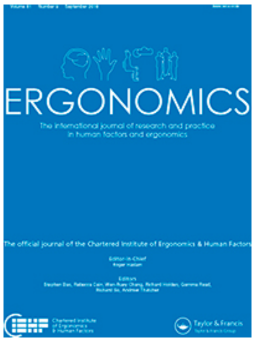

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Personality differences in the phase of circadian rhythms: a comparison of morningness and extraversion

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Individual differences in the phase of circadian (around 24 h) rhythms are thought to be important in determining adjustment to shift work and rapid time-zone transitions. Attempts to predict such phase differences on the basis of paper and pencil 'personality' tests have concentrated on extraversion and morningness, of which Kerkhof (1985), in a recent review of this literature, concluded morningness was the more important. However, the literature on which this conclusion was based suffers from a number of problems. The present study attempted to overcome these problems by examining the trends over a complete 24 h cycle for a range of performance and psychophysiological measures in students with extreme scores for both extraversion and morningness. In general, the results support Kerkhof's conclusion. However, reliable phase differences associated with morningness were confined to subjective ratings of alertness, oral temperature, and, in combination with extraversion, choice reaction time. Two alternative interpretations of this pattern of results are considered, and their practical implications discussed.

1. Introduction

There is no doubt that individuals can differ from one another in the phase of their circadian (around 24 h) rhythms in various measures, including body temperature and performance efficiency for various tasks (Kleitman 1939). Further, there is some evidence to suggest that such differences may be important in determining an individual's suitability for night work, or the speed of adjustment to rapid time-zone transitions. However, the assessment of the phase of an individual's circadian rhythm in any measure is relatively cumbersome, and is unlikely to ever gain widespread acceptance for selection or counselling purposes.

In view of this, a number of investigators have examined the relationship between scores on 'personality' tests and individual differences in the phase of circadian rhythms in various measures. Two main dimensions of 'personality' have been identified that

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may be important in this respect. On the one hand, following the finding of Blake (1967) that introverts have a somewhat earlier phase of their temperature rhythm than extraverts, several studies have examined the interaction between extraversion and time of day in a variety of measures. On the other, following Oqvist (1970), a number of authors have used 'morningness–eveningness' questionnaires that have been specifically designed to tap individual differences in the phase of circadian rhythms.

In a recent and extensive review of both approaches, Kerkhof (1985) concludes that '*individual differences in the phase position of rhythms ... can best be categorized in terms of the morningness–eveningness factor*' (p. 105). There are, however, three major problems with the literature on which this conclusion is based, and which the present study attempts to overcome.

First, very few studies using either approach have obtained measurements over an entire 24 h period. Thus, for example, of the twelve studies reviewed by Kerkhof for which a phase difference between the temperature rhythms of morning and evening types was estimated, the measurements of eight were confined to the normal waking period. Without 24 h measurements, the interpretation of any difference found as reflecting a phase difference, rather than as a more simple difference in the 'shape' of the rhythm is extremely dubious. Such a distinction is important from both a theoretical and practical point of view. Only a true phase difference would imply a difference in the underlying control system and hence in the rate of adjustment of that system to, for example, night work (Wever 1979).

Further, of the four studies that *have* obtained 24 h temperature readings, two (Folkard *et al.* 1979, Hildebrandt and Stratmann 1979) were of experienced night nurses whose rhythms may have been atypical, while the third (Froberg 1977) only found a phase difference (of 2·05 h) after 48 h of sleep deprivation. Thus only the results of Breithaupt *et al.* (1981), for which Kerkhof (1985) reports a phase difference of 1·5 h, can be claimed to support the view for a true phase difference in the temperature rhythms of morning and evening types on a normal diurnal routine.

However, obtaining 24 h measurements for any variable that requires the active co-operation of the subject may itself create biased phase estimates for different types of individual. Night time performance or mood readings require subjects either (a) to be kept awake, in which case they are partially sleep deprived when tested; or (b) to take their sleep during the preceding day-time hours, which reduces the problems of sleep deprivation but means that they have slept at an unusual time; or (c) to be awoken shortly before each testing session, which overcomes the sleep deprivation and unusual timing of sleep problems but creates its own problem, namely that subjects may not have awoken 'fully' when tested. All three techniques have obvious drawbacks, but in the case of the first two there is evidence that different types of individual may respond differently to them. Thus the data of Frobert (1977) suggest that morning, but not evening, types may phase advance their rhythms in response to sleep deprivation, while Breithaupt *et al.* (1978) have shown that evening types are better able to sleep at unusual times than morning types. The third technique, of awakening subjects shortly before the testing session, would thus appear to be the most 'neutral' with respect to individual differences, and was utilized in the present study.

The second major problem, as Kerkhof (1985, p. 99) recognizes, is that most studies of morningness–eveningness have compared relatively extreme groups, while those of introversion–extraversion have not. Strict comparison of the importance of these two dimensions is thus not possible. Indeed, partially as a result of this difference in the selection of subjects, rather different forms of analyses have typically been used. Nor do any studies appear to have examined the possibility that morningness and extraversion may interact in determining the phase of an individual's circadian rhythms. In the present study subjects were thus selected on the basis of their having relatively extreme scores for both dimensions so that their relative importance and potential interaction could be assessed.

The third major problem is that the studies of extraversion have been primarily concerned with performance efficiency, while those of morningness have seldom included performance measures and have relied more on subjective ratings of alertness. The only variable common to the majority of both sets of studies is body temperature. If a simplistic view of the circadian control system is taken, this difference should not be important. Individual differences in the phase of the control system should be reflected in similar differences in all overt rhythms. However, there is good evidence that the underlying control system comprises at least two relatively independent components that jointly control different overt rhythms in different proportions (Wever 1979, Borbely 1982).

In view of this, individual differences in the phase of one overt rhythm need *not* necessarily imply similar differences in the phase of another. Indeed, the mean phase difference between morning and evening types is reliably greater (t, 5 d.f. = 2·70; $p < 0{\cdot}05$) for alertness ratings (mean difference = 2·65 h) than for oral temperature (mean difference = 1·69 h) in the six studies that have measured both (see Kerkhof 1985, pp. 88–89 for details of these studies). Further, there is evidence that the circadian rhythms in temperature, alertness and some types of performance can behave very differently to one another (Folkard *et al.* 1983, 1985). Before drawing conclusions as to the relative importance of morningness and extraversion, it thus is necessary to examine the consistency of any phase difference over a range of variables. Further, it is important to include some measure of autonomic arousal since the phase differences observed in alertness ratings have been assumed to reflect a similar difference in the 'arousal' rhythm. The present study thus examined a range of psychophysiological measures, including skin conductance and heart rate, in order to assess the consistency of phase differences.

2. Method

2.1. *Subjects*

A translation of form B of the Eysenck Personality Inventory (EPI) (Eysenck and Eysenck 1963) and a Croation 'Morningness–Eveningness' questionnaire (Vidaček *et al.* 1977, Šverko *et al.* 1979), based on that of Horne and Ostberg (1976), were administered to a total of 128 undergraduate psychology students at Zagreb University. The mean Extraversion score for this population was 15·10 (s.d. = 3·41) while the mean Eveningness was 24·29 (s.d. = 4·75). There was evidence of a small, but reliable, correlation between the scores on these two dimensions ($r = 0{\cdot}31$, d.f. = 126, $p < 0{\cdot}01$). Since form B of the EPI was used it was not possible to extract an 'Impulsivity' score (cf. Eysenck and Folkard 1980).

From this population, four groups of seven subjects were selected on the basis of their having relatively low or high scores for both extraversion and morningness. In terms of the population from which they were drawn, the mean difference between the introverts and extraverts was of a similar magnitude to that between the morning and evening types (difference = 2·63 and 2·35 s.d.s respectively). The mean scores (and standard deviations) for the four subgroups were:

	Extraversion	Morningness
Morning–introverts	9·4 (0·8)	19·3 (3·3)
Morning–extraverts	18·9 (1·9)	18·4 (2·0)
Evening–introverts	9·9 (2·3)	30·6 (1·0)
Evening–extraverts	18·7 (0·5)	30·0 (1·8)

Note that high scores on the morningness questionnaire used indicate evening types.

The majority (20) of these 28 subjects were female, reflecting a similar bias in the population from which they were drawn. However, there was no evidence that the four groups formed differed in the proportion of males and females that they contained (chi-square = 3·50, d.f. = 3, $p > 0 \cdot 25$). These 28 subjects had a mean age of 22·1 years (s.d. = 1·9). They had undergone a detailed medical examination before entry to university, and were not suffering from any minor illness at the time of the study. None were taking medicaments at the time of the study, and they refrained from consumption of alcohol, coffee and tea during it.

In the case of the female subjects, the study was timed to avoid their menstruation, but otherwise there was a rectangular distribution over the phase of their menstrual cycles. Eleven of the subjects were tested during winter months, and 17 during spring/summer. However, the temperature in the laboratory was approximately constant at 20°C, while natural light was excluded by means of shutters on all the windows.

2.2. *Procedure*

The subjects were tested individually. For two weeks prior to the experiment proper, they came to the laboratory daily to practise the various tasks, and be habituated to the psychophysiological recording techniques. They were thus highly practised at the start of the study, obviating the need to balance out practice effects across time of day (cf. Folkard 1975). On the experimental day they came to the laboratory at 06.30 h, and remained there for the duration of the study (about 24 h). Following placement of the various electrodes, the first experimental session started at 07.45, and subsequent sessions took place every 4 hours through to 03.45. Each experimental session lasted about 90 minutes, and subjects were free to eat, read, sleep, etc., between sessions, but were awoken (if necessary) 25 minutes before the start of each session.

During each session the subjects first rated their subjective alertness on a 10 cm visual-analogue scale (VAS) and had their oral temperatures recorded by means of a thermister probe inserted sublingually for at least five minutes. They then started a 56 minute vigilance session (similar to that of Gale *et al.* 1971), during which they had to detect sets of three successive odd digits in a pseudo-random series of visually presented digits. The digits were presented at a rate of one per 5 seconds, and each new set of three digits was preceded by a visual cueing signal. A total of 168 sets was presented during the 56 minute vigil, of which 24 (1 in 7) were target sets to which the subjects were instructed to respond as quickly as possible on a response key. The scores used for analyses were the number of correctly detected target sets (detections), and the mean correct detection time (vigilance reaction time (RT)).

Skin conductance and heart rate were monitored continuously during performance of the vigilance task using standard placement electrodes. The detailed results for these measures will be reported elsewhere. In this paper we consider only the mean skin conductance and heart rate levels over the entire 56 minute period. Owing to technical problems, skin conductance and heart rate data were unavailable for some of the subjects. The data from further subjects were thus discarded at random in order to equate the size ($N = 5$) of each subgroup for these two measures.

At the end of the vigilance session, the subjects again had their temperatures recorded and rated their alertness. These measurements proved to be less noisy than those taken prior to the vigilance session and were thus used for all the analyses reported in this paper. The subjects then performed simple and four-choice reaction time (RT) tasks, and a simple psychomotor (laborimeter) task. They performed 48 trials on each of the simple and choice RT tasks. In both cases, visual stimuli were preceded by a 1-s visual warning signal. The warning-signal stimulus interval was 2, 3 or 4 s (rectangular distribution). In the choice RT task, the four stimuli were equiprobable. For both RT tasks, the mean correct RT was used for the analyses. The psychomotor task required subjects to place cylindrical pegs in holes that appeared in an aperture in the apparatus. The subjects performed three blocks of two minutes each, and the score taken for analysis was simply the number of correctly placed pegs in the total six-minute period.

3. Results and analyses

Preliminary analyses indicated that there were no reliable effects associated with gender *per se* and thus this factor was ignored. Two main forms of analyses were conducted on the data. First, mixed-design analyses of variance that examined the between-subject factors of 'Extraversion' and 'Morningness', and the within-subject factor of 'time of day', were performed on the raw data for each variable. Second, the phase and amplitude of each individual's circadian rhythm in each variable were estimated by means of the best-fitting 24 h cosine curve fitted by a least-squares method (Monk and Fort 1983). These estimates were then averaged in order to assess the mean differences between the various subgroups, and were themselves subjected to two-factor, independent-groups, analyses of variance.

This latter procedure places equal weight on the phase estimate for each subject, irrespective of amplitude (and vice versa), but suffers from two disadvantages. First, any asymmetry in the waveform affects the estimated phase. Thus any systematic individual differences in the shape of the rhythm could result in spurious differences in the estimated phase. When interpreting these phase estimates, it is thus essential to take account of the shape of the rhythm in the raw data. Secondly, in three cases it was unclear as to whether a phase estimate of, for example, 04.00 should be considered as early or late. In these cases, the difference between the individual's phase estimate, and the phase estimate based on the averaged data for all subjects on that variable, was minimized.

The results of the analyses of variance based on the raw data are summarized in table 1, and the average phase and amplitude estimates shown in table 2. The analyses based on the raw data indicated that all the variables showed reliable main effects of time of day, in most cases at the $p < 0{\cdot}001$ level (see table 1), confirming their sensitivity in this respect. Indeed of the three least sensitive measures two were from the vigilance task which was included mainly for the purpose of recording the psychophysiological measures. The overall detection rate on the vigilance task was extremely high (94%), with some subjects making virtually no omissions. For these subjects no meaningful estimate of phase or amplitude could be made. The estimates shown in table 2 for this variable are thus based on group data.

Table 1. Summary of the results of the three-factor, mixed-design, analyses of variance based on the various measures. The table shows F-ratios for all main and interactive effects. (E = extraversion; M = morningness; T = time of day). *N.B.* The degrees of freedom are 1,24 for all between subject comparisons, and 5,120 for all within subject comparisons, *except* for heart rate and skin conductance where they are 1,16 and 5,80 respectively.

	Between subjects			Within subjects			
Effect =	E	M	E × M	T	T × E	T × M	T × E × M
Alertness	<1	2·22	5·92*	35·53***	2·45*	11·02***	1·83
Temperature	1·40	<1	<1	26·72***	<1	3·86**	<1
Skin conductance	<1	<1	2·08	17·88***	1·29	<1	1·12
Heart rate	1·10	<1	<1	8·55***	<1	1·86	1·00
Simple–RT	<1	<1	<1	17·77***	<1	1·06	3·45**
Choice–RT	<1	<1	<1	16·97***	1·35	1·72	3·06*
Vigilance–RT	1·66	1·50	<1	3·99**	1·61	1·05	1·07
Vigilance–detections	2·43	3·21	6·70*	3·68**	1·08	<1	1·89
Laborimeter	<1	<1	11·24**	2·90*	1·04	1·83	1·32

* $p<0·05$; ** $p<0·01$; *** $p<0·001$.

Table 2. The mean acrophase estimates (in hours) and amplitude estimates (in brackets—see text for units) for morning and evening types, and for introverts and extraverts. The differences between these pairs of means are also shown, together with their reliabilities. (M = morningness; E = extraversion). *N.B.* The only variable for which there was any evidence of an interaction in the phase estimates between 'morningness' and 'extraversion' was Choice–RT where $F(1,24) = 2·96$; $0·05 < p < 0·10$. For all other phase and amplitude estimates, the F-ratio for this interaction was $p > 0·10$.

	Morningness			Extraversion		
	M-types	E-types	Diff. (E − M)	Introverts	Extraverts	Diff. (E − I)
Alertness	13·7	17·6	3·9***	15·8	15·4	−0·4
	(27·5)	(22·8)	(−4·7)†	(25·3)	(25·0)	(−0·3)
Temperature	16·0	18·0	2·0*	17·0	17·0	0·0
	(0·31)	(0·24)	(0·07)	(0·25)	(0·31)	(0·06)
Skin conductance	15·4	15·6	0·2	16·5	14·5	−2·0†
	(15·7)	(14·8)	(−0·9)	(15·5)	(15·1)	(−0·4)
Heart rate	14·4	17·0	2·6	15·1	16·3	1·2
	(5·1)	(4·7)	(−0·4)	(5·2)	(4·6)	(−0·6)
Simple–RT	14·1	15·7	1·6	14·4	15·3	0·9
	(20·0)	(15·3)	(−4·7)	(18·9)	(16·4)	(−2·5)
Choice–RT	14·7	16·7	2·0*	15·1	16·3	1·2
	(23·1)	(20·1)	(−3·0)	(21·3)	(21·9)	(0·6)
Vigilance–RT	17·4	16·6	−0·8	18·5	15·6	−2·9
	(31·4)	(42·4)	(11·0)	(40·2)	(30·6)	(−9·6)
Vigilance–detections	14·7	14·0	−0·7	14·2	14·6	0·4
(see the text)	(0·57)	(0·76)	(0·19)	(0·99)	(0·33)	(−0·66)
Laborimeter	16·2	17·8	1·6	18·0	16·0	−2·0
	(18·3)	(20·1)	(1·8)	(22·4)	(15·9)	(−6·5)

† $0·05 < p < 0·10$; * $p<0·05$; ** $p<0·01$; *** $p<0·001$.

3.1. *Morningness*
Inspection of table 1 indicates that interactions between time of day and morningness were limited to alertness and oral temperature. There were also reliable phase differences for both these measures (table 2). Figures 1 and 2 illustrate the mean trends over the day for morning and evening types in alertness and temperature respectively. In these, and all the other figures, the data have been plotted relative to the starting time of the session from which they were obtained.

There appeared to be a true phase difference (of nearly four hours) between the alertness rhythms of morning and evening types (figure 1). The timing of the main rise, peak, main fall and trough, was later for evening types than for morning types. There was also a suggestion that morning types had a higher amplitude alertness rhythm than evening types ($F(1,24)=3{\cdot}03$; $p<0{\cdot}10$), as might be predicted if this difference in phase reflects a difference in the endogenous period of the underlying oscillator. Similar, but less pronounced, differences between morning and evening types were observed in their temperature rhythms (figure 2).

Inspection of table 1 indicates that for no other variable was there any suggestion of a reliable interaction between time of day and morningness ($p>0{\cdot}10$ in all cases). This lack of any difference is illustrated for skin conductance in figure 3, and is confirmed by the lack of any reliable difference in the phase and amplitude estimates for this variable (table 2). Clearly the skin conductance rhythms of morning and evening types were very similar to one another, with only the slightest suggestion that morning types might

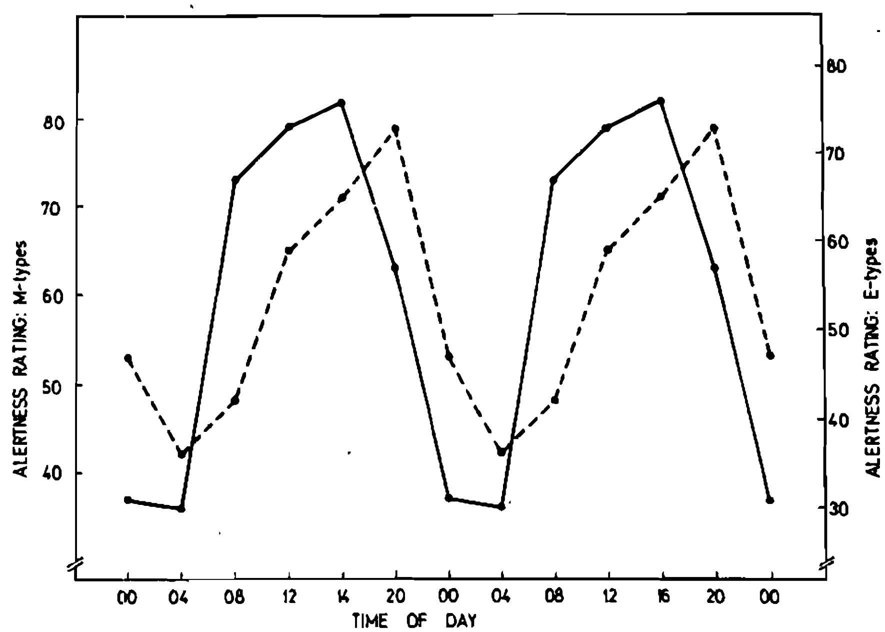

Figure 1. The circadian rhythm in alertness for morning (●——●) and evening (●---●) types. Note that in this, and figures 2–7 the data have been double plotted in order to emphasize their rhythmic nature. In addition, in this and figures 2, 4, 5 and 6 different absolute levels have been selected for the scales of the two groups in order to facilitate comparisons of the phase and amplitude of their rhythms. (M = morningness; E = extraversion.)

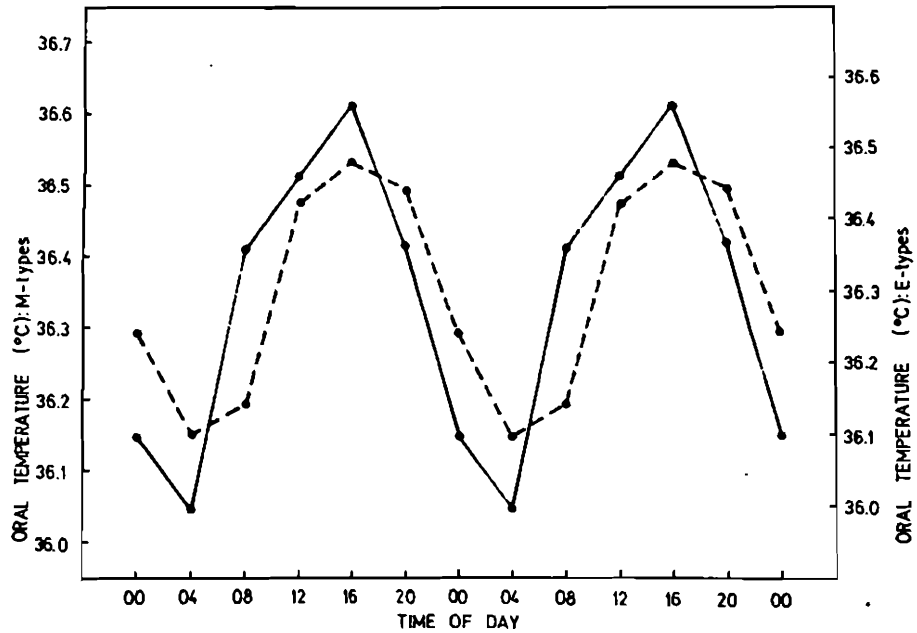

Figure 2. The circadian rhythm in oral temperature for morning (●——●) and evening (●---●) types. See figure 1 caption for further details.

have an earlier phase. Indeed, an analysis of variance comparing the phase estimates for skin conductance and alertness indicated that morningness was associated with a reliably smaller phase difference in skin conductance than in alertness ($F(1,16)=6{\cdot}57$; $p<0{\cdot}025$).

In contrast, and despite the fact that there was no reliable interaction with time of day or difference in phase estimates, the mean rhythms in vigilance RT for morning and evening types appeared to differ considerably (figure 4). Although inspection of figure 4 confirms that there was no obvious phase or amplitude difference associated with morningness, the evening types had a distinctly biphasic rhythm, with a secondary peak at 08.00, in comparison with the morning types. The reasons for this are unclear, and there was no evidence of a similar difference in the other measures. Nevertheless, it does emphasize the importance of obtaining 24 h measurements when attempting to assess the phase of a rhythm, and may go some way to explaining the relatively large differences associated with morningness reported by some authors in the trend over a restricted part of the day.

3.2. *Extraversion*

Inspection of table 1 indicates that only alertness showed a reliable interaction between time of day and extraversion. There was no suggestion of such an interaction for any of the other measures ($p>0{\cdot}10$ in all cases), nor was there a reliable phase difference for any measure (table 2). Figures 5 and 6 illustrate the mean trends over the day in alertness and temperature for introverts and extraverts.

In the case of alertness (figure 5), the peak of extraverts occurred somewhat earlier than that of introverts, although both groups showed a similar timing of their main rise

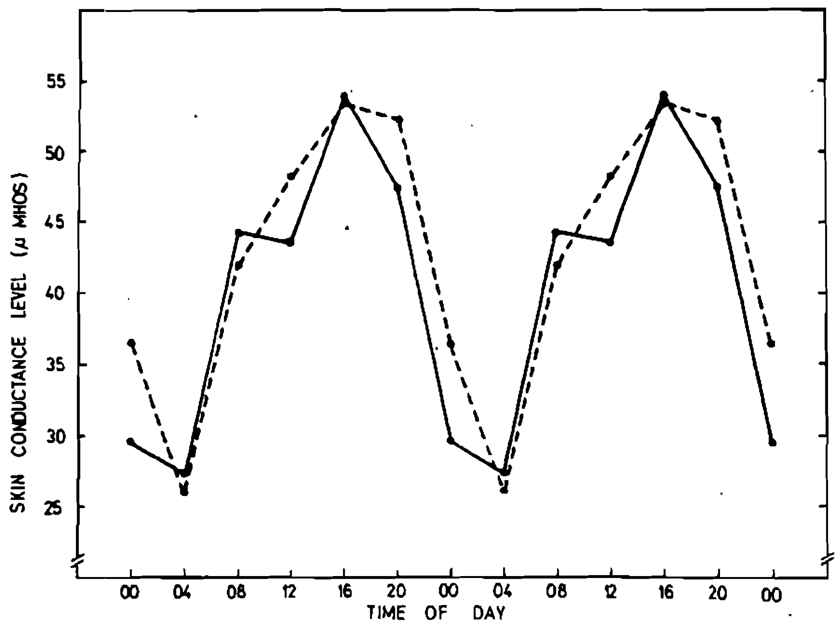

Figure 3. The circadian rhythm in mean skin conductance level for morning (●——●) and evening (●---●) types. See figure 1 caption for further details.

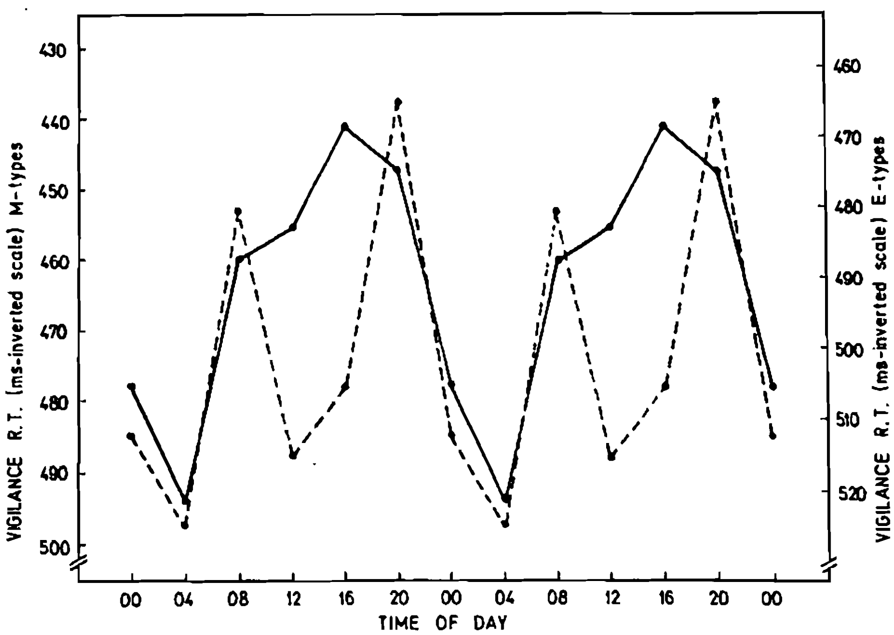

Figure 4. The circadian rhythm in vigilance RT for morning (●——●) and evening (●---●) types. See figure 1 caption for further details.

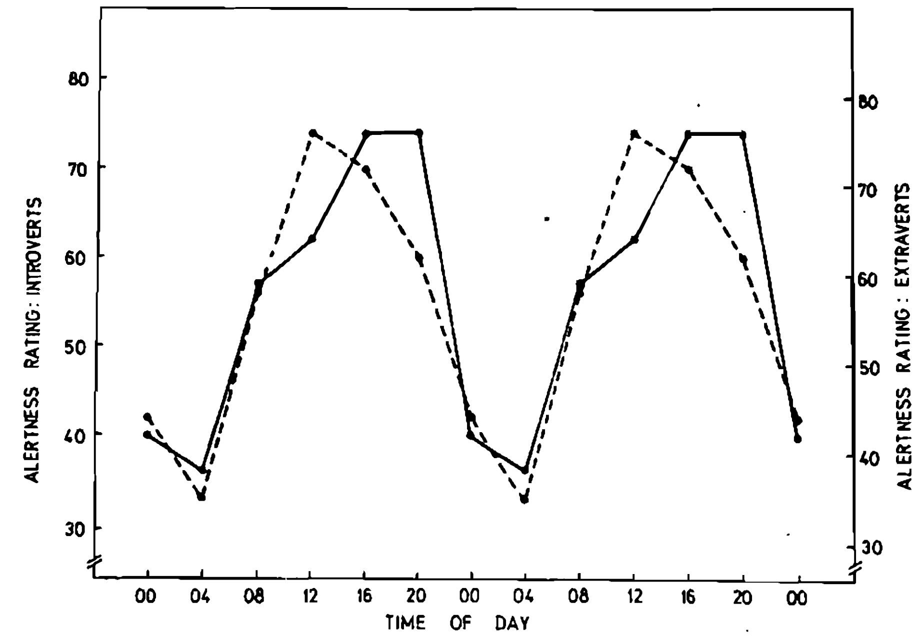

Figure 5. The circadian rhythm in alertness for introverts (●——●) and extraverts (●---●). See figure 1 caption for further details.

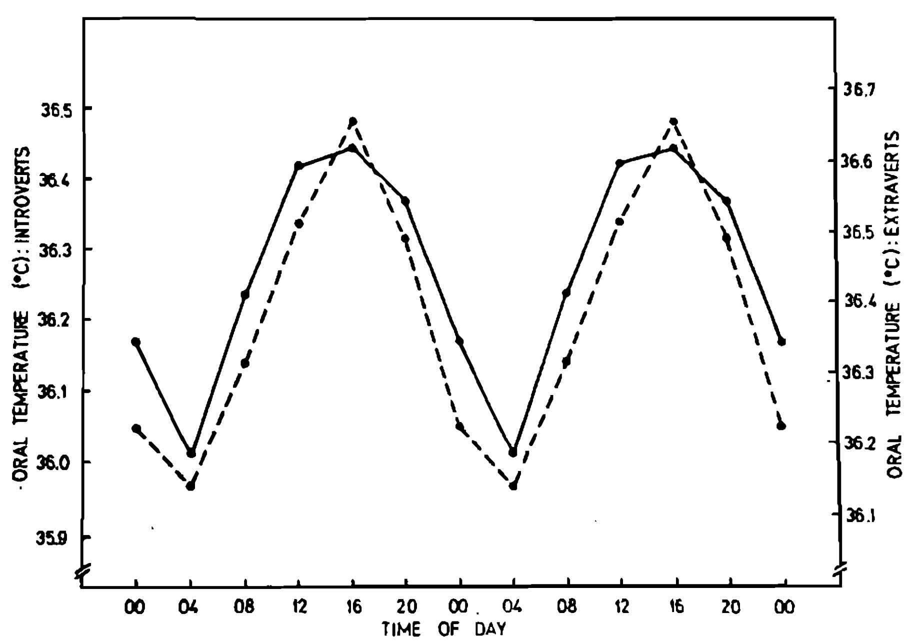

Figure 6. The circadian rhythm in oral temperature for introverts (●——●) and extraverts (●---●). See figure 1 caption for further details.

and fall, and of their trough. This difference between the two groups is thus perhaps best described as a difference in the shape of the trend between 08.00 and 20.00. However, it should be noted that this difference is the opposite to that predicted from earlier studies. Nor was this difference in shape reflected in the temperature rhythms of introverts and extraverts (figure 6). The only difference between these curves was that introverts appeared to have a less pronounced peak.

3.3. *Morningness* × *extraversion*

In the case of both simple and choice RT there *was* evidence of a reliable interaction between time of day, extraversion *and* morningness (table 1). This was paralleled by a reliable effect of morningness on the phase estimates for choice, but not simple RT (table 2), and a suggestion of an interaction between morningness and extraversion in these estimates ($F(1,24)=2{\cdot}96$; $p<0{\cdot}10$). The mean phase estimates for the four subgroups were: morning–introverts 15·0, morning–extraverts 14·4, evening–introverts 15·3, and evening–extraverts 18·1. Clearly the main difference was between the evening–extraverts and the other three groups, and this impression is confirmed by inspection of figure 7 in which the trends for these four subgroups are shown. Evening–extraverts appeared to have a genuinely later phase, and a non-reliable smaller amplitude, than the other three subgroups who showed very similar rhythms to one another. Simple RT showed a similar, but less pronounced, pattern of results.

Finally, it is of interest to note that three measures, alertness, 'laborimeter' performance and vigilance detections, showed evidence of an interaction between extraversion and morningness that was independent of time of day. These three interactions are illustrated in figure 8 in which the scores for the four subgroups have

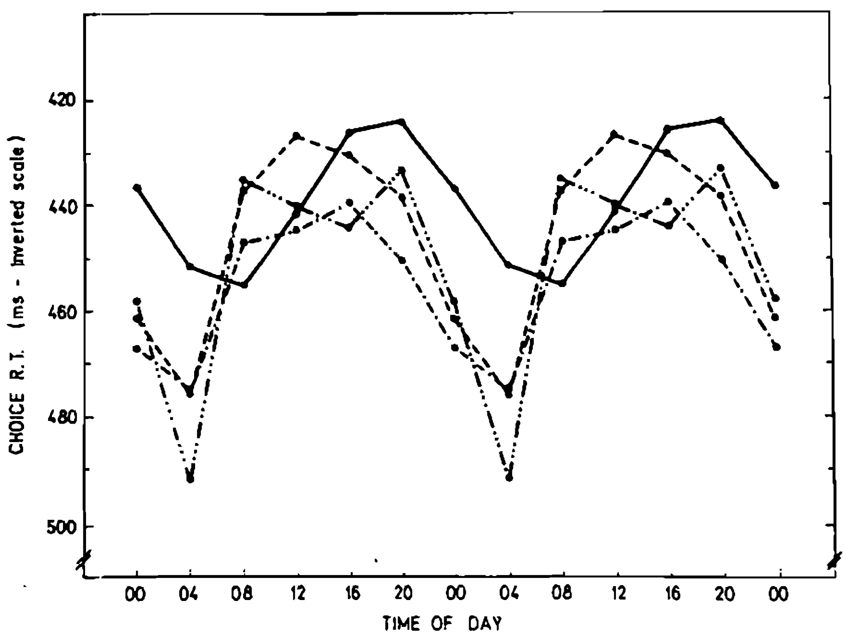

Figure 7. The circadian rhythm in choice RT for morning introverts (●–·–·–●), morning extraverts (●–···–●), evening introverts (●– – –●) and evening extraverts (●——●). See figure 1 caption for further details.

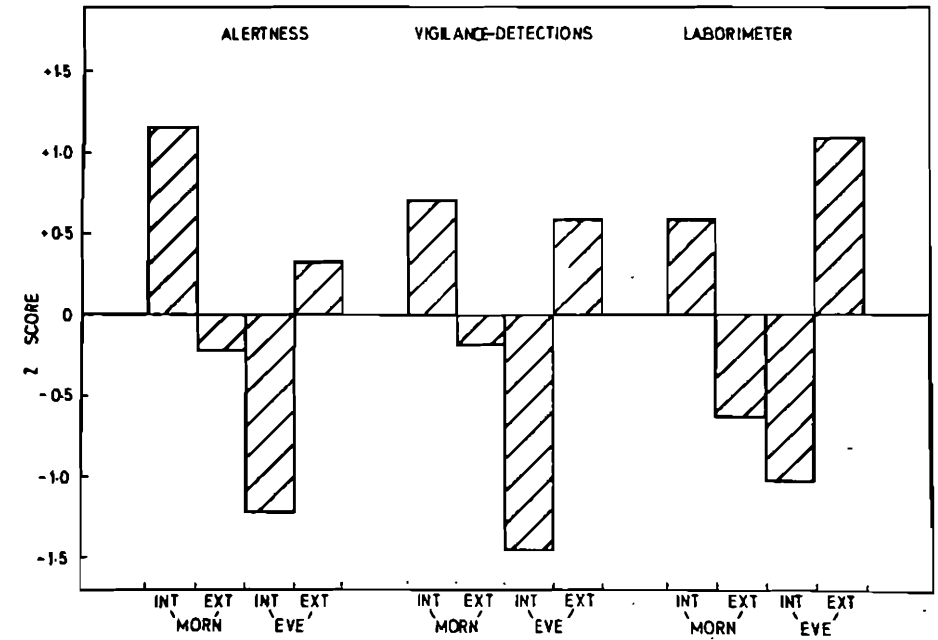

Figure 8. The mean scores, averaged over the six times of day and expressed as Z scores, of the four subgroups for alertness, vigilance detections and laborimeter performance.

been expressed as Z-scores in order to facilitate comparisons between the variables. In all three cases, morning–introverts and evening–extraverts had relatively high (i.e. good) scores, while morning–extraverts and, especially, evening–introverts had relatively low ones. The reasons for these interactions are unclear, and it should be emphasized that the study was not designed to examine them. Nevertheless, it is of interest to speculate that they may reflect a basic incompatibility between being both an introvert and an evening type, or, to a lesser extent, between being both an extravert and a morning type. Clearly it would be of interest to examine these differences in larger groups of subjects.

4. Discussion

The results of this study lend some support to Kerhof's (1985) conclusion that morningness is more important than extraversion in determining individual differences in the phase of circadian rhythms. When the direction of the mean difference in estimated phase is considered, seven out of nine variables showed morning types to have an earlier phase, while only four out of nine showed extraverts to have a later phase. However, the phase differences associated with morningness were reliable only for alertness, temperatures, and (in combination with extraversion) choice reaction time. This is despite the fact that the differences found for alertness and temperature were somewhat *greater* than those typically reported, and the fact that most of the measures used showed highly reliable time of day effects. It is thus difficult to ascribe the failure to find a greater number of reliable phase differences either to the selection of non-extreme individuals or to the use of insensitive measures. Further, only in the case of alertness was there a suggestion ($p<0{\cdot}10$) of a difference in the amplitude of the rhythms of morning and evening types. This is disappointing since a number of authors have suggested that amplitude may be important in determining the ease with which an individual's rhythms might adjust to shift work (Aschoff 1965, Kerkhof 1985, Reinberg *et al.* 1978).

It is, of course, possible that the failure to find reliable phase differences in the performance measures was due to the use of highly practised subjects. However, if the use of practised subjects was crucial in this respect it would imply that the personality differences in the phase of unpractised performance rhythms reported by other authors (see Kerkhof 1985) are of little practical consequence.

The present results thus suggest that the magnitude of the phase difference associated with morningness varies according to the variable under consideration. There appear to be two alternative explanations as to why this might be so. The first is based on the fact that the overt circadian rhythm in any given variable reflects both an endogenous oscillatory component, and an exogenous ('masking') component. Variables differ in the relative magnitude of these two influences such that some (e.g. heart rate) are predominantly exogenously determined, while others (e.g. temperature) have a larger endogenous component (Minors and Waterhouse 1981). If morningness is associated with differences in the phase of the endogenous oscillator then variations in the size of the phase difference in overt rhythms might reflect differences in the magnitude of their exogenous component. If it is assumed that the phase of the exogenous component is uninfluenced by morningness, then purely exogenously determined rhythms should show no effect of morningness, while purely endogenously determined rhythms should show the greatest phase differences associated with morningness. If this view is correct it implies that of the variables considered in this study, the circadian rhythm in subjective ratings of alertness was the least influenced by exogenous factors. There is some evidence to support the somewhat counter-intuitive view that the rhythm in alertness is more endogenous than that in temperature (Folkard *et al.* 1985).

The second explanation differs from the first in assuming that the fundamental difference between morning and evening types lies not in the phase of their endogenous oscillators, but in the phase of their alertness rhythms. The questionnaires used to distinguish between morning and evening types essentially rely on individuals estimating the phase of their circadian rhythm in alertness. The subsequent finding of a phase difference in the alertness rhythms of morning and evening types when assessed more objectively is thus to some extent a measure of the test–retest reliability of morningness questionnaires. If we assume the phase of any given overt rhythm to be normally distributed across individuals within the population, then morningness questionnaires simply select relatively extreme subjects with respect to this distribution for the alertness rhythm.

The finding of a phase difference in the circadian rhythm of another variable would then imply that it was in some way related to that in alertness. Variations in the size of this phase difference would reflect differences in the strength of this relationship (Folkard *et al.* 1987). Such a relationship may, but need not, reflect common control by an endogenous oscillator. If the rhythm in alertness does indeed have a large endogenous component, then a large phase difference between individuals might well be reflected in the phase of their endogenous oscillators. However, a relatively exogenous rhythm might also be related to that in alertness via the potential exogenous or masking influence of variations in alertness. Thus, for example, the unreliable, but relatively large, phase difference in heart rate found in the present study could reflect variations in activity associated with the rhythm in alertness. Indeed rhythms such as temperature might be related to that in alertness through both endogenous *and* exogenous influences.

The present results do not allow us to determine the relative worths of these two explanations, and indeed the authors differ in terms of which they favour. Nevertheless, and despite their obvious overlap, these interpretations make rather different predictions. The first explanation predicts that the magnitude of the phase difference between the circadian rhythms of morning and evening types will increase across variables with an increasing endogenous component. In contrast, the second explanation predicts that it will increase across variables as their relationship to alertness increases. From a practical point of view, the importance of the distinction between these explanations is clearly limited to the variables for which they make different predictions.

More important from the practical viewpoint is the fact that the present results indicate that the magnitude of the phase difference between morning and evening types will differ depending on the variable under consideration. The implications of this is that we cannot use morningness scores to predict relative efficiency on a given task at a given time *unless* we have previously established a phase difference for the task between morning and evening types. The finding of a large phase difference in alertness when individuals are relaxing following completion of a vigilance task has to be offset against the finding of no phase difference in performance or skin conductance during the task itself. Clearly this limits the usefulness of current morningness questionnaires. This is *not* to imply that large phase differences in performance do not exist, but simply to argue that they cannot be predicted on the basis of current 'personality' tests.

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On pense que les différences inter-individuelles dans la phase du rythme circadien revêtent une grande importance pour déterminer l'adaptation au travail posté et à des transitions brusques entre fuseaux horaire. On s'est efforcé de prédire ces différences à partir de résultats à des tests de personnalité (papier crayon) portant sur la dimension d'extraversion et de matinalité. A partir d'une revue bibliographique récente, Kerkhof (1985) a conclu que le critère de matinalité était important. Cependant les travaux sur lesquels il base sa conclusion présentent un certain nombre de difficultés. La présente étude s'efforce de surmonter ces difficultés en examinant les tendances pendant un cycle complet de 24 h pour un ensemble de mesures psychophysiologiques et d'évaluations de la performance chez des étudiants qui présentent des valeurs extrême sur les échelles d'extraversion et de matinalité. Dans leur ensemble, les résultats confirment la conclusion de Kerkhof. Toutefois, des différences significatives dans les phases associées à la matinalité, se restreignent à l'estimation subjective du niveau d'éveil, à la température buccale et, en association avec l'extraversion, au temps de réaction de choix. On examine deux autres possibilitiés d'interprêtation de ces résultats et on argumente leur applicabilité.

Individuelle Phasenunterschiede im Circadianrhythmus (24-h Periodik) erscheinen hinsichtlich der Anpassung an Schichtarbeit und bei raschen Zeitzonenverschiebungen von Bedeutung. Bemühungen mit dem Ziel, Phasendifferenzen mit Hilfe von Papier-Bleistift-Persönlichkeitstests zu bestimmen, behandeln im allgemeinen insbesondere die Extraversion und das Morgenerleben. In einer neueren Literaturrecherche von Kerkhof (1985) wird dem Morgenerleben die Priorität eingeräumt. Allerdings weist die Literatur, die diesen Ergebnissen zugrundeliegt, mehrere Schwachpunkte auf. Die vorliegende Studie versucht diese durch vollständige Trenderfassung über 24 h-Perioden zu vermeiden, indem Studenten herangezogen werden, die Extremwerte hinsichtlich Extraversion sowie Morgenerleben aufweisen; sie werden durch Leistungs- und psychophysiologische Messungen untersucht. Die Ergebnisse Kerkhofs stützen diese Ergebnisse überwiegend. Allerdings zeigen sich Phasenunterschiede beim Morgenerleben, die über die subjektive Empfindung der Wachsamekeit, die Oraltemperatur und in Verbindung mit der Extraversion durch die Wahlreaktionszeit deutlich werden. Zwei unterschiedliche Interpretationen des Lösungsweges werden gezeigt und die praktische Konsequenz wird diskutiert.

概日リズム（約24時間）の位相の個人差は交替制勤務と急速な時間帯変更への適応を決めるのに重要だと考えられる。筆記「性格」試験に基づいてそのような位相差を予測する試みは外向性と朝型に重点を置いてきた。この種の文献の最近の再検討で，Kerkhof（1985）は朝型がより重要であると結論した。しかし，その結論が基づいている文献は幾つかの問題がある。本研究は外向性と朝型の両方で極端な得点をあげた学生の一連の作業成績尺度と心理物理的尺度について丸24時間のサイクルにわたって傾向を調査することによってこれらの問題を克服しようとした。一般に研究結果はKerkhofの結論を裏付けている。しかし，朝型に関連する信頼できる位相差は主観的警戒評点，口腔温および外向性と組み合わさって，選択反応時間に限定されていた。このパターンの結果の2つの可能な解釈を考慮し，その実際的意義を考察する。