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STJEPAN VIDAČEK , BISERKA RADOŠEVIĆ-VIDAČEK , LJILJANA KALITERNA & ZVJEZDANA PRIZMIĆ

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STJEPAN VIDAČEK, BISERKA RADOŠEVIĆ-VIDAČEK, LJILJANA KALITERNA† and ZVJEZDANA PRIZMIĆ†

Institute for Medical Research and Occupational Health, University of Zagreb, 2 Ksaverska cesta, PO Box 291 41001 Zagreb, Croatia

The relationship between individual differences in the phase and amplitude of circadian rhythms and tolerance to shiftwork has been the subject of several studies. Those studies recorded circadian rhythms and shiftwork tolerance at approximately the same time. The present study aimed to examine the predictive relationships between the amplitude, phase, and mesor of 24 h rhythms obtained before exposure to shiftwork, and subsequent indices of tolerance measured after one and three years of shiftwork. The results revealed some stable relations between the various rhythm parameters and subsequent tolerance measures. Workers who had a higher mesor of positive moods, and a lower mesor of negative moods and fatigue, before entering shiftwork tended to tolerate shiftwork better. Further, those whose heart rate rhythm showed an earlier acrophase had better subsequent sleep quality scores, while those with a smaller amplitude of their temperature, negative mood and fatigue rhythms showed better night-shift tolerance.

1. Introduction

The relationship between individual differences in the phase and amplitude of circadian rhythms and tolerance to shiftwork has been the subject of several studies (Andlauer and Reinberg 1979, Reinberg *et al.* 1979, 1981). They showed tolerant workers to have a larger amplitude of temperature rhythm than less tolerant workers. Those studies estimated amplitude and phase at approximately the same time as shiftwork tolerance, hence revealing only concurrent relationships. However, the rhythm parameters of an experienced shiftworker may have been changed by frequent phase shifting of the sleep/wakefulness rhythm. Further, if there is a relationship between rhythm characteristics and shiftwork tolerance, the workers examined may have been selected on the basis of these characteristics. That is, the workers with 'less desirable' rhythm characteristics may have left shiftwork. In view of this, the established relationships need not necessarily imply similar relationships between shiftwork tolerance and rhythm characteristics before one's exposure to shiftwork.

The present study aimed to examine the relationships between the amplitude, phase, and mesor of 24 h rhythms obtained before exposure to shiftwork, and various indices of tolerance measured after one and three years of shiftwork. Thus, the study

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† Present address, Institute for Applied Social Research, University of Zagreb, Marulićev trg 19/1 41000, Zagreb, Croatia

examined whether individual differences in circadian parameters can be used to predict differences in tolerance to shiftwork.

2. Method

2.1. *Subjects*

The study was conducted in a large oil refinery which recruited its young workers from a four-year training school giving them scholarships. All subjects were male. At the beginning of the study 204 final-year students with a mean age of 19·0 years (SD=0·6 years) were examined. Of these, 51 either did not start work in the company or were transferred to a non-shiftwork position. The remaining 153 subjects started to work in a 2:2:3 continuous three-shift system with shift changes at 06:00, 14:00 and 22:00. The shifts rotated in the order mornings–afternoons–nights. At the time of starting shiftwork the subjects' mean age was 20·2 years (SD=0·8 years).

The subjects who remained in shiftwork were followed up twice. At the follow-up there were 132 subjects left whose mean shiftwork experience was 16 months (SD=7 months) and a mean age 21·6 years (SD=1·1 years). At the second follow-up there were 112 subjects left with a mean shiftwork experience of 39 months (SD=6 months) and a mean age of 23·5 years (SD=1·0 years).

2.2. *Measures and procedure*

Before the subjects entered shiftwork, 24 h measurements of oral temperature, heart rate and mood were taken in order to assess the mesor, amplitude, and phase of each individual's circadian rhythm.

The measurements were performed in a training school where subjects came in groups of up to 20 at about 07:00. Heart rate and temperature were measured every hour, and the mood was rated every two hours, starting at 08:00 and in an adjoining laboratory room in groups of three to six subjects. Between the measurement sessions subjects were accommodated in a large room where they were allowed light activity, but no sleep, and were given meals after the sessions at 10:00, 14:00, 18:00, and 21:00 hours. The temperature in the room was approximately constant at 22°C. The lighting was natural during daytime and continuous artificial during night time.

Mood was rated on a five-point intensity scale for 57 mood descriptors by means of an adjective checklist (Taub and Berger 1974). Results were scored in accordance with a principal component analysis for the three factors of 24 h variations of mood which were labelled 'positive moods', 'negative moods', and 'fatigue' (Radošević-Vidaček *et al.* 1990).

Oral temperature was recorded by means of a thermistor probe and heart rate was measured with a Beckman portable polygraph after the subjects had been sitting still for 5 min.

At the follow-up points subjects were administered a battery of questionnaires. This consisted of the Way of Life Questionnaire, which was scored for Night Shift Tolerance and Morning Shift Tolerance (Vidaček *et al.* 1980, 1990), a purpose-built seven-item Sleep Quality Scale (Vidaček *et al.* 1987), and the Health Information Part of General Health and Adjustment Questionnaire (Tasto *et al.* 1978) scored for five scales: generally poor health, musculo-skeletal complaints, respiratory complaints, psychosomatic–digestive complaints, and digestive problems (Vidaček *et al.* 1989).

3. Results

The mesor, amplitude, and acrophase of each individual's circadian rhythm were estimated by means of the COSINA computer program (Monk and Fort 1983). Because of technical problems temperature and mood data were not available for all 204 subjects. Some acrophase estimates for mood variables were transformed before further statistical analyses so that unimodal reasonably symmetrical distributions could be obtained. These decisions were to a considerable extent arbitrary, especially in the case of negative moods, but they made it possible to use the same statistical procedures on the acrophase estimates as were used on the amplitude and mesor. The cosinor parameters for measured variables and percentage of subjects whose data significantly fit a 24 h cosine function are presented in table 1.

Table 1. Cosinor parameters and the percentage of subjects whose data significantly fit a 24 h cosine function.

Variable	No. of subjects	Mesor Mean (SD)	Amplitude Mean (SD)	Acrophase h and min Mean (SD)	% significant cosine fits ($p<0.05$)
Temperature (°C)	201	35·99 (0·49)	0·40 (0·18)	16:47 (1:59)	94%
Heart rate (beats/min)	204	73·52 (9·93)	5·80 (3·11)	15:49 (3:02)	74%
Positive moods (max.=76)	177	38·85 (15·61)	8·13 (5·19)	16:11 (4:01)	57%
Negative moods (max.=100)	177	10·80 (13·94)	4·42 (5·46)	6:07 (5:50)	36%
Fatigue (max.=32)	177	6·66 (5·97)	4·39 (3·28)	4:02 (2:42)	61%

Pearson's product-moment correlation coefficients between estimates of mesor, amplitude and acrophase and measures of shiftwork tolerance are presented in tables 2, 3, and 4. The results are presented such that higher scores on all the tolerance measures indicate better tolerance.

As expected, mesors of mood variables correlated significantly with some of the tolerance to shiftwork scores. All the statistically-significant correlations with the mesors of positive moods were positive, while those of negative moods and fatigue were negative. Eight correlations were reliable at both follow-up points. They indicated: better night shift tolerance in workers who showed a lower average level of 24 h variations in negative moods and fatigue; generally better health in workers who showed a higher average level of positive moods and a lower level of negative moods and fatigue; fewer respiratory complaints in workers who showed a lower mesor of negative moods and fatigure; and finally fewer psychosomatic-digestive complaints in workers who showed a lower mesor of fatigue. Although no relationship between tolerance and the mesor of physiological variables was expected, three slight correlations were found at the first follow-up which were difficult to interpret.

Table 2.   Correlations between mesor estimates and various shiftwork tolerance measures at first (I) and second (II) follow-up points.

		Temperature	Heart rate	Mesor Positive moods	Negative moods	Fatigue
Morning shift	I	0·03	−0·05	0·07	0·05	−0·10
tolerance	II	0·08	−0·04	0·14	0·09	−0·11
Night shift	I ˙	−0·01	−0·03	0·34**	−0·42**	−0·45**
tolerance	II	−0·06	−0·13	0·13	−0·38**	−0·37**
Sleep	I	0·06	0·00	0·26	−0·04	−0·32
quality	II	0·02	0·13	0·10	−0·14	−0·12
Generally	I	−0·06	−0·01	0·31**	−0·27**	−0·37**
poor health	II	0·03	−0·06	0·21*	−0·28**	−0·32**
Musculo-skeletal	I	0·08	0·18*	0·26**	−0·23**	−0·27**
complaints	II	−0·01	0·02	0·05	−0·11	−0·13
Respiratory	I	−0·17*	−0·01	0·22*	−0·18*	−0·23**
complaints	II	0·07	−0·13	0·16	−0·29**	−0·27**
Psychosomatic-	I	−0·10	0·02	0·24**	−0·18	−0·27**
digestive complaints	II	−0·05	−0·07	0·14	−0·33**	−0·31**
Digestive	I	−0·18*	0·03	0·13	−0·16	−0·23**
problems	II	−0·05	0·06	0·05	−0·13	−0·05

$*p<0.05$; $**p<0.01$.
n.b. The same correlation coefficients are not always statistically significant because of different number of subjects used for calculating each coefficient.

Table 3.   Correlations between amplitude estimates and various shiftwork tolerance measures at first (I) and second (II) follow-up points.

		Temperature	Heart rate	Amplitude Positive moods	Negative moods	Fatigue
Morning shift	I	−0·01	0·00	−0·19**	−0·03	−0·22*
tolerance	II	−0·06	0·02	−0·18	−0·06	−0·11
Night shift	I	−0·17*	0·06	−0·14	−0·24**	−0·21*
tolerance	II	−0·22*	−0·10	−0·14	−0·27**	−0·23*
Sleep	I	0·19	0·06	−0·05	0·06	−0·32
quality	II	0·16	0·04	−0·09	−0·01	−0·08
Generally	I	−0·07	0·12	−0·01	−0·08	−0·20*
poor health	II	−0·18*	−0·13	−0·08	−0·04	−0·19
Musculo-skeletal	I	−0·10	0·18*	0·05 ·	0·04	−0·13
complaints	II	−0·19*	0·06	−0·11	0·05	−0·21*
Respiratory	I	0·08	0·18*	−0·05	−0·07	−0·16
complaints	II	−0·01	−0·03	−0·10	−0·14	−0·12
Psychosomatic-	I	−0·07	0·12	0·02	−0·05	−0·16
digestive complaints	II	−0·07	−0·03	−0·07	−0·04	−0·18
Digestive	I	0·12	0·04	0·11	−0·03	−0·01
problems	II	0·07	0·05	−0·01	−0·10	0·06

$*p<0.05$; $**p<0.01$.
n.b. The same correlation coefficients are not always statistically significant ·because of different number of subjects used for calculating each coefficient.

Inspection of table 3 shows that there were fewer statistically-reliable correlations with amplitude estimates than with mesor, none of which exceeded 0·30. There were two positive low correlations with the amplitude of heart rate, both obtained for the one-year follow-up point. All the other significant coefficients were negative and only three were found at both follow-up points. These indicated that the workers with a smaller amplitude of their temperature, negative moods and fatigue before entering shiftwork tended to show better night-shift tolerance after one and three years of shiftwork.

Table 4. Correlations between acrophase estimates and various shiftwork tolerance measures at first (I) and second (II) follow-up points. .

		Temperature	Heart rate	Acrophase Positive moods	Negative moods	Fatigue
Morning shift	I	0·07	0·00 .	−0·15	0·10	−0·12
tolerance	II	−0·05	−0·03	−0·07	−0·04	−0·08
Night shift	I	0·15	0·02	−0·15	0·06	0·12
tolerance	II	0·04	−0·11	−0·19	0·10	0·12
Sleep	I	−0·16	−0·43**	−0·31	−0·31	0·05
quality	II	0·03	−0·23*	0·01	−0·03	0·00
Generally	I	0·02	0·01	0·03	0·11	0·01
poor health	II	0·04	−0·20*	0·02	0·05	0·11
Musculo-skeletal	I	−0·04	−0·02	−0·02	0·07	0·06
complaints	II	−0·05	−0·22*	−0·05	0·04	0·09
Respiratory	I	−0·08	−0·03	0·05	0·09	−0·01
complaints	II	0·03	−0·15	0·01	0·03	0·03
Psychosomatic-	I	0·05	0·07	0·02	0·15	0·08
digestive complaints	II	0·04	−0·13	0·09	0·07	0·15
Digestive	I	0·01	0·12	0·10	0·06	0·02
problems	II	−0·03	−0·13	0·06	−0·07	0·04

*$p<0·05$; **$p<0·01$.

n.b. The same correlation coefficients are not always statistically significant because of different number of subjects used for calculating each coefficient.

Inspection of table 4 indicates that there were even fewer statistically-reliable correlations for the acrophase estimates than for those of amplitude and mesor. The only significant correlations were found for heart rate. One of them was found at both follow-up points, indicating better sleep quality after one and three years of shiftwork in workers whose heart rate rhythm showed an earlier acrophase before entering shiftwork.

Differences in the parameters of 24 h rhythms between those still working in shifts and those who had left shiftwork before reaching the second follow-up point were analysed to examine whether those who stayed in shiftwork might differ in some rhythm characteristics. There were 36 workers who quit shiftwork before having reached three-years-experience. Statistically-significant differences were found only between the acrophase estimates of negative moods ($p<0·01$) and those of fatigue ($p<0·05$). The workers who left shiftwork showed an earlier acrophase than those who stayed both in negative moods (means=3:19 and 6:27 hours, respectively) and in fatigue (means=2:54 and 3:52 hours, respectively).

4. Discussion

In general, the results of this study showed either small or no relationships between the parameters of 24 h rhythms obtained before workers entered shiftwork and their subsequent tolerance after a few years of shiftwork. This indicates that circadian rhythm parameters may be of limited importance in predicting short-term tolerance to shiftwork. However, some of the relationships, although small, proved to be consistent over a three-year period of shiftwork.

Mesors of mood variables proved to be related stably to nightshift tolerance and to some health measures. These relationships indicate that if a young student shows a higher average level of positive moods and a lower level of negative moods and fatigue over a 24 h period, he will tend to tolerate working in night shift and show fewer health complaints after a short period of shiftwork.

Further, a stable relationship was found between acrophase estimates for heart rate rhythm and sleep quality, but this was in the opposite direction to that found in earlier studies that assessed phase differences by means of the morningness-eveningness questionnaires (e.g., Åkerstedt and Torsvall 1981). The present results indicated that students with a later heart rate acrophase tended to show poorer sleep quality after a short exposure to shiftwork.

The differences between those remaining in shifts and those who left shiftwork before reaching three-years experience indicated that those who left had earlier acrophases of negative moods and fatigue. However, these results for acrophase estimates in mood variables should be considered with great caution in view of the low percentage of subjects whose data were significantly fitted by a 24 h cosine function.

In their concurrent studies Reinberg and co-workers (Andlauer and Reinberg 1979, Reinberg et al. 1979, 1981) found that workers with good tolerance had a greater amplitude of their temperature rhythm than those with poor tolerance. In the present longitudinal study, relatively stable predictive relationships were found between the amplitudes of temperature, negative moods and fatigue and subsequent nightshift tolerance scores. Students who showed a lower amplitude of 24 h variations in these variables before entering shiftwork tended to have better night shift tolerance after working in shifts for one and three years than those with a greater amplitude. In view of this, it seems that when short-term tolerance to a rapidly-rotating shift system is concerned, the workers who exhibit less pronounced rhythms before entering shiftwork show better tolerance after a few years of shiftwork. This beneficial subjective outcome of not having a pronounced rhythm may be viewed in the light of the notion 'that individuals with low amplitudes, having less to invert, adapt more easily' (Åkerstedt and Froberg 1976).

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