Fitness problem in shift workers while adjusting in ever changing working schedule

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Abstract
The present study was aimed to assess the diurnal variations in few physiological processes in rotational shift workers suffering irregular life styles due to having regular and/or irregular workload during night shift. The diurnal variations in rest-activity was monitored, using wrist actigraphy, in cohorts of 14 shift workers (SWs) employed in the Sponge Iron Manufacturing Industry (SIMI) and 20 shift workers (SWs) of the Chhattisgarh State Electricity Board (CSEB). The former organization adopts regular rotational shift system and the latter an irregular rotational shift pattern. SWs of both organizations worked in a counterclockwise 3-shift system. All SWs were provided an activewatch around the clock covering all three shifts to monitor their sleep-wake activity pattern. One-minute epoch length was chosen for collection of wrist actigraphy data. Data were analyzed using computations of dichotomy index (\(I/O\)) and autocorrelation coefficient (\(r_{24}\)). The irregular rotational SWs from CSEB took rest/nap/sleep in the night shift while on duty. Therefore, the activity pattern of these subjects was somewhat similar to that of the day workers. Results of the present study showed that autocorrelation coefficient was significantly (\(p < 0.05\)) lower in irregular rotational shift workers as compared to regular rotational shift workers only during the morning shift. There are no statistically significant differences between the means of \(r_{24}\) obtained for the morning, afternoon, and night shifts, when values were compared separately for each organization. Further, the regular rotational SWs exhibited significantly lower dichotomy index during night shift as compared to morning shift.

Keywords: Circadian rhythm, rest-activity, irregular rotational shift, regular rotational shift, dichotomy index, autocorrelation, circadian period

INTRODUCTION

Homo sapiens have been evolved as a diurnal being: they are attuned to work during the day and to take rest in the night (Gangopadhyay et al., 1998). This type of working system is called day work. However, indispensability of the current day shift working, especially night shift does not allow them to stick to their evolutionary dictum. Eventually this unusual work schedule conflicts adverse effects on human health and well being (Pati, 2001). Therefore, it is mandatory to examine the effects of shift working on human health, especially on biological clock that dictates an individual, when to get up and when to sleep.

Shift work forces workers to change their diurnal habits into nocturnal habits. This may eventually leads to complete internal and external rhythm desynchronization in shift workers including sleep/wake cycle disruption and circadian rhythm disruption (Silbergliedt et al., 2006; Aschoff et al., 1975; Moore-Eda et al., 1983). As reported above shift workers often experience complete temporal disorganization characterized by both external as well as internal desynchronization of biological rhythms (Reinberget al., 1984, 1988, 1989; Gupta and Pati, 1994a; Gupta et al., 1997; Chandrawanshi and Pati, 2000). Even though the main hazardous effects of shift work are well documented, it is evident that not all individuals are equally affected, while some people suffer and others better tolerate (Akerstedt and Torsvall, 1981; Folkard and Monk, 1981; Härma, 1993; Reinberget al., 1984). Several individual properties such as, diurnal types, circadian amplitude, sleep flexibility and ages have been investigated as reason of the discrepancy in tolerance (Axelsson et al., 2003; Nachreiner, 1998). Further the same has been reported for circadian rhythm in rest/activity and thus the performance of shift workers is affected (Gohet al., 2000).

Circadian adaptation to night work requires that circadian rhythm phase shift to retrain the newly imposed light dark cycle and sleep wakefulness cycle (Sharkey and Eastman, 2002). However, there is still a considerable gap between the implications of chronobiological approach for shift work research and actual practice (Akerstedt, 1988). Therefore, the aim of the present study was to assess the circadian rhythm in regular and irregular rotational shift workers with heavy or less workload during night shift.

METHOD

Subjects

The rest-activity rhythm was studied in thirty-four subjects consisting of 20 irregular rotational shift workers (IRs; age range 24 to 56 years; median age: 35 y) and 14 regular rotational shift workers (RRs). The SWs were randomly selected from two different organizations, namely Chhattisgarh State Electricity Board (CSEB) and Raipur Alloys (RA) characterized by irregular rotational shift, regular rotational shift respectively. All participants gave written consent for their participation in the study. The subjects in the RA and the CSEB routinely experienced heavy and low workload, respectively. Shift workers of both organizations were working in a 3-
shift system, characterized by the rotation from night (NS, 22:00-06:00) to afternoon (AS, 14:00-22:00) and to morning shift (MS, 06:00-14:00) in a counterclockwise fashion. Each subject works for six consecutive days on each shift followed by 1-day rest during transition between adjacent shifts. However, in CSEB the rotation was considered irregular, as timings of shifts were not very strictly adhered to on account of mutual adjustments. SW had considerably light workload during the night shift.

Procedure

Each subject wore an Actiwatch (AW64, Mini Mitter Co. Inc., USA), which monitored rest-activity for 21 consecutive days. None of them had a history of major diseases, except occasional digestive troubles among the SWs. No restriction was imposed upon them concerning their sleep schedules and food preferences. The SWs had ample opportunity to have sleep during night shifts.

Statistical analyses

Graphical representation of the rest-activity pattern was obtained in the form of actograms for each subject by using Actiware sleep software (version 3.3). The circadian rhythm characteristics, such as average of the rhythmic function (Mesor, M, rhythm-adjusted 24-h mean), amplitude (A, one-half of the difference between the highest and the lowest value of the rhythmic function), and peak or acrophase (Ø, timing of the highest value of the rhythmic function) were estimated shift wise (Nelson et al., 1979) at two different fixed windows, i.e., τ = 24 h and τ = 12. The additional 12-h period was especially selected because bimodality in the activity pattern was detected in the actograms of most of the subjects. Harmonic means were calculated for M, A, and Ø obtained at both windows. The prominent period in each dataset belonging to each subject was computed using the power spectrum method (De Prins et al., 1986) that was suitable to analyze time series with or without missing data. Autocorrelation analyses, which do not presume the shape of any cyclic function, were also applied to derive the autocorrelation coefficient at τ = 24 (i.e., r24) to obtain another measure of the regularity of the activity pattern over the 24 h. The dichotomy index (I<O), i.e., the differences in activity distribution between the daily activity and rest spans was also computed (Minors et al., 1996). The dichotomy index I<O is the percentage of the 1 min activity values measured while the subject is in bed that is inferior to the median value when the subject is out of bed. The value of this index can vary between 0% and 100%. In case of a marked circadian rhythm with complete rest at night and high activity during daytime, I<O tends to reach 100%. Both r24 and I<O were computed shift wise for each subject, including the controls. Other conventional statistical techniques, such as ANOVA followed by Duncan’s multiple-range test, and t-test were also used whenever required.

RESULTS

Rest-activity rhythm

Figure 2.1 A-B represents illustrative examples of double-plotted actograms of rest-activity pattern in an irregular shift worker and a regular rotational shift worker (CRS # 01 and RRS # 03). The irregular rotational shift worker (CRS # 01) displayed more activity during the daytime and rest during the nighttime irrespective of morning, afternoon and night shifts. Whereas, the rest activity cycle of the regular rotational shift worker shifted with the three shifts system.

Circadian rhythm

A statistically significant circadian rhythm in rest-activity with a prominent period of τ = 24 h was validated in both the shift worker groups, irrespective of its computation at fixed windows with or τ = 12 h and shift type. Circadian periodicity (τ = 24 h) appears to be the dominant feature among most of the irregular rotational and regular rotational shift workers irrespective of the shifts. However, few shift workers (n = 8, CRS; n = 2, IRS) showed ultradian rhythm (τ = 12 h) in rest-activity during their night shifts work. Figure 4 (IRS: A - MS, B - AS, C - NS, and CRS: D - MS, E - AS, F - NS) shows illustrative examples of circadian and ultradian prominent periods in rest-activity rhythm of a regular rotational shift worker (CRS # 01 and RRS # 03) while performing morning afternoon and night shifts. Figure 2 illustrates the best-fitting cosine curves based on harmonic averages of 24 h mesor, amplitude and acrophase in a regular rotational shift worker (A: CRS # 01 and B: RRS # 03) during morning, afternoon and night shift.

There were no statistically significant differences between the harmonic averages of 24 h average, amplitude and acrophase obtained for the morning, afternoon, and night shifts, when values were compared separately for irregular rotational organization (Table 1). However, the regular rotational SWs exhibited significantly lower (p<0.05) amplitude and advanced peak during night shift (Table 3). Figure 3 shows illustrative examples of day-to-day changes in peaks of rest-activity rhythm (harmonic mean) in a regular rotational shift worker (CRS # 01 and RRS # 03).

Further, comparison of rhythm characteristics was made between shift workers of CSEB and RA while they worked morning, afternoon and night shifts (Table 5). The results indicated that the amplitude of rest-activity rhythm, was found to be significantly (p<0.01) lower among the RA shift workers, as compared to the CSEB shift workers, while they were in the afternoon and night shift (Table 5). The acrophase was found to be earlier in RA shift workers as compared to the CSEB shift workers during the morning and night shift (Table 5). The peak spread was found to be exceptionally larger in subjects of RA, while they worked night shift.

Dichotomy index (I<O) and Autocorrelation (r24)

Dichotomy index (I<O) and autocorrelation coefficient (r24) were also computed for individual shift workers from irregular rotational and regular rotational shift worker in their respective morning, afternoon and night shifts (Table 2 and 4). In each subject the value of r24 was statistically significant irrespective of shifts and organization. A statistically significant difference could not be obtained when means of dichotomy index obtained for morning, afternoon, and night shifts, were compared separately for irregular rotational shift workers (Table 2). However, the regular rotational SWs exhibited significantly lower dichotomy index during night shift as compared to morning shift. Further, there are no statistically significant differences between the means of r24 obtained for the morning, afternoon, and night shifts, when values were compared separately for each organization (Table 2 and 4). Moreover, comparison of dichotomy index and autocorrelation was made between shift workers of CSEB and RA while they worked morning, afternoon and night shifts (Table 5). The results indicated that the
Dichotomy index of irregular rotational shift workers does not differ from that of the regular shift workers while performing morning, afternoon and night shifts (Table 5). It was revealed that the autocorrelation coefficient was significantly \( (p < 0.05) \) lower in irregular rotational shift workers as compared to regular rotational shift workers only during the morning shift.

Table 1. Characteristics of rest-activity circadian rhythm in CSEB CRSs as function of shift type.

<table>
<thead>
<tr>
<th>Shift</th>
<th>24-h average</th>
<th>Amplitude</th>
<th>Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning</td>
<td>1.56 ± 0.06</td>
<td>0.56 ± 0.04</td>
<td>13.4 ± 0.13</td>
</tr>
<tr>
<td>Afternoon</td>
<td>1.59 ± 0.05</td>
<td>0.59 ± 0.03</td>
<td>13.2 ± 0.38</td>
</tr>
<tr>
<td>Night</td>
<td>1.60 ± 0.06</td>
<td>0.60 ± 0.03</td>
<td>13.1 ± 0.68</td>
</tr>
</tbody>
</table>

ANOVA Summary (Shift effect):
- 24-h average: \( F \)-value = 0.13; \( df = 2, 49; p = 0.87 \)
- Amplitude: \( F \)-value = 0.41; \( df = 2, 49; p = 0.66 \)
- Peak: \( F \)-value = 0.10; \( df = 2, 49; p = 0.90 \)

Table 2. Characteristics of dichotomy index and autocorrelation obtained for rest-activity rhythm in CSEB CRSs as function of shift type.

<table>
<thead>
<tr>
<th>Shift</th>
<th>Dichotomy index</th>
<th>Autocorrelation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning</td>
<td>96.61 ± 0.61</td>
<td>0.24 ± 0.02</td>
</tr>
<tr>
<td>Afternoon</td>
<td>97.00 ± 0.40</td>
<td>0.24 ± 0.02</td>
</tr>
<tr>
<td>Night</td>
<td>96.52 ± 0.41</td>
<td>0.24 ± 0.02</td>
</tr>
</tbody>
</table>

ANOVA Summary (Shift effect):
- Dichotomy index: \( F \)-value = 0.30; \( df = 2, 49; p = 0.74 \)
- Autocorrelation: \( F \)-value = 0.006; \( df = 2, 51; p = 0.99 \)

Table 5. Comparison of rest activity rhythm parameters between CSEBand RA as a function of shift type.

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<table>
<thead>
<tr>
<th>Variables</th>
<th>CSEB Mean ± SE</th>
<th>RA Mean ± SE</th>
<th>( t ) value, ( P ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>M (Mesor)</td>
<td>1.56 ± 0.06</td>
<td>1.64 ± 0.04</td>
<td>26.1, 101; 0.141</td>
</tr>
<tr>
<td>A (Amplitude)</td>
<td>0.56 ± 0.04</td>
<td>0.59 ± 0.03</td>
<td>26.0, 590; 0.280</td>
</tr>
<tr>
<td>O in h (Acrophase)</td>
<td>13.403 ± 0.13</td>
<td>11.45 ± 0.26</td>
<td>18.6, 812; 0.000</td>
</tr>
<tr>
<td>D1 (Dichotomy index)</td>
<td>96.609 ± 0.61</td>
<td>97.35 ± 0.38</td>
<td>24.1, 144; 0.153</td>
</tr>
<tr>
<td>T24 (Autocorrelation)</td>
<td>0.242 ± 0.02</td>
<td>0.29 ± 0.02</td>
<td>27.1, 311; 0.047</td>
</tr>
</tbody>
</table>

Afternoon shift

| M (Mesor) | 1.588 ± 0.05    | 1.62 ± 0.05  | 29.0, 503; 0.309           |
| A (Amplitude) | 0.594 ± 0.03 | 0.49 ± 0.03  | 31.2, 262; 0.015           |
| O in h (Acrophase) | 13.188 ± 0.38 | 15.55 ± 0.36 | 31.6, 687; 0.249           |
| D1 (Dichotomy index) | 97.017 ± 0.41 | 96.30 ± 0.55 | 26.1, 052; 0.153           |
| T24 (Autocorrelation) | 0.244 ± 0.02 | 0.25 ± 0.02  | 30.1, 343; 0.005           |

Night shift

| M (Mesor) | 1.600 ± 0.06    | 1.584 ± 0.06 | 27.0, 181; 0.429           |
| A (Amplitude) | 0.600 ± 0.03 | 0.436 ± 0.05 | 18.2, 861; 0.005           |
| O in h (Acrophase) | 13.104 ± 0.68 | 9.258 ± 1.76 | 16.2, 034; 0.029           |
| D1 (Dichotomy index) | 96.522 ± 0.41 | 95.61 ± 0.56 | 23.1, 310; 0.101           |
| T24 (Autocorrelation) | 0.244 ± 0.02 | 0.273 ± 0.02 | 29.1, 005; 0.162           |
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Fig 1. Illustrative examples of double plotted rest-activity profile of an irregular rotational SW (A: CRS # 01; B: RRS # 12). Rest-activity was monitored for 21 days in free living condition. Although the SW performed rotational shiftwork, there is no difference in the activity pattern as a function of shift (A); The rest and activity spans shifted with respect to night shift (NS), afternoon shift (AS) and morning shift (MS).

Fig 2. Representative examples of cosine-fitted curve in two irregular rotational SWs and a regular rotational shift worker in morning afternoon and night shift (A: CRS # 01 and B: RRS # 03), based on harmonic means of Mesors, amplitudes and acrophases obtained independently at fixed windows with periods equal to 24 h and 12 h.

Fig 3. Illustrative examples of day-to-day occurrence of peaks (Harmonic means) in rest-activity rhythm of an irregular rotational SW (CRS # 01) and a regular rotational SW (RRS # 03). The peak spread was more in regular rotational shift worker.

Fig 4 Illustrative examples of prominent periods in rest-activity rhythm of an irregular rotational SW (CRS # 01) and a regular rotational SW (RRS # 03) during morning (A, D: MS), afternoon (B, E: AS) and night shift (C, F: NS).
DISCUSSION

In the present study, the shift workers worked in the Chhattisgarh State Electricity Board (CSEB) substation and Raipur Alloys (Sponge Iron Manufacturing Industry) characterized by substantially low and heavy work load respectively, during the night shifts. They also had irregular and regular rotational shift work schedules respectively. Using a wrist actigraphy technique (with a sampling frequency of 1 minute), the study of the rhythm of activity was recorded in subjects on morning, afternoon and night work. The shift work was characterized clearly by the difference with work load in the rest activity pattern, derived from actigraphy counts. The activity count during the night shift for the irregular rotational shift work group was decreased owing to their taking long naps. It has been pointed out that this strategy probably favored the maintenance of a diurnal orientation (Daurat and Foret, 2004). However, the regular rotational shiftwork group performed intensive physical work and, di not obtain dozing during the night shift. This indicates that regular rotational shift workers were more prone to health risk due to their altered rest-activity rhythm as compared with irregular rotational shiftworkers. Shah (1990) pointed out that non-rotational workers enjoyed more frequent and longer naps and had fewer disturbances in their sleep patterns than rotational workers. There are, however, no clear indications that irregular work hours cause alteration in rest activity rhythm. Though, it has been shown that irregular work hours exert strong, negative effects on sleep, health, social life and satisfaction of workers (Åkerstedt, 2003; Choobineh et al., 2006). In the present study, irregular rotational shift workers adopted napping strategy to restore normal rest activity pattern. This findings corroborate the result of Portelaet al. (2004), where they did not find significant differences between night and day workers with reference to sleep complaints due to the nature of the shift-work schedule (no successive night shifts) and perhaps nap taking during the night shift. The cross-sectional questionnaire study by Takahashi et al. (2005) reported that, male operators at nuclear power plants who reported good adaptation took more frequent, longer nap during night shifts. Further, synchronized rest-activity rhythm characterized by unaltered rhythm parameters observed in the most of the shift workers of irregular rotational shiftworkers could be attributed to the magnitude of workload and nature of their job. Rhythm synchronization was also observed in most of the regular rotational shiftworkers which suggests that they have tolerance to rotational shift work. In the present study it was revealed that the autocorrelation coefficient was significantly lower in irregular rotational shift workers as compared to regular rotational shift workers only during the morning shift. This suggests that the morning shift could be detrimental for the irregular rotational shiftworkers. Moreover, because of the altered work schedules, during night shift, the regular rotational shift workers exhibited significantly lower amplitude and advanced peak as compared to morning and afternoon shift. In contrast, earlier authors found that night workers exhibited, during their work periods, an approximately five-hour delay in the acrophase of their rest/activity rhythm as compared with their rest periods (Delafosse et al., 2000). However, their findings were may not be based on harmonic means of acrophase. It is well known that the 24-h pattern of the rest-activity rhythm in humans is shaped more like a square than a sinusoidal waveform; hence the Cosinor method at single window $\tau = 24$ h is less meaningful in the present context. Therefore, we have calculated harmonic means for $M$, $A$, and $\hat{\Omega}$ obtained at two different fixed windows, namely $\tau = 24$ h and $\tau = 12$ h. We selected 12-h period especially since bimodality in activity pattern was discerned in the periodograms/ actograms of most of the subjects. Further, it was observed that the amplitude of rest-activity rhythm, was found to be declined among the regular rotational shift workers, as compared to the irregular rotational shift workers, while they were in the afternoon and night shift. The decrement in amplitude of circadian rhythm among shiftworkers corroborates the results of previous studies (Soni et al., 2008; Reinberg et al. 1984; Touitou et al. 1990). Acrophase timings alteration occurs due to masking effects of factors, such as greater work load and extended working time, or to the desynchronization of the circadian regulatory system (Slovene&Minkova 1997). Also, the acrophase was found to be earlier in RA shift workers as compared to the CSEB shift workers during the morning and night shift. However, there has been little previous research on the differences due to workload in connection with rest-activity rhythm during a night shift. We suggest, therefore, that an early start for the morning shift and night work should be avoided as much as possible (Knauth, 1996). CarvalhoBoset al. (2003) studied the activity indices that measure the overall activity pattern, activity when out of bed or in bed, or the activity in the hours adjacent to going to bed or getting up of night workers, working 2 to 4 successive night shifts during rest days and night shifts. The dichotomy indices indicated that night work was associated with lower activity when the subjects were out of bed and higher activity when in bed (CarvalhoBoset al., 2003). In the present study however, the regular rotational SWs exhibited significantly lower dichotomy index during night shift as compared to morning shift. This phenomenon might be ascribed to misalignment between circadian processes and sleep wakefulness as suggested earlier by Van Dongen (2006). Results of this study conclusively demonstrate that rotational shift work whether it is irregular or regularalters circadian rhythm characteristics of shiftworkers significantly because these shifts does not suit the majority of shift workers in terms of tolerability to night work and early morning work. In summary, nature of work modulates the peak and the amplitude of biological clock of shift workers. These results are of immense value for planning optimization of human shift work that may eventually lead to less health problems for the workers and the maximum productivity of the organization.

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REFERENCES


