during night shift than during morning or afternoon shift (Lennernäs et al. 1994). The redistribution of food intake from diurnal eating to nocturnal eating elevates serum total cholesterol and LDL; in contrast it decreases HDL, thus increasing the risk for cardiovascular diseases (Lennernäs et al. 1994). Even if the dietary intake and quality is similar in day workers as well as shift workers, there are still differences in eating habits that might contribute to differences in the levels of serum lipids (De Backer et al. 1987, Roman et al. 1992). This makes night workers susceptible to the cardiovascular risk (Knutsson 1989).

Disruption of circadian rhythm may also modulate the general susceptibility of shift workers to various diseases. Knutsson & Boggild (2000) provided evidence to suggest that sleep deprivation could deteriorate carbohydrate tolerance, a known mediator of metabolic and cardiovascular disease in shift workers.

Other important risk factors, namely cholesterol and serum triglyceride levels for CHD have also been studied extensively. Shift workers often have elevated cholesterol level (Knutsson & Boggild 2000). De Backer et al. (1984) found that workers with the most irregular working hours tend to have significantly higher total cholesterol. Knutsson (1989) has also found higher total cholesterol levels in shift workers than day workers, but the differences seem to be small and statistically insignificant. Furthermore, high serum triglyceride levels have been shown to be more prevalent among the shift workers than the day workers (Knutsson & Zamore 1982, Knutsson 1989, Roman et al. 1992, Karlsson et al. 2001). Meals at night may elevate serum triglyceride level a known risk factor for coronary artery disease (Carlsson & Böttiger 1981, Morgan et al. 2003). It has been reported that rotating shift workers have abnormally elevated norepinephrine levels, which if not controlled, may lead to higher cardiovascular risks (Ely & Mostardi 1986). Most of the studies discussed above provide evidence in support of a relationship between cardiovascular diseases and shift work.

Gastrointestinal complications

It is well known that diet has a relationship with the human health, for which not only the total intake of energy and nutrients, but also meal patterns (including frequency and time of its consumption) is of major importance (Halberg 1989, WHO 1990, Moore 1992). The timing of meal intake in relation to the circadian phase seems to have an impact on the uptake, digestion and metabolic responses. Meal timing is considered as an important socio-environmental synchronizer of the circadian rhythm in humans.

Rotating shift work and permanent night work by way of disrupting circadian rhythm, sleep-wakefulness and eating patterns in the long run cause gastrointestinal diseases. Alteration in eating habit is one of the risk factors that make shift workers more vulnerable to gastrointestinal disorders (Costa et al. 1981, Brief and Scala 1986, Knutsson et al. 1990). It includes changes in the frequency and timing of the meal, and the composition of the diet (Reinberg et al. 1979, Armstrong 1980, Adams & Morgan 1981, Verboeket-van de Venne & Westerterp 1991, Moore 1992). It can be argued that the gastrointestinal disturbances result from eating food at *wrong* time with abnormal patterns of gut motility and gastric acid secretion (Reinberg et al. 1979, Lenzi et al. 1985). It has been reported that irregular meal times may lead to poor *eating satisfaction,* among shift workers (Duchon & Keran 1990). However, there are contradictory reports suggesting no links between shift work, eating habit and associated complications (Lennernäs et al. 1990, Tepas 1990). Other possible risk factors which may lead to gastrointestinal disorders are: the lack of provision of hot food at night, therefore reliance on sandwiches, etc.; the tendency to nibble rather than take full meals; the higher intake of carbohydrate, caffeine and alcohol; and the higher consumption of tobacco. All these factors might play some role in increasing the prevalence of gastrointestinal disorders in rotational shift workers and permanent night workers. Gastrointestinal complaints of gastric upset, disturbed appetite, gas, constipation, diarrhea, poor eating, dyspepsia, epigastric pain, gastroduodenitis, peptic ulcer etc. are strongly correlated with shift work (Costa et al. 1981, Brief & Scala 1986, Kaliterna et al. 1990, Mazzetti et al. 1990).

More frequent occurrence of peptic ulcer disease in night workers could be attributed to the alteration in the pattern of secretion of gastrin/acidopepsin (Tarquini et al. 1986). Angersbach et al. (1980) reported an early occurrence of gastrointestinal disease among rotating shift workers than among day workers. Nocturnal eating has negative consequences on metabolism due to circadian rhythm factors. Food intake during night shift may coincide with the circadian nadir of most physiological functions, which in turn induce abnormal metabolic behaviour (Armstrong 1980, Halberg 1989, Lennernäs et al. 1994, 1995). Thus frequent night eating might lead to undesirable metabolic effects, such as increased levels of serum lipids or an increased body mass index in shift workers.

Cycle of sleep wakefulness maintains a constant phase relationship with different anabolic and catabolic processes. Therefore, an early night meal and early morning meal might disturb the circadian rhythm (Armstrong 1980). This phenomenon might, in turn, cause an imbalance in the endocrine rhythms associated with fat metabolism. Shift work unequivocally upsets the temporal distribution of meal timings, which in turn may act unfavorably both on the digestion and the psychophysiological conditions (Rutenfranz et al. 1977, Angersbach et al. 1980).

Non-clinical problems

Performance

It has been well established that shift workers are more susceptible to diminished performance and attentional deficits that considerably compromise public health, safety and productivity. Folkard & Tucker (2003) emphasized that safety declines over successive night shifts, with increasing hours on duty. Worker's inability to adjust to night work leads to negative safety and performance decrement. Studies conducted in various laboratories demonstrated that performance deteriorates during the nighttime (Tepas et al. 1981, Tilley et al. 1982, Monk & Folkard 1985, Folkard 1990, Purnell et al. 2002).

Several investigators have documented a significant circadian rhythm in performance variables (Folkard 1990, Pati & Saini 1991, Gupta 1992, Gupta & Pati 1994b). However, the characteristics of circadian rhythm in performance depend upon the nature of task being performed (Folkard 1990, Folkard et al. 1993). A circadian rhythm of performance in maximal speed of tapping and judgment/estimation of 10-second interval has been demonstrated (Aschoff 1978). However, the author did not specify the exact nature of tapping task. In case of shift workers, rhythm in performance variables desynchronizes externally as well as internally (Pati & Saini 1991). Gupta & Pati (1994a) reported rhythm desynchronization for two performance variables, namely finger counting speed and random number addition speed among shift working nurses. According to Tilley et al. (1982) night shift work is associated with reduced reaction time and poor mental arithmetic on the night shift. A higher error rate in performing addition problems and fewer signal detections during the night shifts have been demonstrated (Tepas et al. 1981). Bjerner et al. (1955) reported that error in meter reading over a period of 20 years in a gas works has been shown to have a pronounced peak on the night shift. A secondary peak has also been reported during the afternoon shift. Browne (1949) showed that performance declines in telephone operators on night shift. Similarly, Hildebrandt et al. (1974) found that locomotive engineers fail to operate their alerting safety device more often at night than during the day, with a secondary peak around 15:00. A study on air traffic controllers reveals that the performance impairment was significantly higher at the end of an 8-hour midnight shift than an 8-hour day and evening shift (Heslegrave & Rhodes 1997). Further, they emphasized that performance deterioration was similar for 8-hour midnight shift and 12-hour day or evening shift. A significant decline in speed of performance on a vigilance task by aircraft maintenance engineers on the first night shift has been reported (Purnell et al. 2002). It has also been demonstrated that shift-working nurses take longer time than their day working counterparts to perform finger counting and random number addition (**figure** 4) (Pati & Saini 1991, Gupta 1992). However, the rotating shift work has more adverse effect on performance than permanent night shift work (Alward & Monk 1990, Totterdell et al. 1994). The mean score on work-home conflict was found to be more in the rotating shift worker (Spelten et al. 1995) (**figure 7**). Performance decrement can also be assessed by task duration. It has been pointed out as a powerful determinant of decreased performance in a sleep-deprived person (Dinges & Kribbs 1991). Generally longer duration of a task is associated with the greater impairment in performance. Purnell et al. (2002), therefore, anticipated that the longer vigilance task might be more sensitive than the shorter duration simple reaction task in detecting performance decrement associated with sleep loss. Further, age was found to be associated with the performance deterioration for at least complex task, which was demanding, in attentional resources and memory load (Bonnefond et al. 2003). They reported that subjects of different ages cope with cognitive task, specifically for accuracy during the night, in different ways.

Sleep and sleep deprivation are intimately related to performance. Sleep management of people working in different sectors has a great bearing on performance, health, and safety. The detrimental effects of sleep

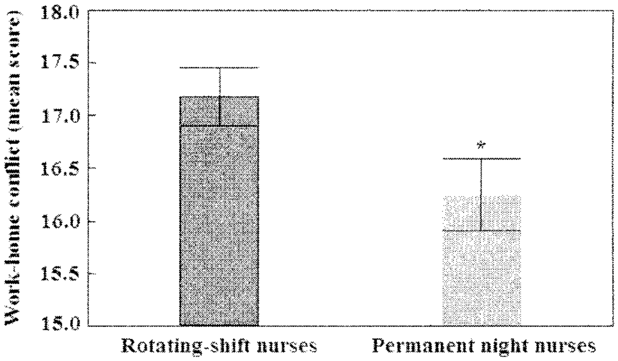


Figure 7. Mean score and standard deviation of work-home conflict for rotating-shift nurses and permanent night nurses. Rotating-shift nurses experienced significantly more work-home conflict. $*p<0.05$ (From Spelten et al. 1995).

deprivation on psychological and physiological performance have been reported (Himashree et al. 2002). Poor sleep quantity, quality and increased sleepiness have been considered as the key factors in modulating the performance of shift workers during the night shift (Frese & Harwich 1984, Siebenaler & McGovern 1991). In addition, duration of prior wakefulness before the start of the night shift has also been pointed out as one of the important predictors of performance and alertness. Decrement in performance on vigilance task increases with the increase in periods of sleep loss due to prior wakefulness (Pilcher & Huffcutt 1996, Williamson & Feyer 2000). Furthermore, in shift workers sleep deprivation and desynchronization of biologic rhythms lead to impaired physical performances (Smolensky et al. 1985). Gupta & Pati (1993) did not find an association between sleep deprivation and performance deterioration among shift working Indian nurses, who invariably slept past mid night while on duty. The results negate the hypothesis that implicates sleep deprivation or sleep debt as one of the major reasons for performance decrement (Gupta 1992, Gupta & Pati 1993). Could it be that sleep during the habitual timing, but not the length of sleep is imperative for normal human performance?

Psychophysiology of shift work involves circadian rhythm in sleep and wakefulness. People working either in rotating shifts or in a static/shift system have to work during the night at the low phase of their circadian rhythm. On retiring to bed although they fall asleep rapidly but are prematurely awaken due to the high phase of their circadian rhythm. This leads to severe sleepiness and reduced performance (Åkerstedt 1990). Gupta & Pati (1994a) examined the impact of shift rotation pattern on performance of shift workers. They observed that 12-h night shift system for 15 consecutive days was the worst one as compared to other two shift patterns, i.e., 12-h night shift for 1 week and 8-h rotational shift system (Gupta 1992, Gupta & Pati 1994a).

Performance efficiency on a night shift depends primarily upon several factors, namely (1) the demands of task; (2) the type of shift system and hence potential for both short and long term adjustment; (3) individual differences between shift workers in the degree to which their rhythms adjust to night work, and (4) sleep deprivation (Vidacek et al. 1986, Phillips et al. 1991, Gupta & Pati 1994a).

On duty injuries and/or accidents

Major industrial accidents occurred in the night. Table-1 illustrates some of the worst disasters that occurred past mid-night. All these are attributed to human factors (Lee & Cho 1982, Leigh 1986, Kreiger 1987, Novak et al. 1990, Folkard 1997, Rajaratnam & Arendt 2001, Ohayon et al. 2002).

Table 1: Time of occurrence of some major industrial accidents.

Accidents	Time
Bhopal gas tragedy	0:56
Chernobyl nuclear disaster	1:23
Three-mile island incident	4:00
Rhine chemical spillage	early morning
Gaisal train disaster, India	1:15

Single vehicle accidents have been found at a significantly higher rate during past-midnight, despite a considerable reduced traffic during night (Hamelin 1987, Ouwerkerk van 1987). Studies conducted on train drivers also revealed that they tend to overlook and/or issue more warning signals during the night shift.

Human errors are higher in the circadian trough of performance compared with other time of the day when it is easier to carry out the same performance. This is supported by the findings of Smith et al. (1994) in that higher rate of injuries due to accidents has been noticed in machine-paced workers at night. They stated, "that it would seem probable that the increased injury rates at night reflected on the individual's circadian rhythm in performance capabilities and alertness which had failed to adjust sufficiently to the night shift". Several authors illustrated that inadequate circadian adjustment, an accumulation of sleep deficits (Quaas & Tunsch 1972, Vinogradova et al. 1975) and social factors (Monk & Wagner 1989) seem to play predominant role in the occurrence of accidents during night shift.

Transport area has been identified as a major risk area where most of the accidents occurred at night. Night workers have increased sleepiness, which is associated with the lack of alertness; eventually this association increases the chances of occurrence of accidents. With respect to air accidents Ribak et al. (1983) found that military air mishaps mostly occur in the early morning. Fatigue on account of improper work scheduling appears to be one of the most important causes of civil air transport accidents (Price & Holly 1981). A number of spectacular nuclear accidents have been partly attributed to fatigue-inducing work schedules (Mitler et al. 1988). Work environment may also induce the risk of workplace accidents. Nag & Nag (2001) reported prevalence of he at-induced accidents. They showed that the night workers were more vulnerable and less tolerant to heat as compared to the rotating day workers.

Bhopal gas tragedy and Chernobyl nuclear disaster affected the population dwelling around the sites. Thus the implication of failure in the circadian rhythm of alertness in an individual or a group of individuals is paramount. The peak time of risk at night should be handled with utmost precaution in order to prevent population disasters of extremely high magnitude.

Shift work and Personality

The human population can be divided basically under two major categories, namely morning active persons (lark type) and evening active persons (owl type) (Minors & Waterhouse 1989). These are called the chronotypes. The term 'morningness' and 'eveningness' used to describe people whose natural day-active and night-rest circadian rhythm behaviour begins either earlier or latter than usual in the day (Pati & Parganiha 2005) (**figure 8**). These individuals can differ from one another in the phase of their circadian rhythms in various measures, such as body temperature and performance efficiency for various tasks. These variations may be attributed to contributions from multiple genes and environmental factors (Toh et al. 2001). It has been reported by them that a mutation in *hPer2* gene is responsible for familial advanced sleep-phase syndrome (FASPS) in members of a Utah family. The affected

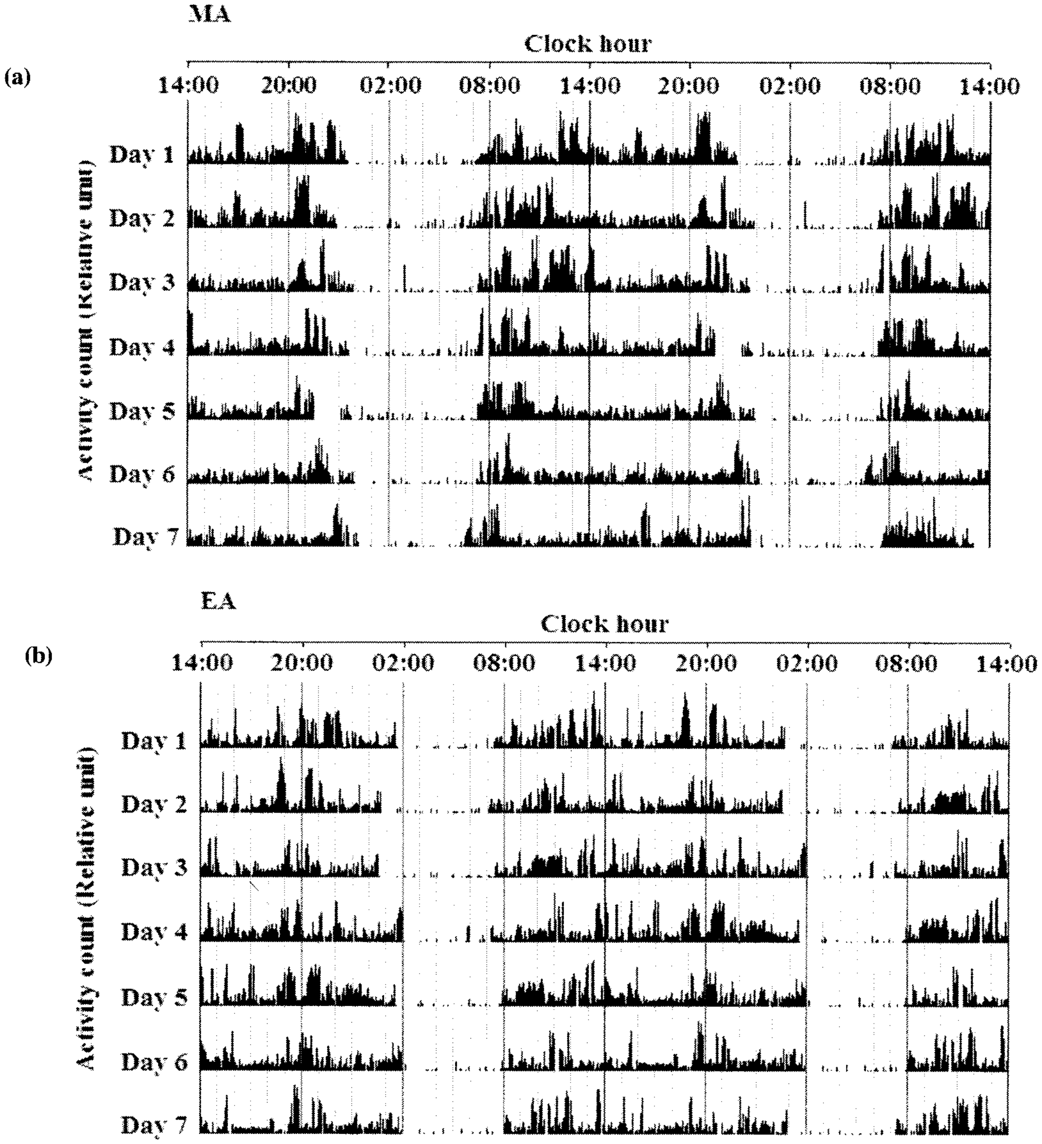


Figure 8. Illustrative examples of sleep-wakefulness rhythm in a morning active (a) and an evening active (b) individual. A phase delay occurred in onset and offset of the activity in the evening active individual as compared to the morning active individual.

family members sleep at around 7 p.m. and get up at around 2 a.m. in the early morning. Archer et al. (2003) reported a significant association between the *hPer3* polymorphism and extreme diurnal preferences. They emphasized that length of allele is associated with morningness/eveningness. The shorter allele was strongly associated with the delayed sleep-phase syndrome (DSPS). These studies may help in having important insights into the human circadian machinery with potentially practical clinical benefits. Such differences may also have a bearing on an individual's coping ability to night shift work.

A morning type person gets up easily and is more alert in the morning than in the evening, has a hard time sleeping late, and fall asleep quickly in the evening. Evening types person, on the other hand, are more alert at night, are able to sleep late in the morning and take a long time to fall asleep at night. Further, evening types tend to have more flexible sleep habits and sleep significantly less than morning types (Natele et al. 2003). Taillard et al. (2001) speculated that morningness was associated with worse sleep and difficulty in maintaining sleep, whereas eveningness was associated with feeling less energetic, physical mobility, difficulty in initiating sleep and morning sleepiness.

Circadian rhythm in various variables, namely body temperature, heart rate and melatonin are paramount for determination of the chronotype in human population (Gupta & Pati 1994b, Griefahn et al. 2002a,b). These rhythms have been shown to vary as a function of morningness and eveningness. The minima of rectal temperature and heart rate as well as the onset of melatonin synthesis occurred significantly earlier in morning than in evening type individuals (Griefahn 2002). However, the melatonin onset is a more reliable indicator of the diurnal type than the nadir of rectal temperature (Griefahn et al. 2002b). They reported occurrence of rectal temperature minima approximately 1.5 h and onset of melatonin synthesis 3 h earlier in morning type individuals than in evening types. The peak time of oral temperature was earlier about 4.9 h in the morning active individuals of the tropical population than their evening active counterparts (14.5 ± 0.85 h *vs* 19.4 ± 0.55h) (Gupta & Pati 1995) (**figure 9**). It has also been witnessed that the morning active subjects remain at their best between 8.6 - 10.7 h with reference to the performance variable, random number addition speed, whereas, evening active subjects remain at their best between 16.9 - 20.2 h, approximately six hours later (**figure 9**).

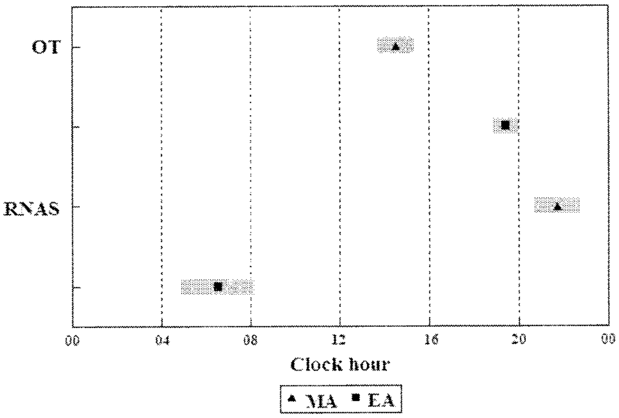


Figure 9. Acrophase map for oral temperature (OT) and random number addition speed (RNAS) in a group of morning active (MA) and evening active (EA) subjects. Each point represents the estimated maximum (acrophase, Ø) of each group. The horizontal bar defines the 95% confidence limits of acrophase. OT peak occurred 4.9 h earlier in MA subjects as compared with the EA subjects. Morning active subjects exhibited the best performance in between 8.6 and 10.7 hours whereas EA were at their best between 16.9 and 20.2 hours (Based on data from Gupta & Pati 1994b, 1995).

Individual differences, for example being morning active or evening active type, can be focused on determining individual suitability for night- or shift-work (Kleitman 1963). Evening types appear to be better suited for night because of their greater ability to sleep during the day (Östberg 1973, Fiala & Klepác 1988). According to Åkerstedt (1990) older age and *morningness* personalities have problems in adjusting to shift work. Breithaupt et al. (1978) observed that it is predominantly morning types who react to late shift work with sleep deficiency and its accompanying pathological symptoms. According to them it is not that morning types have a less efficient adaptive capacity than evening types, but rather the evening types have a constitution which is inherently less vulnerable to delayed sleep, simply because of their delayed circadian phase position (Breithaupt et al. 1978).

According to Folkard (1990) in situations where safety is paramount the solution to the problems of shift work adaptation is the creation of nocturnal sub-society that not only always works at night but also remains on a nocturnal routine on rest days. This seems impractical to some extent because this suggestion advocates creation of a sort of isolated world for a human sub-population of desired dimension.

Intolerance to shift work

Some workers tolerate shift work better, while others are intolerant (Folkard et al. 1983, Reinberg et al.

1989). On the basis of intensity of medical complications, it is possible to classify shift workers having good tolerance (with neither complaints nor medical problems), poor tolerance (with medical complaints) and very poor tolerance (severe clinical problems). Clinical intolerance to shift work was defined by the existence and intensity of a set of medical complaints: (1) Sleep alterations; (2) Persisting fatigue; (3) Changes in behaviour; (4) Digestive troubles; (5) The regular use of sleeping pills. Symptoms 1, 2 and 5 are present in any intolerant subject (Andlauer et al. 1979, Reinberg et al. 1988, Reinberg & Smolensky 1992). Clinical intolerance to shift work appears to be independent of individual's age and length of shift working experience (Andlauer et al. 1979, Reinberg et al. 1984, 1988). On the contrary, aging could be associated with decreased tolerance to shift work, critical age being on an average 40-50 years (Koller et al. 1978, Åkerstedt & Torsvall 1981, Foret et al. 1981, Tepas et al. 1993).

Could it be possible to evolve a chronobiological index to assess the level of intolerance to shift work? A satisfactory index is not available at the present. Attempts, however, have been made to associate tolerance/ intolerance with some easily measurable rhythm parameters apart from the one based on the severity of medical complications (Reinberg et al. 1988, Reinberg & Smolensky 1992). The medical complications appear at a later stage of intolerance. Shift workers with lower 24-h average of negative moods and fatigue rhythms tolerate night shifts better. They also show fewer respiratory and psychosomatic-digestive complaints (Vidacek et al. 1993). The study conducted by Costa et al. (1989) indicates that the characteristics of flexibility of sleeping habits, ability to overcome drowsiness, and lower manifest anxiety, are associated with better tolerance to shift work.

Morningness has been associated with intolerance to shift work; the determination of the melatonin profile might be a valuable element of the criteria when assigning a person to shift work (Griefahn et al. 2002b). Further, a constellation of personality factors may influence an individual's tolerance to shift work (Smith et al. 2001). Nurminen (1998) and Labyak et al. (2002) demonstrated that sleep disturbances that lead to menstrual irregularities could be a marker of shift work intolerance.

Reinberg et al. (1984, 1988) suggested that alteration in circadian amplitude of oral temperature rhythm in shift worker probably ideally reflects on its tolerance to shift work. They further emphasized that amplitude alteration could be taken as an index to assess individual worker's shift work coping ability. It is suggested that individuals with large circadian amplitude are more tolerant to shift work, since it helps the subjects to maintain their internal synchronization (Andlauer et al. 1979, Reinberg et al. 1984). It seems that persons who possess weak circadian time structure, i.e., a rhythm with low amplitude are more prone to develop biological intolerance to shift work later in life (**figure 10**). However, those with a strong (high-amplitude) time structure are the least prone (Smolensky & Reinberg 1990). Reinberg et al. (1988) reported large circadian amplitude of oral temperature, right- and left-hand grip strength, heart rate and peak expiratory flow rate in good tolerant shift workers than with poor tolerant shift workers (**figure 11**).

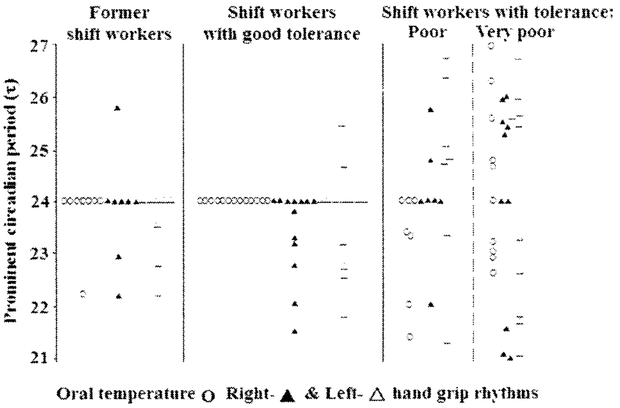


Figure 10. Prominent circadian period resulting from power spectrum analyses for oral temperature, right- and left-hand grip strength and period of each subject is plotted with regard to each of the four groups and their tolerance to shift work (From Reinberg et al. 1988).

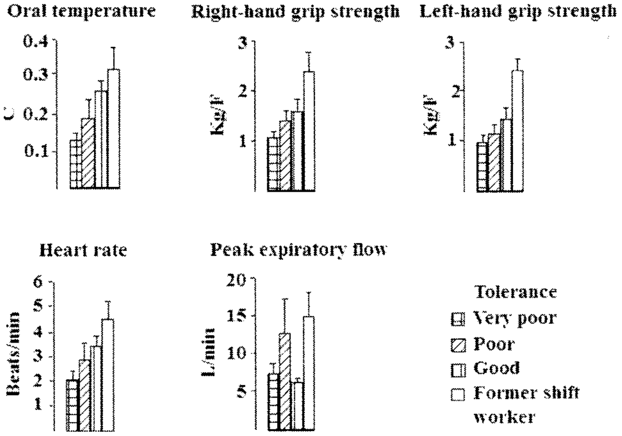


Figure 11. Amplitude of oral temperature, right- and left-hand grip strength, heart rate and peak expiratory flow rate with regard to the four subgroups of shift workers and their tolerance to shift work (From Reinberg et al. 1988).

Factors, namely circadian, sleep and social/ psychosocial/ domestic factors have been considered to be important in determining the coping ability of a worker to shift work (Reinberg et al. 1984, 1988, 1989, Monk 1988, Folkard 1990, Härmä et al. 1990, Skipper et al. 1990). According to Monk (1988) each of these three factors consists of several other sub-factors (**figure 12**). All these factors interact with each other and produce considerable influence on workers' tolerance to shift work. However, Monk's (1988) list is not exhaustive. There may be many more factors yet to be identified and understood. It is also important to underline that some but not all of these factors are present or relevant simultaneously in case of an individual shift worker. Some of them are job specific while others depend upon the internal constitution of the individual itself.

Shift Management

Shift work is indispensable and its detrimental effects are real. How and to what extent we can ensure healthy work life for shift workers? Chronobiologists offer a number of countermeasures to tackle problems related to shift work.

Speed of Rotation

Night shift has been identified as the most disruptive of all shifts in terms of physiological adjustment, sleep, fatigue or alertness. The rotation of the shift may be either slow or fast. The quickly rotating shift system has more advantages as compared to slowly or weekly rotating shift system (Phillips et al. 1991, Knauth 1993, 1995, 2002, Fischer et al. 1997).

A fast rotation helps in minimizing sleep deprivation (Fischer et al. 1997), circadian rhythm disruption and improve social contacts (Knauth 1993, 1995), alertness and well-being (Williamson & Sanderson 1986, Phillips et al. 1991, Härmä et al. 2006). Further, rapidly rotating shift system was found to be most preferable for jobs that involve a high memory load (Monk & Embrey 1981). Rapid rotation (2 to 4 days) from a chronobiological point of view is advantageous with regard to the conventional weekly rotation. Results of field studies involving oil refinery operators support the above statement (Chaumont et al. 1979, Foret & Benoit 1979, Vieux et al. 1979). These authors have categorically demonstrated that the resynchronization of circadian rhythms is faster (with fewer transients) and the extent of desynchronization of sleep-wake rhythm is smaller with the rapid rotation as compared with the weekly rotation. But the rapid rotation does not solve the problem of nocturnal risk of accidents. Further, there are reports that do not support the quick rotation system. The main argument is that the extremely quick rotation would have reduced free time between shifts by several hours (Totterdell & Folkard 1990, Kurumatani et al. 1994) leading to substantial sleep loss. Then one should find out the threshold for 'free time' between shifts that would not cause loss of sleep. However, there is no such study to support the above. Nevertheless for the time being quickly rotating shift system appears to be better.

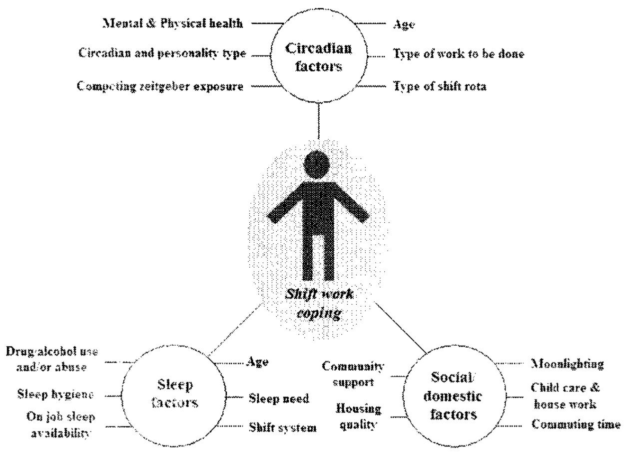


Figure 12. Factors and sub-factors that are known to modulate coping ability of workers to shift work (Based on Monk, 1988).

Direction of rotation

Besides the speed of rotation, the direction of rotation might also influence the coping ability of shift workers. The direction of rotation may be either clockwise (forward rotation or delaying system) or counterclockwise (backward rotation or advancing system). It is of considerable interest to examine the role of this factor in shift optimization. Shift workers tolerate clockwise rotation better than the one that follows counterclockwise pattern. A change from counterclockwise to clockwise rotation has been documented to improve production, well-being (Czeisler et al. 1982), sleep quality (Epstein et al. 1991, Barton & Folkard 1993). This also reduces physical, social and psychological problems (Landén et al. 1981). Backward rotation appears to be related with an increased need for recovery and poor general health as compared to forward rotation. Furthermore, a forward rotation was associated with the less work-family conflict and better sleep quality (van Amelsvoort et al. 2004). However, Tucker et al. (2000) showed few effects of direction of rotation on chronic measures of health and well-being. They demonstrated that advancing continuous shift system was associated with marginally steeper decline in alertness. In contrast, findings of Cruz et al. (2003a, b) do not support that a clockwise rotation will result in better outcome on vigilance task performance and various sleep measures. They indicated that main problem in both clockwise and counterclockwise shift schedules are early morning and midnight shifts (Cruz et al. 2003a, b).

Theoretically clockwise rotation of work schedule (i.e., Morning-Evening-Night) seems to be the best universal pattern, although there are limited evidences in its favour. The findings from jet lag research that the westward travel produces quicker resynchronization of human circadian rhythms as compared with the eastward travel support the above conjecture.

Switching workers from shift duty to day duty

Study conducted in our laboratory shows that desynchronized circadian rhythms in shift workers returned to normal when they were obliged to behave as day workers with nocturnal sleep (Chandrawanshi & Pati 2000, Pati et al. 2001). **Figure 13** shows illustrative examples of spectral analysis that clearly support the above conclusion. Results indicate that in 1st spell of study several variables, namely skin temperature, heart rate and peak expiratory flow rate had non-24 h periods. However, in the 2nd spell after about 16 months all variables exhibited circadian periodicity (t = 24 h) when the shift workers had opportunity to sleep while *on job* in the night. These results support the findings reported by Reinberg et al. (1984) in that when a shift worker with poor tolerance was transferred from shift work to diurnal work, the desynchronized rhythm in oral temperature became resynchronized after about 1 year exhibiting prominent period equal to 24 h in oral temperature rhythm (**figure 14**). In our study this transfer was achieved accidentally following an irregular but frequent shutdowns of the cement factory (Parganiha & Pati 2005).

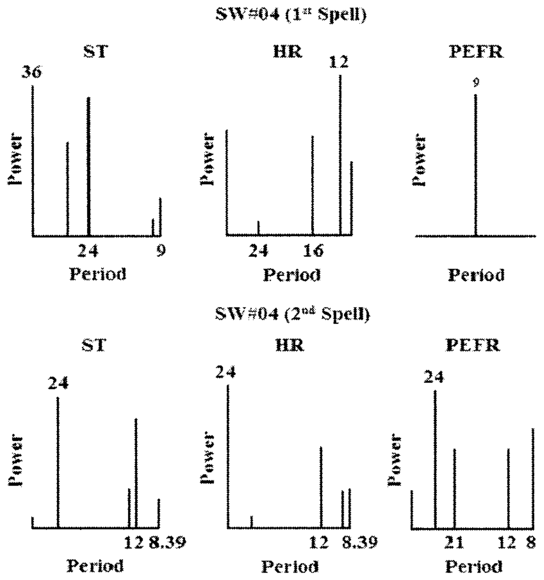
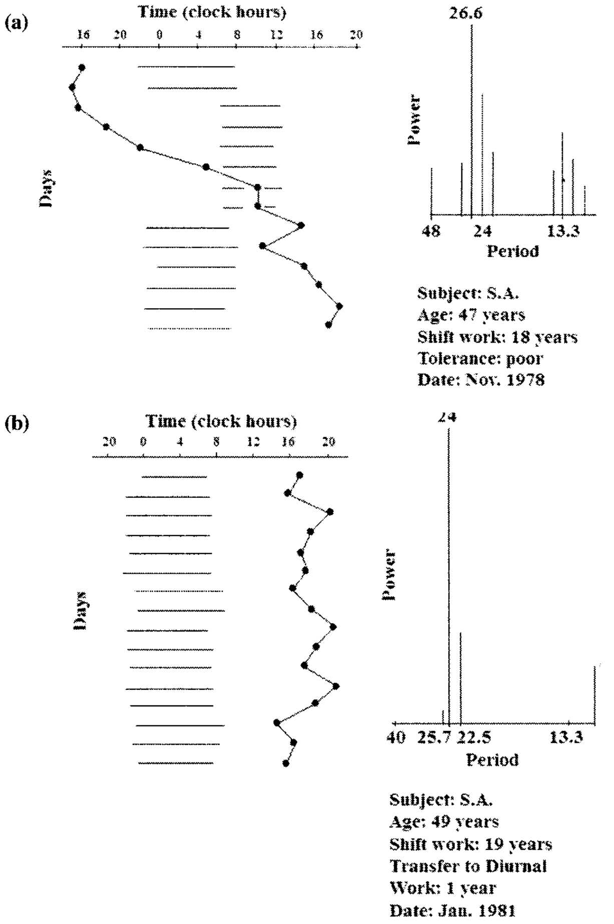


Figure 13. Power spectra for rhythms in three variables, namely skin temperature (ST), heart rate (HR), and peak expiratory flow rate (PEFR) in a shift worker (SW # 04) in two spells of studies. See text for details. (Based on Chandrawanshi & Pati 2000, Pati et al. 2001).

Nap

Napping is one of the important strategies that has received increased attention as a useful countermeasure



Subject: S.A.
Age: 47 years
Shift work: 18 years
Tolerance: poor
Date: Nov. 1978

Subject: S.A.
Age: 49 years
Shift work: 19 years
Transfer to Diurnal Work: 1 year
Date: Jan. 1981

Figure 14. a, Desynchronization of the oral temperature circadian rhythm of subject S.A. with poor tolerance to shift work. **(Left),** horizontal bars represent both duration and location of rest (lights-off to lights-on) governed by shift schedules (rapid rotation); black dots and solid line represent day-to-day acrophase (Ø) location (peak time) of the temperature rhythm. **(Right),** power spectrum of the temperature rhythm with period (τ) in hours. Prominent line for τ = 26.6 h.
b, 24-h synchronized temperature rhythm of subject S.A. about 1 yr after his transfer to diurnal work (From Reinberg et al. 1984).

(Schweitzer et al. 2006). Effective napping including its timing and duration has the potential to improve our daily lives. Scheduled napping can counteracts decreased alertness and performance under conditions of sleep deprivation (Takahashi 2003). To achieve the maximum advantage of napping one should identify the strategies of napping that are compatible with individual cases including aging, work schedules, and sleep disorders (Takahashi 2003).

In several studies the effects of nap on alertness, performance, and sleep quality have been assessed (Batejat & Lagarde 1999, Hayashi et al. 1999, Takahashi et al. 1999). Brief naps during work may be helpful to some workers as this enhances alertness temporarily. It has been shown that short naps of 20 to 40 minutes can be beneficial as it may improve sleep quality, performance and mood (Batejat & Lagarde 1999, Hayashi et al. 1999, Purnell et al. 2002). In Japan night-shift naps are officially sanctioned (Kogi 1981).

Bright light and Melatonin

Appropriately timed exposure to bright light during night could produce circadian adaptation to night work (Bjorvatn et al. 1999, Burgess et al. 2002, Horowitz & Tanigawa 2002). Czeisler & Dijk (1995) reported that after four cycles of light treatment the endogenous circadian rhythms of body temperature, subjective alertness, cognitive performance, urine production and plasma cortisol secretion completely adjusted to the new schedule. In addition, exposure to bright light during the night shift has been reported to improve daytime sleep, performance, alertness and physical and emotional well-being in shift workers than control subjects (Czeisler et al. 1990, Yoon et al. 2002, Lowden et al. 2004). NASA scientists in manned space flight have implemented this principle for the first time (Czeisler et al. 1991). NASA is now regularly using the bright light technology (therapy) on all space shuttle missions (Czeisler & Dijk 1995). The effect of bright light is probably brought about through its melatonin suppressing ability.

Besides the bright light, non-photic synchronizers, such as exercise and exogenous melatonin are also equivocal to overcome the maladaptation to night work (Horowitz & Tanigawa 2002). Bright light affected the circadian rhythm of melatonin synthesis, rectal temperature and heart rate (Griefahn et al. 2002b). In addition, bright light significantly suppressed the melatonin level during night work and most strongly at 02:00 hours (Lowden et al. 2004). They concluded that photic stimulation in industrial settings might enhance adaptation to night work.

Melatonin has chronobiotic properties in humans. A relationship between the potential therapeutic effects of melatonin and physiological rhythms in humans has been established (Arendt 1983). Griefahn et al. (2002b) documented that the temporal parameters of the melatonin profile are better indicators of the individual circadian rhythm. Repeated melatonin administration has been shown to shift circadian rhythms in both humans and rats (Redman et al. 1983, Arendt et al. 1984, 1985). Late afternoon administration of melatonin in low pharmacological doses (2 mg) could induce an advance phase shift of its own endogenous rhythm, however, a phase delay was reported after early morning administration (Arendt et al. 1984, 1985, Lewy et al. 1992, Zaidan et al. 1994). Effect of melatonin in adapting to night shift has been reported in two field studies (Folkard et al. 1993, Sack et al. 1994). Folkard et al. (1993) reported that melatonin significantly improved day sleep duration and quality, and night shift alertness. Sack et al. (1994) reported that melatonin improves synchrony between endogenous circadian rhythms and daytime sleep. The use of melatonin as a phase-shifting mechanism offers a convenient alternative to bright light (Czeisler et al. 1990). The combined use of timed melatonin and bright light is likely to provide optimum phase-shifting condition.

Future directions of research and Recommendations

There have been lots of controversies regarding the efficacy of speed and direction of rotation of schedules in the optimization of human shift work. The effects of the duration and timing of initiation of night shifts are highly debatable. It is also not known if discrepancies observed in the studies involving above-mentioned factors have some relationship with the chronotype of the worker and their level of tolerance to shift work. Therefore, it is extremely important to gauge the degree of their intolerance to shift work as function of chronotype. This may have significant implications in the effective management of problems of shift workers. Till this day an appropriate index of tolerance to shift work has not been envisaged. Further, although_the effects of light and melatonin as circadian synchronizers in shift workers have been studied, any conclusive recommendation in the form of 'chronotherapy package' is yet to be developed. Future researches in these directions are indispensable.

We propose establishment of chronoclinic in all work places that involve shift work or permanent night work (**figure 15**). The primary objective of such clinics should be to assess the levels of tolerance/ intoler-

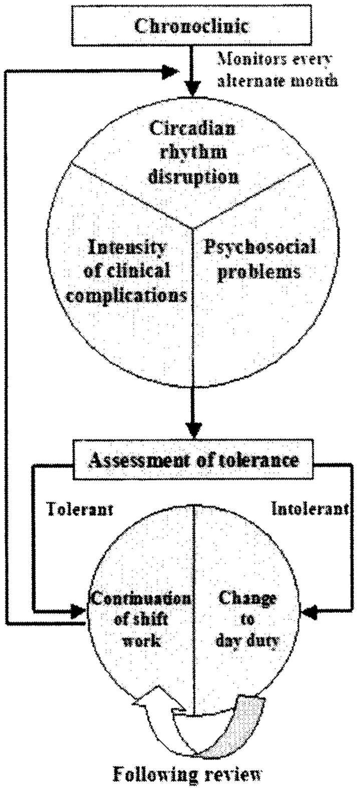


Figure 15. Optimization of human shift work: A model. See text for details (Modified from Pati 2001, Pati et al. 2001).

ance in each worker periodically. The criteria of assessment must be based on three important tolerance modulators, such as circadian, clinical and social/ psychosocial/ domestic factors. Relevant chronotherapy should be administered to those with poor shift work coping abilities. These efforts might optimize human shift work, i.e., minimize occupational health problems and maximize work place safety and productivity.

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