Time-of-day effects on attention and memory efficiency: Is chronopsychology a method for studying the functioning of the human subject?

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Psychol. Belg
1993, 33-2, 159-170.

TIME-OF-DAY EFFECTS ON ATTENTION AND MEMORY EFFICIENCY: IS CHRONOPSYCHOLOGY A METHOD FOR STUDYING THE FUNCTIONING OF THE HUMAN SUBJECT?

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Chronopsychology has shown that human mental efficiency fluctuates rhythmically in time, and that the periodicity of these fluctuations varies. Apart from ultradian rhythms, circadian rhythms have been studied the most frequently, particularly in regards to attentional efficiency and memorization. However, the data gathered so far are highly inconsistent and mental efficiency rhythms seem to be modulated by numerous so-called "masking" factors. Instead of using the conventional group methodology, we tested the intraindividual stability of cognitive performance in the course of the day. Attentional capacities and memory were measured for 10 weeks at 9 a.m. and at 4 p.m., always on the same weekday. For certain tasks, the subjects consistently exhibited greater efficiency either in the morning or in the afternoon. The tasks in question were not the same for all subjects, but the fact that systematic fluctuations in performance were found in the same subject shows that the temporal factor cannot be ignored.

INTRODUCTION

The discovery in chronobiology of the existence in all living beings of rhythmical fluctuations in biological functions has raised the question of whether rhythms of this type exist at the behavioral level. Several hypotheses can be imagined: Are psychological processes subject to periodic variations in efficiency which are independent of biological rhythms? Or do they vary to some extent along with biological rhythms? Or still again, are there reciprocal interactions between biological rhythms and behavioral rhythms? We are currently unable to validate any of these hypotheses, but it is now evident that human mental efficiency fluctuates rhythmically across time, and that these fluctuations vary in periodicity.

Within the past century, many studies have found evidence of substantial instabilities in human performance across time, and particularly according to the time of day (Fraisse, 1980). These observations do not seem to have had much impact on many psychologists, however, who still believe that optimal mental efficiency can be tested at any time of the day.

Evidence of cyclic variations in psychological efficiency

Chronopsychology focuses essentially on two main types of rhythmicity: ultradian rhythms, whose period is approximately 90 minutes, and circadian rhythms, whose period is about 24 hours (Beugnet-Lambert, Lancry & Leconte, 1988; Leconte & Lambert, 1990). But most of the data concerns the circadian rhythms and their effect on attentional efficiency and memorization.

In the research on attentional capacities (for a review, see Leconte-Lambert, 1991), there are a number of studies demonstrating the existence of circadian fluctuations in detection tasks (e.g., cross out the E's in a text, Blake, 1967; Warm, 1984). Performance has been found to improve as the day progresses, stabilize near the end of the afternoon, and begin decreasing in the evening. The same holds true for simple reaction time tasks, where efficiency is at its maximum between 5 and 8 p.m. (Pöppel, Aschoff & Giedke, 1970). In these studies, performance has been shown to vary along with the organism's daily nervous activity level, indirectly measured for instance by body temperature. These results confirm Kleitman's initial findings (1963) indicating the existence of a positive correlation between central body temperature and efficiency.

However, there are other data indicating that the situation is far from simple. The arousal level theory (Colquhoun, 1971) predicts a performance maximum at around 8 p.m., but many of the results obtained are much more complex and sometimes contradictory. For certain tasks, the maximum performance occurs much earlier. For example, on a shape insertion task, Monk and Leng (1982) obtained optimal performance at 11 a.m. Moreover, the variations seem to depend on task complexity. Folkard, Knauth, Monk and Rutenfrantz (1976) found optimum performance at the end of the afternoon for a simple 2-letter detection task, but the opposite curve was obtained for a complex 6-letter detection task. Finally, a number of studies have found substantial interindividual differences:

introverted subjects appear to attain greater attentional efficiency in the morning than extroverts, where-as the tendency is reversed in the evening (Blake, 1971). Similarly, "evening" types increase in efficiency as the day progresses, whereas the performance of "morning" types gradually decreases as the day goes by (Horne, Brass & Pettitt, 1980). Circadian patterns also interact with the field dependence-independence factor: the performance of field-independent individuals is relatively stable throughout the day, where-as it declines for field-dependent individuals (Beugnet-Lambert, 1985).

Research on circadian variations in memory has also produced highly contrasted results (Leconte, 1988, 1989), although it is generally accepted that short-term memory performance is better in the morning, and that long-term memory performance is better in the late afternoon.

As early as 1916, Gates showed that immediate recall was superior in the morning than in the afternoon. According to certain studies (Blake, 1967; Folkard, 1979), the number of digits retained reaches a maximum during the morning, and then diminishes in the course of the afternoon. However, some studies have not found any changes at all during the day (Folkard, 1982; Jones, Davies, Hogan, Patrick & Cumbertach, 1978), and others have even observed an improvement in the early afternoon (Adams, 1973, cited by Folkard, 1982)! For free recall, Laird (1925) recorded maximum performance at 8 a.m. and minimum performance at 8 p.m.. Folkard and Monk (1979) found the same optimal efficiency at 8 a.m. However, in Lancry's study (1986), where the familiarity of the items and the categorization possibilities of the lists were varied, maximum recall was observed at 5 p.m. regardless of the material. Finally, for a text memorization task followed by immediate recall, Folkard et al. (1976) noted better performance at 9 a.m. than at 3 p.m. The opposite tendency was found for long-term recall, which was better when the information had been learned at 3 p.m.

Thus, the results obtained vary extensively from one study to the next. It is evident that the role of interindividual differences must be considered. According to Lancry (1986), for short-term free recall, memory efficiency decreases as the day progresses for morning types of individuals, whereas the opposite pattern is observed for evening types. Likewise, on delayed recall a week later (at the same time of day as the learning session), the performance of morning subjects declines as the day progresses, while that of evening subjects tends to improve. Lancry (1986) also found a relationship between circadian variations in memory performance and sleeping time variability. Short-term memory performance of subjects with a low degree of variability was found to improve during the morning and decline in the afternoon, whereas subjects with a high degree of variability remained at a low level all day. Moreover, this difference was observed on Monday but not on Friday! Finally, the field-dependence/independence feature of the individual seems to be another consideration. Beugnet-Lambert (1985) showed that immediate memory in the classroom was stable for field-independent children, whereas field-dependent children performed better in the afternoon.

It is clear, then, that the data on circadian rhythms in attention and memory are extremely difficult to summarize at the current time. Some studies have used "unsorted" subjects, while others have defined subject-type variables and find diverging results. Individual characteristics are so important that it seems premature at this point to attempt to define any general laws for the circadian patterns of mental efficiency.

For an analysis of "masking" effects in chronopsychology research

In addition to the influence of the individual characteristics mentioned above, it has been shown that the appearance of circadian rhythms in all living beings can be modified by changes in some events. Changes of this type are generally called "masking effects". Reinberg (1989) pointed out that sleeping modifies the appearance of the body temperature cycle in humans. Sleep thus has a masking effect on this circadian rhythm, a fact which questions the validity of the relationships described by various psychologists between temperature rhythms and performance rhythms. For Reinberg once again, masking effects may affect the neocortex as much as the archaic or vegetative brains. It is therefore legitimate to assume that masking effects can also influence the rhythms of psychological activities such as attention and memory, making them all the more difficult to demonstrate. Indeed, human functioning, and in particular human psychological activity, is so complex that it undoubtedly prevents us from objectively determining what part of mental activity stems solely from endogenous functions and what part is due to environmental variables, whether they are acting as synchronizers or as masking factors.

As Minors and Waterhouse (1989) remind us, biologists originally used the term masking to refer to the effects of the environment on endogenous rhythms. They used the terminology proposed by Moore-Ede (1986), who interpreted most masking effects as the production of normal, homeostatic responses. This led the authors to consider that, although masking effects are the plague of researchers attempting to study internal clocks and the endogenous components of rhythms, they must nevertheless be viewed as essential characteristics of normal human physiology. The adaptive value of such masking effects, as their name indicates, lies in their ability to counter the expression of the internal oscillators.

As psychologists, we can draw upon the experience of biologists and consider that various kinds of "masks" (for example, the increase in motivation when a subject experiences a feeling of success and/or is informed of the outcome) may be the reason why no evidence is found of certain rhythmic patterns in psychological efficiency. Lavie (1989) considered this to be a plausible explanation of Kripke, Mullaney and Fleck's (1985) failure to demonstrate ultradian cyclicity in the performance of repetitious tasks by adult subjects.

But above all, we should assume that the purpose of the behavioral modifications dependent on masking is to enhance efficiency at moments of lesser capacity: this very often triggers a high energy demand and sooner or later leads to a massive drop in efficiency. From a psychologist's point of view, countering the expression of the internal pacemakers in order to inhibit or modify some rhythmicity — which would be the work of various masking factors — may lead to fluctuations in performance which could be detected and analyzed as such. A concrete manifestation of this would be the "inversion" of the activation level rhythms, to the benefit of attentional functions. This type of inversion is frequently detected in subjects who are being particularly careful to perform well at a time of day they know to be an activation "low point", thereby causing unusual variations in performance during task execution (see Leconte-Lambert, 1991). Suppose we agree with Lavie (1989) that circadian rhythms can be masked by variations in the arousal level, either by the coexistence of slow ultradian components which are particularly dominant during the second half of the day or by some specific conditions, as-yet-undetermined by psychologists, then a worthwhile and quite original objective in chronopsychology would be to find out whether the hypothesized "masking" factors do indeed exist, and if so, what their respective roles are in the alleged rhythm-based psychological activities. One of the present authors has already begun investigating some of these factors (Leconte-Lambert, 1991). Not only is the list of such factors still incomplete, but most of them have joint effects which prevent us from drawing any definite conclusions about the observed fluctuations in performance.

Thus, a large number of experiments are necessary in order to test for the effects of these factors. This would be the only way to gain insight into psychological rhythms *per se* and to validate one of the three hypotheses proposed in the introduction. Among these factors, we have shown (Leconte-Lambert, 1991) the masking effect of interindividual differences (sex, cognitive style...) and of tasks characteristics. Therefore we have tried at first to control both these factors in studying attention and memory rhythms with an intraindividual method. So we would need to make sure that the so-called optimal attentional and memory performance times are indeed stable for a given subject — this would afford undeniable proof of the existence of psychological rhythms, and would allow us above all to develop some specific research protocols for testing masking factors.

Study of the intraindividual stability of time of day effects

Twenty-five subjects (5 men and 20 women) between the ages of 21 and 25 were tested over a period of 10 weeks on the same day each week, at 9 o'clock in the morning and at 4 o'clock in the afternoon. For each subject, the measures were overall anxiety level (Cattel), field dependence-independence scored on the "Group Embedded Figure Test" (G.E.F.T., 1985), morningness-eveningness scored on the Horne and Ostberg questionnaire (1976), body temperature (taken every day for 10 weeks upon rising, at 9 a.m., at 4 p.m. and before going to bed), daily sleep schedules throughout the entire experiment, eating habits, medication if any, and unusual events (i.e., familial events, examinations...).

A battery of tests was used to specifically measure attentional and memory processes and evaluate fatigue, concentration capacity and vigilance. Each testing session lasted 30 minutes and included eight tasks carried out in the following order: (1) Self-evaluation of fatigue on an analog scale, (2) self-evaluation of concentration capacity on an analog scale, (3) self-evaluation of vigilance on the Thayer (1967) scale, (4) a symbol crossing-out task with a non-variable target (duration 2 min.), (5) a symbol crossing-out task with a variable target (2 min.), (6) a dual task (4 min.) consisting of crossing out letters (the "e's" in a foreign language text) and a categorical judgment task (words on a list were read in succession and the subject had to point out the ones belonging to the semantic category stated at the beginning of the task), (7) immediate recall of a list of 20 unclassifiable words, and (8) a working memory task (quickly state the number of vowels in a series of 5 words read aloud).

All tests except the self-evaluations were presented in parallel forms (20 versions each).

Subjects were eliminated if they were taking medication which could interfere with cognitive evaluation (N = 2), exhibited substantial variations in waking-sleeping rhythms (N = 3), or related important unusual events during the experiment (N = 2). Among the 18 remaining subjects, those whose anxiety scores, field dependence/independence scores, and sleep duration and stability measures were near the mean were selected for our initial analysis (N = 11).

For each subject and dependent variable, this gave us 10 measures at 9 a.m. and 10 measures at 4 p.m. In our preliminary analyses, the 9 a.m. data were compared with the 4 p.m. data for each variable and each subject (Student' t for paired groups was used). Only some of the variables are presented here.

For certain tasks the subjects *systematically* exhibited greater efficiency either in the morning or in the afternoon. The tasks in question differed across subjects. For a given subject, efficiency could be greater in the morning for one task and greater in the afternoon for another.

The Table 1 indicates the cases where performance was significantly better either at 9 a.m. or at 4 p.m. for certain dependent variables. Further analysis of some of the tasks revealed significant effects. For immediate recall, for instance, the time of day for certain subjects had an effect on response time or on the magnitude of the recency effect (an experiment aimed at describing these phenomena in greater depth is now in progress).

Table 1. *Time of Best Performance (statistically significant) for Some of the Variables and Each of the 11 Subjects Studied*

	Intermediate Types			Morning Types			Evening Types				
Subjects	S2	S12	S23	S8	S16	S21	S11	S13	S14	S18	S24
Feel the best (self-evaluation)			$		*				$	$	$
Concentration capacity (self-evaluation)	*	*			*	$					$
Vigilance (self-evaluation)	*	*	$		*		$		$	$	$
Crossing-out speed Constant target							$	$		$	
Crossing-out accuracy Constant target											
Crossing-out speed Variable target				$		$					
Crossing-out accuracy Variable target	$		$		*					$	
Crossing-out speed Dual task	$	$	$	$	$		$			$	
Crossing-out accuracy Dual task	$							$			
Immediate recall accuracy	*			*		*		*	*		
Working memory speed	$	$	$					$		$	
Working memory accuracy		*	$	$			*				

Note. Subjects were classified by their degree of morningness-eveningness. For certain tasks which varied across subjects, greater efficiency was observed either in the morning (9 a.m. = *) or in the afternoon (4 p.m. = $). For a given subject, performance could be better in the morning for one task and better in the afternoon for another.

Discussion

These results, which only represent a small part of the massive amount of data now available but not yet processed (a more detailed article is in preparation), reinforce the classical findings in chronopsychology where a group methodology has been used. Indeed, the fact that the same subject consistently performs differently at two times of the day shows that performance fluctuations are not a random phenomenon and that the temporal factor is indeed significant.

Granted, these effects were only found for some of the variables, and they were not the same for all subjects. And granted, the reason why certain correlations were observed while others were not remains to be determined. And granted, a great deal of "background noise" still exists, making a more thorough analysis of the "masking" or "modulating" factors necessary. It nevertheless appears legitimate in the light of the data to contend that our approach is a fruitful one for gaining a better understanding of how human subjects function in complex situations. Indeed, a variety of cognitive processes are at work in complex situations, and we can see that the efficiency variations of each have a different temporal course. We also know that the various processes involved in such situations interact. What we currently do not know is whether the conjunction of these processes constitutes a modulating factor of the activity rhythms of each process taken separately, or whether a new rhythm is generated. For example, it has been shown (Folkard et al., 1976) that circadian variations in attention are a function of task complexity, which is dependent upon the memory load. This means that one of the mandatory prerequisites in chronopsychology is to analyze the tasks used and determine their relevance to the psychological process they are assumed to assess. Our approach allows for such an analysis.

Furthermore, the lack of observed variations in performance between the morning and the afternoon may be indicative of a strategy change enabling the subject to execute the task in a different way but just as efficiently. It is thus important to be able to better understand time-of-day changes in strategy selection, another potential capability of our approach.

The unresolved issues we claim to be able to address are:

(1) How do subjects deal with variations in efficiency in order to produce more or less stable performance regardless of the time of

day? The significance of the notion of "resource management" becomes clear here.

(2) Is it relevant in chronopsychology to refer to factors which have a masking effect on rhythms, or should we speak instead of the "modulating" effects of these factors? Are both types present? For example, what role is played by the morningness-eveningness factor, whose differentiating effects on rhythms cannot be ignored?

(3) Finally, what means are available for answering the question of the dependence and independence of psychological activity rhythms with respect to biological rhythms? For example, when an inconsistency is observed between variations in the self-evaluation of vigilance and the measured attention levels, should the validity of the indexes be questioned or the strength of the relationship between physiological rhythms (here, the vigilance rhythm) and psychological rhythms (here, the attentional rhythm)?

As touchy as they are, these questions have provided highly interesting perspectives and incentives to our research team, as we pursue our studies in chronopsychology.

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