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Diurnal trends in mood and performance do not all parallel alertness

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Objectives This study examined the hypothesis that alertness can be used to predict time-of-day effects on performance.

Methods For 6 or 7 days the volunteers (24, highly preacticed young women) were required to retire to bed at 0000 and were awakened at 0800. A battery of mood and performance tests was completed every 2 hours while the women were awake; the result was 9 equally spaced measures per day. Measures of mood, serial reaction time, and memory scanning were recorded. Rectal temperature was recorded continuously.

Results After omitting the data from the first day to avoid any carry-over from the "first-night" effect on sleep, average time-of-day functions were calculated for each subject, for each variable, and were then z-transformed. Cross-correlations between the pooled time-of-day trends indicated that, while alertness was a reasonably good "predictor" of the simple perceptual-motor speed measures, it fared less well for some of the other measures. Two-way analyses of variance indicated that the time-of-day trend for all measures differed from that for alertness, although the magnitude of this difference varied substantially and, for some measures, was very largely due to the last reading of the day (0000).

Conclusion It is clear from these results that, while alertness may successfully "predict" variations in some measures of performance capability, and especially those of simple perceptual motor speed, care should be exercised in extrapolating to other performance measures.

Key terms circadian, memory, psychological functioning, reaction time.

Although similarities in mood and performance rhythms have been reported by some authors (1,2), others have concluded that rhythms in performance are not simply the direct result of circadian variations in mood (3). Nevertheless, over the past 10 years the 3-process model of alertness has been developed, validated, and used to predict diurnal variations in alertness (4—9), sleep latency (4,10), duration (4,11), and hits on a 30-minute vigilance task (6). More recently it has been suggested that alertness can be used to predict psychological performance (4). This suggestion implies that all performance measures show a similar time-of-day trend towards alertness, a prediction that the current paper aims to examine.

Measures of subjective alertness are quicker and easier to obtain and less disruptive to a normal schedule than the assessment of performance; thus predicting performance from alertness is an attractive idea that could prove to be extremely valuable in an applied setting. An alertness nomogram (4) has been developed to predict low levels of alertness among shift workers dependent upon the time of day and length of time since their last sleep. A similar nomogram predicting performance could be invaluable for determining the safety implications of various types of work and could potentially be used in the development of safer shift systems.

The tasks employed in the present study ranged from relatively simple measures, such as response speed on a serial reaction-time task, to more demanding tasks calling for considerable working memory involvement. Thus we were able to examine the relationship between

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alertness and a wide range of other psychological functions that placed varying demands upon the highly practiced volunteers.

Subjects and methods

Subjects

Twenty-four female undergraduates aged 18—30 (mean 19.98) years participated in a series of experiments. All of them gave their informed consent and were pronounced medically fit by a medically qualified doctor.

Procedure

The volunteers attended a training session with the experimenters 2 weeks prior to the start of the study. At this session the use of hand-held computers (PSION organisers, see reference 12) to be used to collect the data was explained to them and the importance of familiarizing themselves with the tests prior to the start of the study was emphasized. The volunteers were asked to practice performing the battery of tasks at 2 hourly intervals while awake for 8—10 days during the fortnight preceding the start of the study. An average of 64.5 (SD 8.32) practice trials was completed. After the practice days the volunteers entered the experimental facility to which they were confined for a total of 23 or 31 days. Normal time cues were present throughout, including clocks and watches and access to television and radio programs. Ten volunteers were exposed to the natural light-dark cycle through windows. On the afternoon that they first entered the facility, the volunteers were familiarized with the procedures involved in the study, including the continuous recording of rectal temperature. On the subsequent 6 or 7 days they were required to retire to bed at 0000 at night and were awakened by an alarm at 0800 the following morning [mean sleep time 7.03 h (SD 12.09 min)]. It is the data from this period of 24-hour days that is reported.

Tests of mood and cognition were completed at 2 hourly intervals while the volunteers were awake throughout the duration of each study. Meals were consumed at specific times by 16 of the volunteers after awakening each day: breakfast at 0900, lunch at 1300, dinner at 1900, and a bedtime drink 30 minutes before retiring. The remaining 8 volunteers were free to eat whatever and whenever they chose, but were required to keep the timing of meals consistent across the days.

Temperature

Rectal temperature was recorded every 6 minutes using Squirrel Data Loggers (Eltek, Cambridge, England). The mean rectal temperature was calculated using readings taken during the 30 minutes prior to and the 30 minutes following each hour of the day. The means corresponding to the times that the performance tests were completed were analyzed further. Temperature data were not available for 1 volunteer due to technical failure.

Mood scales

Visual analogue (20-point) scales (12) were employed to assess mood both before and after 2 cognitive tests. Three bipolar scales (- to +) were used to measure alertness, calmness and cheerfulness for 8 volunteers in the first experiment. The remaining 16 volunteers completed 9 monopolar scales (0 to +), which were used to compute the 3 bipolar dimensions of alertness [alert+energetic +(20-sluggish)/3], calmness [calm+relaxed+ (20-tense)/3] and cheerfulness [cheerful+happy+(20-sad)/3].

Serial reaction time

A 400-trial, serial, 4-choice reaction-time task (12) was completed. An asterisk symbol appeared in 1 of the 4 positions on the handheld computer (PSION) display, each position corresponding to that of 1 of 4 response keys on the keyboard. The volunteer was required to rest the first and second fingers of each hand over the appropriate, spatially compatible response keys and to press the key corresponding to the position of the asterisk as quickly as possible, after which the next stimulus was presented immediately. Three derived measures are reported, namely, mean correct reaction time, accuracy, (ie, the percentage of correct responses), and "gaps" (ie, the percentage of responses above 1 second).

Memory-search task

The memory-search task was based on Sternberg's (13) paradigm. The subject had to remember a set of letters and then indicate whether they were present or not in a series of 40 probes presented one at a time in the middle of the display by pressing the T (true) or F (false) key (12). Four memory sets were presented (1, 5, 3, and 7 letters), each followed by 40 probes.

The number of correct responses (accuracy) was recorded for each memory set. Reaction times to true positive and true negative probes were used to compute the mean correct reaction time. Only the accuracy and correct reaction time data from the low (1 item) and high (7 items) load memory sets were analyzed further. However, to represent the speed (and accuracy) of processing across the different levels of memory load, a regression line was fitted to the mean correct reaction times for each of the memory sets at each time-of-day, and the slope and intercept were calculated. Before a regression line was fitted, a minimum of 80% accuracy had to be achieved on at least 3 of the 4 memory sets at each of the test sessions.

Statistical methods

The data from the first day were omitted to avoid any carry-over from a "first-night" effect on sleep, familiarization with the laboratory, and the like. The response-time measures, including the intercept values for the memory-search task, were then inverted (1/CRT) to normalize their distributions, while the "gaps" were transformed using the formula $\sqrt{(X)} + \sqrt{(X+1)}$ to stabilize variance and reduce the skewness associated with near 0 values. The mean time-of-day function for each measure for each subject was then calculated and subjected to a z-transformation. This procedure equated the means and standard deviations across both subjects and measures, and therefore greatly facilitated the comparison of the different measures by putting them all on an identical scale.

One-way repeated analyses of variance (ANOVA) were employed to look for significant time-of-day effects in each of the variables. Correlations were then performed between the 216 (24 subjects x 9 times of day) alertness z values and those for each of the other measures to assess the extent of their covariation. A 2-way ANOVA (with the Greenhouse-Geisser correction for sphericity applied) was used to compare the time-of-day effect for each variable with that of alertness.

Results

The initial, 1-way repeated ANOVA confirmed that there were significant time-of-day effects for each of the variables except calmness, the slope of the regression line fitted to the memory search results and accuracy on the 1-target memory search task. Pooled correlations (table 1) indicated that variations in alertness accounted for much of the variance in the measures of simple, perceptual-motor speed (correct reaction time, $r^2 = 0.381$; 1-target reaction time on the memory search test, $r^2 = 0.279$; and the intercept value, $r^2 = 0.287$) as illustrated in figure 1, which shows the average time-of day trends for these measures. It is clear that, with the possible exception of the 0000 reading, these measures paralleled variations in alertness over the day very closely. In contrast, accuracy on the 1- and 7-target versions of the memory search task showed virtually no relationship to alertness (1-target, $r^2 = 0.004$; 7-target, $r^2 = 0.003$), while that for gaps showed only a very modest, but nevertheless statistically reliable relation ($r^2 = 0.046$). This finding is illustrated in figure 2, which shows the average time-of-day trends for these measures.

The failure of some measures to show a relationship to alertness need not necessarily have reflected the sort

Table 1. Mean time-of-day values for each variable and the results from the comparison of the time-of-day trends in mood and performance with that of alertness. (CRT = correct reaction time, Acc = accuracy, RT = reaction time, Temp = temperature, df = degrees of freedom)

Variable	Mean values at each time of day (standardized)[a]									Pooled correlation	ANOVA	
	0800	1000	1200	1400	1600	1800	2000	2200	0000	r^2 (df=214)	Main effect F (8, 184)	Interaction F (8, 184)
Alert	**-1.574**	**-0.032**	**0.690**	**0.525**	**0.461**	**0.550**	**0.391**	**-0.109**	**-0.903**	N/A	N/A	N/A
	0.134	*0.109*	*0.087*	*0.117*	*0.105*	*0.077*	*0.076*	*0.100*	*0.113*			
Calm	**-0.370**	**-0.070**	**0.134**	**0.082**	**0.067**	**-0.129**	**0.127**	**0.090**	**0.071**	0.015	19.26***	11.79***
	0.257	*0.140*	*0.122*	*0.136*	*0.142*	*0.177*	*0.109*	*0.137*	*0.136*			
Cheerful	**-1.410**	**-0.247**	**0.325**	**0.368**	**0.199**	**0.174**	**0.266**	**0.320**	**0.004**	0.324***	36.16***	7.66***
	0.141	*0.156*	*0.146*	*0.124*	*0.120*	*0.188*	*0.118*	*0.122*	*0.141*			
CRT	**-1.986**	**0.215**	**0.492**	**0.394**	**0.414**	**0.613**	**0.181**	**0.013**	**-0.336**	0.381***	83.78***	3.05**
	0.116	*0.142*	*0.131*	*0.086*	*0.116*	*0.118*	*0.089*	*0.116*	*0.142*			
Gaps	**-0.596**	**0.307**	**0.499**	**0.473**	**-0.111**	**0.388**	**-0.279**	**-0.262**	**-0.418**	0.046**	28.84***	5.21***
	0.205	*0.156*	*0.184*	*0.178*	*0.133*	*0.179*	*0.178*	*0.215*	*0.166*			
Errors	**-0.775**	**-0.114**	**0.115**	**0.021**	**0.080**	**0.457**	**0.377**	**0.045**	**-0.204**	0.083***	22.95***	4.98***
	0.215	*0.244*	*0.164*	*0.167*	*0.206*	*0.121*	*0.185*	*0.173*	*0.145*			
Acc1	**-0.115**	**0.064**	**-0.464**	**0.050**	**0.083**	**0.481**	**-0.078**	**0.118**	**-0.138**	0.004	16.09***	9.69***
	0.217	*0.230*	*0.213*	*0.173*	*0.178*	*0.158*	*0.140*	*0.195*	*0.191*			
Acc7	**0.388**	**0.430**	**0.284**	**0.241**	**-0.171**	**0.050**	**-0.346**	**-0.427**	**-0.449**	0.003	12.94***	15.99***
	0.205	*0.177*	*0.183*	*0.159*	*0.201*	*0.164*	*0.176*	*0.198*	*0.185*			
RT1	**-1.876**	**0.082**	**0.488**	**0.362**	**0.212**	**0.260**	**0.449**	**0.046**	**-0.023**	0.279***	63.53***	4.33***
	0.157	*0.148*	*0.124*	*0.077*	*0.178*	*0.124*	*0.113*	*0.146*	*0.126*			
RT7	**-1.216**	**0.246**	**0.252**	**0.240**	**0.504**	**0.313**	**-0.054**	**-0.088**	**-0.196**	0.122***	36.30***	3.34**
	0.236	*0.111*	*0.171*	*0.153*	*0.190*	*0.162*	*0.154*	*0.154*	*0.167*			
Intercept	**-1.817**	**0.036**	**0.514**	**0.434**	**0.106**	**0.289**	**0.399**	**0.074**	**-0.035**	0.287***	57.73***	4.25**
	0.146	*0.167*	*0.120*	*0.086*	*0.173*	*0.112*	*0.114*	*0.153*	*0.153*			
Slope	**0.265**	**0.217**	**-0.089**	**-0.040**	**0.254**	**0.068**	**-0.473**	**-0.032**	**-0.170**	0.008	11.02***	13.21***
	0.195	*0.194*	*0.218*	*0.151*	*0.231*	*0.155*	*0.149*	*0.213*	*0.193*			
Temp	**-1.960**	**-0.230**	**0.062**	**0.192**	**0.225**	**0.721**	**0.813**	**0.538**	**-0.361**	0.431***	74.02***	9.37***
	0.067	*0.124*	*0.155*	*0.097*	*0.088*	*0.101*	*0.074*	*0.088*	*0.159*			

[a] The mean values are in boldface with the standard error of the mean in italics.
** P<0.01, *** P<0.001.

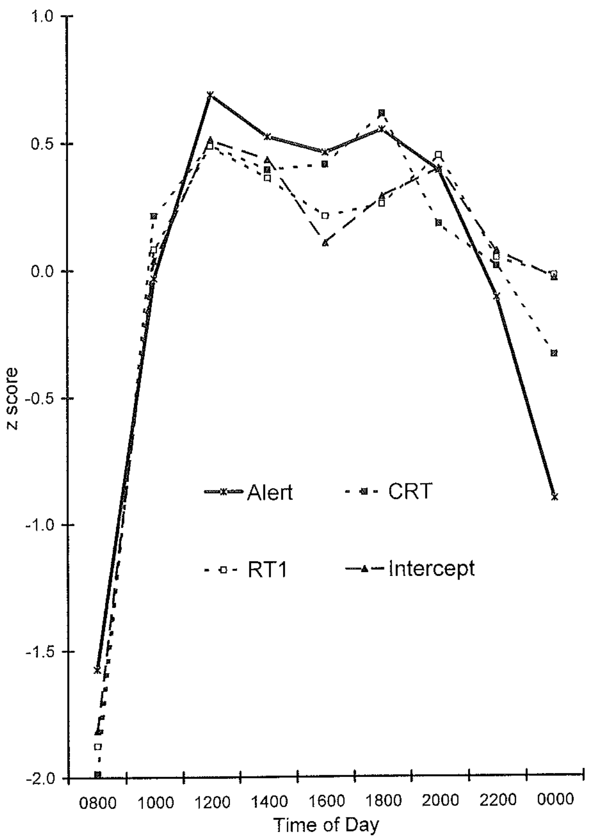

Figure 1. Time-of-day profiles of alertness and speed of simple perceptual performance. All the values were z-transformed, for each subject, prior to the plotting of the mean values for each time of day. In all cases the higher the score the better the performance. See the legend of table 1 for an explanation of the terms.

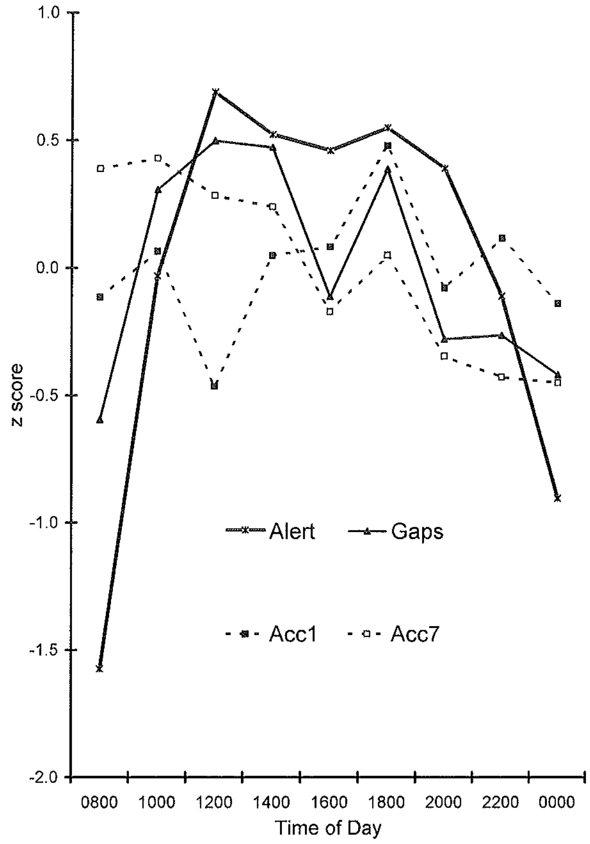

Figure 2. Time-of-day profiles of alertness and more complex performance measures. All the values were z-transformed, for each subject, prior to the plotting of the mean values for each time of day. In all cases the higher the score the better the performance. See the legend of table 1 for an explanation of the terms.

of systematic differences that might be expected if there had been a genuine difference in the timing or nature of the underlying control processes of alertness and other variables. However, comparisons of the time of day effect for each variable with that of alertness indicated that there was a reliable interaction between time of day and measure (ie, alertness versus variable under consideration) for all the variables and therefore suggested that the time-of-day effect for each of the considered variables differed systematically from that of alertness (table 1).

In the case of the 3 measures of simple, perceptual motor speed (correct reaction time, 1-target reaction time on the memory-search test, and the intercept value) (figure 1), the interaction term, although statistically reliable, accounted for very little of the explained variance (3—6%) and was no longer reliable when the 0000 readings were omitted and the analyses repeated. Thus for these measures the interaction appeared to simply reflect the fact that at the end of the day alertness decreased to a greater extent than response speed. However, for other measures, such as accuracy on the 1- and 7-target memory and search tasks, and gaps on the serial-choice task (figure 2), the interaction was both highly significant and accounted for a more substantial percentage of the explained variance (17—50%). Furthermore, these interactions remained significant when the first (0800) or last (0000) readings of the day were omitted from consideration. Thus the time-of-day trends for these measures appeared to differ reliably and systematically from that of alertness.

For completeness, table 1 also shows the main effect of time of day from these analyses. While it is clear that these main effects were all reliable, they should be interpreted with extreme caution since they may simply reflect the massively reliable time-of-day effect of alertness rather than any similarity between alertness and the measure under consideration. Thus, for example, there were reliable main effects of time of day in the analyses comparing alertness and accuracy on the 1- and 7-target versions of the memory-search task. This result occurred despite the fact that accuracy on the 1-target version did not show a significant time of day effect when analyzed by itself and the fact that there was a total lack of any evidence for a relationship between these 2 accuracy measures and alertness from the pooled correlations.

Discussion

We assessed a range of performance and mood variables for highly practiced subjects, and, although some showed a very similar time-of-day trend to that shown by alertness, they all differed reliably from it. For the 3 measures of simple perceptual motor speed that were obtained, this difference was largely confined to the last reading of the day (0000) when alertness had decreased to a greater extent than response speed. It is noteworthy in this context that, like response speed, the 3-process model of alertness also frequently underestimates the fall in subjectively rated alertness at the end of a period of wakefulness. Thus the subjects' knowledge of clock time and of how long they had been awake may have resulted in their overestimating the extent of their fatigue when they made subjective ratings at the end of their waking day.

However, for other measures, the time-of-day trends differed rather more substantially from that of alertness, and this finding is particularly important given the recent suggestion that the 3-process model of alertness may be generalized to predict measures of performance (4). While it is certainly the case that the time-of-day trends for some measures of performance parallel that of alertness, a finding noted by others following visual inspection of their data (1), it is equally true that other performance measures show no such parallelism. Our results suggest that the 3-process model of alertness may predict simple perceptual motor speed with considerable accuracy, especially if modified to take account of the "end-of-day" effect. However, they also suggest that minor modifications to the "wake-up" and "end-of-day" effects would prove insufficient to enable accurate prediction to be derived for other measures of mood and performance and, in particular, the performance of tasks requiring more complex cognitive functioning.

It is, of course, the case that the measures obtained by us were limited to the normal waking day. It is possible that, if readings had been obtained during the night-time hours, when the subjects would normally have been asleep, a rather different pattern of results might have emerged. Thus, for example, if all measures showed similar low values in the early hours of the morning to those typically obtained for alertness, their relationship to alertness would be increased. In contrast, if the rather different trend found over the day for accuracy on the 7-target version of the memory-search task reflected the night-time peak in performance previously reported for high-memory-load tasks (14), then this ability of alertness to predict variations in this measure would be reduced even further.

To summarize, the present study collected mood and performance data at regular intervals throughout the normal waking day from 24 highly practiced volunteers living in a controlled environment. Under such conditions reliable time-of-day trends were found for most of the variables, and, while some such trends paralleled that of alertness fairly closely, in all cases they differed reliably from it. It is concluded that the 3-process model of alertness cannot be generalized to predict successfully all measures of mood and performance.

Acknowledgments

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