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Circadian Rhythms: Implications for Psychology[1]

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Biological and behavioural functions are typically characterised by regular 24-hr or circadian fluctuations in rate or magnitude. Reaction to drugs and other stressors, performance of psychological and psychomotor tasks, learning, drive, reinforcement, and receptor sensitivity have been demonstrated to vary with time of day, frequently interacting with temperament, social conditions, and complexity. Loss of the normal time relations among the various circadian rhythms often leads to impairment of physical and psychological well-being, and may be significantly implicated in the problems of rapid transmeridial travel and industrial shift work, and in certain psychiatric disorders. Failure to take the temporal factor into account distorts much research in the life sciences, as well as reducing the potential effectiveness of a number of applied endeavours.

During the past decade, members of the scientific community as well as the lay public have become increasingly aware that a vast range of biological properties in a wide range of species are characterised by systematic fluctuations in rate or magnitude. Some rhythms, such as those recorded in the electroencephalogram, are rapid; others, like ovulation and the metabolic rate of hibernators, are of lower frequency. Especially prominent are cycles that recur daily—the so-called circadian (from *circa* = "approximately" plus *dies* = "a day") rhythms. Rate of cell division, lymphocyte count, pH of tears, adrenal and pituitary secretion, plasma sodium level, resting blood pressure and pulse, body temperature, and many other characteristics vary regularly over the course of 24 hr in a pattern that is neither random nor simply the passive response to environmental changes.

Particularly striking are the time-of-day differences in the organism's reaction to various challenges or stressors. For example, a dose of amphetamine that is lethal for 78% of a group of rats if injected at 3 a.m. will kill only 7% if injected just three hours later (Scheving, Vedral, & Pauly, 1968b); a nicotine dose kills more than eight times as many at the beginning of the dark phase of the cycle than four hours earlier (Scheving, 1980); identical injections of lidocaine hydrochloride produce convulsions in 6% and 83% of experimental animals at 3 p.m. and 9 p.m., respectively (Lutsch & Morris, 1967); audiogenic seizures are most frequent at night (Halberg, Bittner, & Gully, 1955); and shock-induced ulcers are much more likely to result from sessions during the dark (active) phase than during the light (Brown & Finger, 1974). Not surprisingly, the therapeutic effectiveness and toxic side effects of a variety of medicinal substances are time-related, clearly demonstrable with pheno-

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barbital (Ross, Sermons, & Walker, 1978; Scheving, Vedral, & Pauly, 1968a), sodium salicylate (Reinberg, 1967), chlordiazepoxide (Marte & Halberg, 1961), anti-histamines (Reinberg, 1967), and several oncostatic drugs (Hrushesky, Levi, Halberg, Haus, Scheving, Sanchez, Medini, Brown, & Kennedy, 1980; Levi, Hrushesky, Haus, Halberg, Scheving, & Kennedy, 1980; Scheving, 1980).

The importance of the temporal variable in these and other functions is recognised in the emergence of a quasi-independent discipline, sometimes called chronobiology, with its own appropriately labelled journals *(The International Journal of Chronobiology* and *Chronobiologia)* and organisation (International Society for Chronobiology). A number of reviews (Aschoff, 1963; Danilevsky, Goryshin, & Tyshchenko, 1970; Halberg, 1969; Hillman, 1976; Luce, 1970/1978; Mills, 1966; Rusak & Zucker, 1975), reports of meetings (Aschoff, 1965; Cold Spring Harbor Symposium, 1960; Brown & Graeber, 1982; International Society for Chronobiology, 1977; Menaker, 1971; Rentos & Shepard, 1976; Scheving & Halberg, 1980; Scheving, Halberg, & Pauly, 1974), and general treatises written from the background of several disciplines (Brady, 1979; Bünning, 1973; Colquhoun, 1971; Conroy & Mills, 1970; Hastings & Schweiger, 1976; Hedlund, Franz, & Kenny, 1975; Mayersbach, 1967; Mayersbach, 1979; McGovern, Smolensky, & Reinberg, 1977; Mills, 1973; Palmer, 1976; Richter, 1965; Saunders, 1977), provide a convenient starting point for detailed exploration of the field.

Examples of Circadian Rhythms

Psychologists have been somewhat slow to recognise the extent to which the results of their investigations can be distorted by circadian rhythmicity, and the far-reaching implications for their applied endeavours. Because of the short history of research efforts in this area, with relatively few behavioural scientists having become directly involved, it is possible at this point to do little more than illustrate the kinds of problems touching on psychology that demand clarification.

Body Temperature

When the oral temperature of a healthy human subject is recorded at regular intervals for several days under standard conditions, a reasonably consistent circadian cycle is revealed, with a range of two degrees or so (Colquhoun, 1971, p. 41). From its lowest point shortly before waking, the curve starts to rise slowly, after about an hour accelerates to a steep rate until around noon, and continues its upward trend more slowly until the maximum is reached between 6 and 9 p.m. As sleep time approaches, a precipitous drop begins, continuing through most of the sleeping hours.

Individual and group differences. There are of course minor deviations from this general pattern, under the influence of such transitory factors as extreme ambient temperature, ingestion of hot or cold substances, and vigorous exercise. There are also reliable individual differences in both the amplitude of the temperature curve and its temporal details. So-called "morning people", identified by their expressed preference for early rising and retiring and for doing their important work relatively early in the day, tend until afternoon to have higher temperatures than do "evening people"; the converse relationship holds during the evening (Horne & Östberg, 1976). There is a tendency for extreme morningness to be associated with high scores on scales of introversion, and eveningness with extroversion (Pátkai, 1971). Thus it is reported that body temperature of individuals who are strongly introverted average higher in the morning and lower in the evening than that of extraverts (Blake, 1967), and that the peak of the temperature curve of schizophrenics occurs earlier than that of other psychiatric patients and of non-psychiatric controls (Morgan & Cheadle, 1976).

Temperature as a master rhythm. It would seem reasonable to argue that the hour-to-hour changes in body temperature are simply the reflection of varying energy need, resulting from changing levels of general muscular activity. This interpretation is contradicted by the observation that increases in activity tend to follow rather than precede rises in temperature (Aschoff & Saint Paul, 1973). At the least, temperature level may be a predictor of changes in other functions, and it is worth exploring the possibility that temperature plays a causal role in modifying other functions—that the temperature cycle is in some respects a master rhythm.

What other characteristics, biological or psychological, fluctuate in parallel with temperature, suggesting the possibility of their partial control by temperature? Informal testimony indicates that mood, or temporary emotional status, is a likely candidate, both in normals and in depressed individuals. It has been postulated that the superior performance of competitive athletes in the evening (Rodahl, O'Brien, & Firth, 1976) and the greater training effect of late afternoon exercise sessions (Baier & Rompel-Pürckhauer, in press) are functions of the elevated temperature. Brainwave features that are used in the diagnosis of auditory-system pathology vary in circadian fashion, and their regular relation to temperature has been demonstrated (Marshall & Donchin, 1981). Reliability of diagnosis might be improved by adopting a time-adjusted correction factor.

Performance on the simple task of letter cancellation has been shown to correlate closely with oral temperature over the waking hours, except for the brief drop in score during early afternoon similar to that found in a great many psychological and psychomotor tests (Blake, 1971). Since the temperature of introverts averages higher than that of extraverts at 8 a.m., with the relationship reversed at 9 p.m., it might be predicted that the former group will have the higher scores in the morning and the lower scores during the evening hours. Such a result has been obtained—at least when the subjects are tested in isolation. When the testing is carried out in a group setting the inter-group difference disappears (Blake & Corcoran, 1972). Perhaps the face-to-face confrontation, with the intimation of competition, differentially affects the arousal or motivation level of the two groups; it may be proposed that time of day (or temperature) is a predictor more of *preference* for working, than of *ability* to perform this simple task under optimal motivation conditions.

A further complication is the complexity of the task. With performances more intellectually demanding than letter cancellation, such as required on logical-syllogism and grammatical-transformation tests, the direct relationship breaks down during the afternoon and evening when speed scores are plotted, and with accuracy measures the trend of the group is downward throughout the entire day, even as the temperature curve is continuing to rise (Folkard, 1975). It has been hypothesised that performance on tests with low short-term memory load is closely correlated with body temperature, but that when a high memory load is imposed the correlation becomes negative and peak performance occurs earlier in the day (Folkard, 1975; Folkard, Knauth, Monk, & Rutenfranz, 1976).

Learning

Acquisition (Gordon & Scheving, 1968; Pagano & Lovely, 1972) and performance (Ghiselli & Patton, 1976) of shock avoidance in the rat have been shown to vary with clock hour, as does acquisition of the conditioned emotional response (Evans & Patton, 1970). There is some evidence that advantage would accrue from scheduling school subjects according to time of day, with repetitive drill (spelling, arithmetic tables) being more effective in the morning and material requiring complex thinking and restructuring better learned during the afternoon (Mackenberg, Broverman, Vogel, & Klaiber, 1974). The duration of the acquisition-testing interval may be an interacting variable, with short-term retention superior after morning study of verbal material and delayed retention favoured by practice later in the day (Folkard, 1982; Folkard, Monk, Bradbury, & Rosenthall, 1977).

Drive and Reinforcement, Aggression

The circadian cycle of learning may depend in part on temporal variation of drive level and reinforcement, which has been demonstrated in a variety of situations. The sexual performance of male rats depends on the point in the light-dark cycle (Beach & Levinson, 1949; Richter, 1970). The oestrous cycle of the female is most often of 4-day duration (Finger, 1969), and the onset of receptivity almost always occurs during the dark portion of the 24 hr (Blandau, Boling, & Young, 1941). Individual differences in daily pattern of sex drive have not been studied intensively in humans, but invite consideration in instances of marginal compatibility and sexual hypesthesia. Ingestion by rats with ad libitum access to food takes place largely at night, presumably reflecting a 24-hour cycle of hunger (Bare, 1959; Peng, Jiang, & Hsü, 1980). The rate of rats' bar-pressing for reinforcing stimulation via hypothalamic or septal electrode placement is several times greater during night than during day (Terman & Terman, 1975). At least with extraverted subjects, knowledge of results increases speed of letter cancellation during morning sessions while the same factor impairs performance during the evening (Blake, 1971).

Aggressive behaviour in rodents peaks early in the dark 12 hr, whether induced by electric shock of pairs (Sofia & Salama, 1970) or by the introduction of a stranger (Landau, 1975).

Receptor Functions

A few examples indicate that receptor sensitivity is far from invariant around the clock. Visual acuity and rate of dark adaptation are maximal around 3 a.m.; in a practical situation this advantage is probably more than cancelled by a concurrent low point of such functions as vigilance and reaction speed (Hildebrandt & Engle, 1972; Knoerchen, Gundlock, & Hildebrandt, 1975). Chronic pain patients rate their discomfort as increasing until a late evening peak, about the same time that threshold to experimentally-induced pain is lowest (Folkard, Glynn, & Lloyd, 1976; Glynn, Lloyd, & Folkard, 1976; Pöllmann & Harris, 1978). Circadian variation in pain sensitivity may in the rat be confounded by the cycle of food intake (McGivern & Bernston, 1980), which in turn affects the endorphin cycle. The analgesic effect of placebo is greatest about noon (Pöllmann & Hildebrandt, 1977), and hyperalgesia in rats is considerably greater when naloxone is injected midway through the dark phase than early in the light (Frederickson, Burgis, & Edwards, 1977).

Internal Pacemakers

Since the early demonstrations of daily rhythms in plants (e.g., De Mairan, 1729), one of their most challenging properties has been the tendency to continue cycling in the absence of apparent time cues in the immediate environment. The activity cycle of rats living in running wheels under conditions of continuous darkness will sometimes persist for months, but with a period reliably shifted a few minutes from 24 hr (i.e., circadian). Under these free-running conditions, there are consistent individual differences, with the cycle lengths of some rats a few minutes less than 24 hr and of some as much a half-hour longer than 24 hr. When human subjects are isolated without timepieces, in caves or carefully shielded bunkers, the results are similar (Wever, 1979). While an occasional cycle of greatly deviant period may intrude into the records of activity, temperature, and urine volume and composition, most are within a few hours of 24, and the mean period of a long series of subjects is a few minutes more than 25 hr. In the absence of obvious environmental cycles that match the observed behavioural and physiological cycles and that might therefore serve as the controlling rhythms or Zeitgebers, most investigators have concluded that under these circumstances the control must be endogenous, and probably an inherent property of the organism. The natural tendency to oscillate with periods somewhat different from 24 hr is ordinarily overridden by the external exactly-24-hour cues (chiefly the illumination regimen in most species, and the socially-imposed schedule in humans); that is, the slight deviation is corrected daily, rather than being allowed to accumulate.

The search for the hypothesised internal pacemaker(s) or biological clock(s) has most often involved extirpation of various organs or neural centers and observation of the resulting changes in rhythms (Block & Page, 1978; Menaker, Takahasi, & Eskin, 1978; Rusak & Zucker, 1979). For example, after pinealectomy the sparrow's perch-hopping rhythm under conditions of constant dark or light is abolished, reappearing when a transplant is made of a donor's pineal (into the eyeball). This is interpreted as evidence that the pineal is a critical part of the bird's timing system. It is apparently not the only pacemaker, however, for even after extirpation the activity can be entrained to a light-dark cycle, with anticipation of dawn, and when the bird is transferred to continuous darkness the loss of the free-running rhythm occurs only gradually. In rodents the principal timing component thus far identified is the suprachiasmatic nucleus of the hypothalamus; its removal is followed by distortion or loss of rhythmicities of locomotion, ingestion, temperature, ovulation, pineal N-acetyltransferase production, sleeping, and adrenal cortical secretion. Other species investigated with success are *Aplysia californica* or the sea hare, with the eye not only maintaining its autonomous circadian rhythm of electrical discharge when isolated, but apparently exerting some controlling effect on locomotor activity under normal circumstances; the cockroach, with locomotion under the influence of the lobula and medulla of the optic lobes; and the silkmoth, in which the hour of eclosion within a population of larvae is under the control of the cerebral lobes of the brain.

The principal assumption regarding the timing system is not without challenge. The exogenous point of view (Brown, Hastings, & Palmer, 1970) is that the cycles of the organism are always the consequence of some sort of external cycles, and that if the organism could be shielded from all of them, including those of a subtle and presently unidentified geophysical nature, circadian rhythms would disappear. In somewhat modified form, the argument accepts the existence of internal cycles—but these are cycles of fluctuating sensitivity to the controlling external stimulation. Individual differences in period of biological and behavioural rhythms would then be attributed to individual differences in this cycle of sensitivity—to differences, as it were, in the mechanism by which the bodily functions are coupled to the cycles of external stimulation (Avery, 1974).

Granting that circadian rhythmicity, either of an autonomous internal clock or of sensitivity to external control, is under powerful genetic influence, it is not impervious to experimental factors. As the result of extended exposure to non-24-hour schedules of light and dark in early life, the free-running activity cycle of cockroaches deviates significantly and persistently from normal (Page & Block, 1980), and an appreciable effect of experience is demonstrable in rats (Finger & Brown, 1971) and mice (Pittendrigh & Daan, 1976).

Desynchronization of Rhythms

The timetable according to which the many bodily processes function is a complex one, some of the details of which have been described. For example, in the mouse RNA synthesis peaks seven or eight hours earlier than DNA synthesis and about 12 hours before liver weight reaches its daily maximum. In the human the rate of urinary excretion of magnesium reaches its high point five hours before the end of sleep, sodium two and a half hours after waking, and potassium four hours thereafter. According to some investigators loss of the normal time relations, termed dissociation or internal desynchronization, impairs the bodily economy. In such a state intellectual, psychomotor, and physical performances may be reduced. emotional state disturbed, and perhaps resistance to disease diminished. It is hypothesised that dissociation is implicated in the symptoms of the transmeridial traveller (Antal, 1975; Graeber, 1982; Klein & Wegman, 1980; Sasaki, 1980), the health and production problems of the industrial shift worker (Rentos and Shepard, 1976), the episodic depressions of some psychotics (Wehr, 1982), suicide (Rockwell, Winget, Rosenblatt, Higgins, & Hetherington, 1978) as well as the generally inefficient and unhappy days periodically experienced in the course of normal living, and the deterioration of capacities that characterises aging (Samis, 1968).

Transmeridial Jet Travel

The first problem facing jet travellers is the possibility that they will be required soon after arrival at their destination to perform according to local time, with their internal clocks still set to the time at point of origin and their capability cycles therefore out of step with the new temporal demands. Their circadian rhythms will eventually adjust to the new clock time—a rough rule of thumb calls for one day of recovery for each time zone traversed, whether the trip is continuous or interrupted—but meanwhile the additional factor of dissociation presumably adds its interfering effect. It is inevitable that the normal phase relations among the various functions will temporarily be lost during the adjustment process, because some of the biological cycles shift to match the new time zone almost immediately while others change by only an hour or so a day. It is only when the most resistant function has reached its proper niche in the internal schedule that optimal synchrony is regained. The effectiveness of countermeasures, including the manipulation of ingestion pattern and of social factors surrounding travel, is under investigation (Cuthbert, Graeber, Sing, Schneider, Sodetz & Tyner, 1979; Ehret, Groh, & Meinert, 1980; Graeber, Cuthbert, Sing, Schneider & Sessions, 1979).

Both anecdote and objective study indicate that westward travel is for most people less disruptive than eastward, although the complexity of the real-life situation makes a dogmatic statement inappropriate. The usual explanation is that a flight toward a later time zone requires that one or more cycles be lengthened for the resynchronization to be accomplished. This is relatively easy for the majority of individuals, whose natural period is already longer than 24 hr. Conversely, individuals with free-running period of less than 24 hr have been reported to adjust more readily to eastward than to westward travel (Atkinson, Kripke, & Wolf, 1975).

Individual differences enter not only into the asymmetry of the directionality effect, but apparently into the degree of susceptibility to dissociation. The greater severity seems to be associated with morningness, strong introversion, and high scores on tests of neuroticism (Lund, 1974). Still to be examined in depth are more idiosyncratic factors in susceptibility, and the possible protection afforded by general experience or specific training.

Industrial Shift Work

A similar sort of analysis can be applied to the shift work situation (Colquhoun, Folkard, Knauth, & Rutenfranz, 1975). Changing from day shift to night shift is in a sense equivalent to jetting eastward across eight time zones (or westwards across 16). When the change is first made, night workers find some of their capacities at low ebb when needed for the job, and there is presumably the complication of internal desynchronization. By the end of the first work week a considerable degree of phase shifting will have taken place, but it is usually the case than on the weekend the workers will revert to the normal ("day-shift") pattern of the community. The beginning of the next week on night shift will therefore find them faced once more with the necessity of adjusting their internal timetable, although the magnitude of the problem may be less than it was the week before.

The traditional rotating schedule—one week on day shift, one week on night shift, one week on evening shift, and repeat—would be expected to be the worst of all, since the state of dissociation would be virtually continuous. There are data confirming this, with measures of accidents and minor illness (Tasto, Colligan, Skjei, & Polly, 1978). On logical grounds it might be predicted that a rapidly rotating schedule, with a change to the new work hours coming after only one or two sessions on the previous regimen, would be less deleterious. This schedule would be especially desirable with workers demonstrated to be relatively resistant to phase shifts of the internal clock.

A predictor of long-range tolerance to shift work would be useful. There is preliminary evidence that this capacity is associated with both high resistance to phase shifting and high amplitude of the body temperature cycle (Reinberg, Vieux, Andlauer, Smolensky, Ghata, Laporte, & Nicolai, 1979). Flexibility of sleep habits, more likely to characterise evening people than morning people, seems also to be a desirable trait in workers on a continuing shift program (Folkard, Monk, & Lobban, 1979). Total duration of experience with shift work, and age, are also factors affecting ability to maintain efficiency and health (Glenville, 1979).

It is easier to assert that long-continued exposure to shift work must have harmful physical and psychological consequences than to demonstrate it unequivocally. A favourite strategem is to assume the relevance of an animal model, and subject laboratory animals to repeated phase shifts by manipulating the illumination pattern (Finger, 1982). Experiments with a variety of insect species (Aschoff, Saint Paul, & Wever, 1971; Hayes, Cawley, Halberg, Sullivan, & Schechter, 1976), and with mice (Halberg, Nelson, & Cadotte, 1977) point to a shortening of life span, with no mediating mechanism of a specific sort identified. Unfortunately, from the standpoint of consistency, a recent study (Finger, 1982) found no overall difference in longevity between rats never phase shifted and those phase shifted 12 hr weekly beginning shortly after weaning and continuing until death.[2]

Mood Disorders

The proposition that alteration of the circadian timetable increases the probability of psychiatric disturbance is supported by the observation that the circadian rhythm of adrenal cortical activity tends to be advanced several hours in groups of depressed patients (Fullerton, Wenzel, Lohrenz, & Fahs, 1968), and that the diurnal temperature cycle is sometimes modified (Kramer & Katz, 1978; Nikitopoulou & Crammer, 1976)[3]. It may be that the therapeutic effectiveness of lithium depends upon its demonstrated ability to lengthen internal cycles (Kripke, Mullaney, Atkinson, & Wolf, 1978), and that successful treatment by sleep shifting (Wehr, Wirz-Justice, Goodwin, Duncan, & Gillin, 1979) or sleep deprivation (Pflug, 1976; Rudolph & Tölle, 1978) depends on the restoration of normal synchrony among various circadian functions or between the overall pattern of internal rhythms and the environmental cycle.

In a speculative extrapolation from the psychiatric to the normal population, it may be hypothesised that a lesser degree of dissociation or a minor mismatch between internal and external rhythms underlies the transient episodes of inefficiency and mood disturbance that many people experience. In the search for factors contributing to the disturbances of synchrony, it is relevant to examine the occasional individual in whom the deviation of the internal pacemaker from 24 hr accumulates rather than being corrected each day (Miles, Raynal, & Wilson, 1977).

Memory

From the animal laboratory comes the suggestion that desynchronization impairs retention, not just temporarily but permanently (Tapp & Holloway, 1981). Immediately following rats' acquisition of a passive shock-avoidance response, the light-dark regimen was phase shifted. Testing after synchrony had been reestablished revealed significant performance deficits, with the severity of loss related to the magnitude of the shift. This experimental paradigm may prove useful in the analysis of the neurochemical substrate of learning and memory (Tapp & Holloway, 1979).

Aging

Associated with the aging process are a variety of temporal changes, such as in the pattern of rat activity (Finger, 1979) and ingestion (Peng *et al.*, 1980) and in the distribution of sleep episodes and of stages of sleep (Feinberg, 1974; Webb, 1978). The evidence that dissociation becomes increasingly prevalent in older persons is modest (Cahn, Folk, & Huston, 1968; Ehret, Groh, & Meinert, 1978), and it is unclear whether the disruption of synchrony is the cause or the result of physical deterioration. In either case, the identification of factors minimising desynchronization will have practical implications for gerontology as well as for jet/space travel and shift work. The socially dictated pattern of living is apparently the most potent Zeitgeber in the human (Aschoff, Fatranska, Giedke, Doerr, Stamm, & Wisser, 1971). It would seem reasonable therefore to insure the occurrence of meaningful and prominent events to take the place of the demands from which the individual is released, voluntarily or involuntarily, with increasing age. The emphasis, perhaps, should be upon active participation, involving as much physical exertion as the state of health permits.

"Biorhythms"

The popularised concept of "biorhythms," with its accompanying notion of "critical days," has attracted considerable attention and commercial exploitation. It is alleged that birth initiates a 23-day physical cycle, a 28-day emotional cycle, and a 33-day intellectual cycle, and that these continue indefin-

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[2] Internal desynchronization and altered phase relations with the environmental cycles have been observed in the subordinate members of grouped mice maintained on a normal lighting regimen. Deleterious effects upon health of such social conditions could only be inferred, since the subjects were followed for a relatively brief segment of their life span (Farr & Andrews, 1978). It has been suggested that the stress of group living can interact with repeated light-dark shifts to increase susceptibility to drug injection (Halberg, Nelson & Cadotte, 1977, pp. 136-137).

[3] But cf. Kripke, Mullaney, Atkinson, Huey, & Hubbard, 1979.

itely without change in period. When one of these sinusoidal functions crosses the midline there is likely to be trouble of some sort, and on those less frequent days when two or three cross simultaneously ("double-critical" and "triple-critical days"), there is potential for disaster. While chronobiologists have described rhythms longer than circadian—e.g., circaseptan (rejection of organ transplants, de Vecchi, Halberg, Sothern, Cantaluppi, & Ponticelli, 1978), circatrigintan (pain threshold, Procacci, Corte, Zoppi, & Maresca, 1974), and circannual (migratory activity and hibernation, Pengelley, 1974), the data that would support the existence of the postulated biorhythms, or define them empirically, are presently inadequate (but cf. Neil & Sink, 1966). There is abundant evidence of the long-range variability of circadian rhythms, even when strong environmental signals are provided, and of wide individual differences under free-running conditions. Against such a background, the contention that the momentary phase of any of the purported biorhythms can be computed automatically and precisely from birthdate, after the vicissitudes of decades of living and with no known synchronizers, strains credulity. Finally, at the pragmatic level, controlled tests of the critical-day hypothesis in terms of actual job performance, accidents, and mood are negative (Haywood, 1979; Persinger, 1978; Rodgers, Sprinkle, & Lindberg, 1974; Wolcott, McMeekin, Burgin, & Yanowitch, 1977). One or more of these rhythms may indeed exist, and have predictive or explanatory value, but their demonstration waits upon further investigation.

Conclusion

Much of what can be said of circadian phenomena must still be regarded as tentative. Replication, refinement, revision, and extension are required before the full extent of theoretical and practical implications can be delineated with assurance. This developing field allows full scope for the whole range of psychological expertise, and needs the varied contributions that psychologists can make.

Whether or not the behavioural scientist is attracted to circadian research in its own right, it is obvious that any investigation in the life sciences that overlooks the possibility of time-of-day effects runs the risk of serious flaw or limited generality. The temporal factor can no longer be ignored in the design of psychological research.

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