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Robert A. Henning , Steven L. Sauter & Edward F. Krieg

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Work Rhythm and Physiological Rhythms in Repetitive Computer Work: Effects of Synchronization on Well-Being

Robert A. Henning

Department of Psychology
University of Connecticut*

Steven L. Sauter
Edward F. Krieg,

National Institute for Occupational Safety and Health
Cincinnati, OH

This study tested the hypothesis that asynchrony between the work rhythm and a worker's internal physiological rhythms may be a source of stress in repetitive computer work. Experienced typists ($N=20$) entered lines of numeric data using a video display terminal in a simulated office environment. Each day of the 2-day experiment consisted of six 40-min work periods. The work rhythm was varied between work periods by adjusting the field length of data entry lines (3–13 characters). Breathing and cardiac responses were monitored continuously throughout work periods, and a mood survey was administered at the end of each work period. The extent of synchronization between (1) breathing response and the work rhythm, (2) cardiac response and the work rhythm, and (3) all three measures (breathing and cardiac responses, and the work rhythm) was scored for each work period using cross-spectral analysis. Synchronization scores were then evaluated as predictors of mood state and physiological response using multiple regression techniques.

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Correspondence and requests for reprints should be sent to Robert A. Henning, Department of Psychology, University of Connecticut, 406 Babbidge Rd., Storrs, CT 06269-1020

Results indicated that synchronization between the work rhythm and breathing response was predictive of reduced heart rate and increased heart rate variability (suggesting reduced stress). Synchronization between the work rhythm and cardiac response was predictive of both reduced fatigue and reduced boredom. Synchronization among all three measures (breathing and cardiac responses, and the work rhythm) was predictive of reduced boredom and reduced heart rate. These results suggest that the uncoupling of work and physiological rhythms may partly explain worker dissatisfaction and health complaints in highly regimented, computer-based tasks.

INTRODUCTION

Highly repetitive work at computer terminals (e.g., data entry tasks) has been linked with affective and psychophysiological disturbances indicative of stress (Cakir, Reuter, Von Schmude, & Armbruster, 1978; Canadian Labor Congress, 1982; Elias, Cail, Tisserand, & Christmann, 1980; Office of Technology Assessment, 1985; Smith, Cohen, Stammerjohn, & Happ, 1981; World Health Organization, 1987). These findings are not surprising. Such effects have been extensively documented in a broader and earlier literature on health aspects of short-cycle and paced work (e.g., Khaleque, 1981; Salvendy & Smith, 1981; Weber, Fussler, O'Hanlon, Gierer, & Grandjean, 1980).

The mechanisms of stress in repetitive work are not fully understood. Most theoretical approaches propose mechanisms involving either changes in sympathetic arousal, or dissatisfaction resulting from the fragmented, stereotypic, and highly structured aspects of repetitive work (e.g., Gardell, 1971; O'Hanlon, 1981). This study explores an additional explanation for stress in highly repetitive work, an explanation related purely to the temporal characteristics of repetitive tasks. Specifically, it is postulated that stress can result when task-induced work rhythms are at variance with short-cycle biorhythms such as the breathing cycle.

There is some empirical evidence to suggest that coherence between work rhythms and short-cycle biorhythms has adaptive value. Data from a number of studies suggest that synchronization between the work rhythm and either the respiratory or cardiac biorhythms is associated with improved work efficiency (Bramble & Carrier, 1983; Dietrich, Raschke, & Hildebrandt, 1982; Jasinskas, Wilson, & Hoare, 1980; Kohl, Koller, & Jager, 1981). These studies have generally involved physically demanding, aerobic activity (e.g., pedaling a bicycle ergometer or running) where asynchronization or incoordination between muscles controlling breathing and locomotion may have significant biomechanical and metabolic costs.

Other research, however, has shown a tendency toward synchronization of breathing and perceptual motor behavior to occur in the absence of significant physical demands. Two studies (Haas, Distenfeld, & Axen, 1986; Wilke, Lansing, & Rogers, 1975), for example, have demonstrated entrainment of the breathing rhythm to externally manipulated finger-tapping rhythms. These findings, according to the investigators, reflect a natural tendency toward synchronization of breathing and perceptual motor functions inherent to the nervous system.[1]

If synchrony between biorhythms and perceptual motor function is a natural and desirable state that benefits neurobehavioral function, then circumstances that prevent synchronization from occurring should place the organism in a relative state of stress. In this study, we test this proposition in a sample of computer terminal operators performing a repetitive data entry task. The work rhythm was systematically varied in relation to the operator's breathing frequency to induce varying degrees of synchrony between the two rhythms. The degree of synchrony between the work rhythm, breathing rhythm, and respiratory-sinus arrhythmia of heart rate (RSA rhythm) was then evaluated as a predictor of the operator's mood and cardiac responses.

METHOD

Subjects

Subjects (N=20 women aged 18–40, M = 27.4) were experienced data entry personnel recruited through a local temporary help agency. Subjects were required to pass a typing skills test to participate in the experiment. Subjects were compensated for their participation in accordance with local pay scales.

Design

Subjects performed a data entry task under 12 work rhythm conditions in a within-subjects design. Each work-rhythm condition consisted of two 20-min trials in a 40-min work period. The work-rhythm conditions were randomized for each subject over 2 days (6 conditions per day).

Experimental Task

A single line (field) of randomized, numeric characters was displayed in large type (double high, double wide) on a visual display terminal (VDT, IBM model 3163). Subjects used the VDT's numeric keypad to enter the displayed characters into a database. A carriage return completed the cycle. Immediately following the carriage return, the VDT screen was cleared and the cycle was repeated. A different work rhythm was "task-induced" during each work period by controlling the

[1]Neurophysiological mechanisms governing synchronization are thought to involve changes in arousal that are phase-linked to the breathing rhythm and irradiate throughout the nervous system (Cohen, 1979; Haas et al., 1986; Wilke et al., 1975).

number of characters (3 to 13) in the data field, thereby affecting the cycle time of the repetitive task.[2]

A brief computer-controlled pause occurred after each line was entered (i.e., a new data line did not appear on the VDT until after this brief pause ended). The length of this pause was proportional to the line length [(number of characters + 1) × 100 ms]. The purpose of this computer-controlled pause was to help prevent the work-rhythm manipulations from affecting workload. Without this adjustment in pause length, keystroke output would be necessarily higher in conditions with large data fields because the time between data lines would become a smaller portion of each work cycle.

Subjects could use the backspace key for correction of keying errors, but corrections were limited to the most recent character keyed so that multiple backspacing could not occur. Correction of keying errors was not possible after the line had been entered with a carriage return.

Measures

Work Rhythm. The work rhythm was defined by the time between carriage returns that marked completion of a work cycle.

Breathing Response. Changes in lung volume were measured by summing the output of two inductive plethysmographs (Respitrace, Ambulatory Monitoring, Inc.) that encircled the body and measured changes in cross-sectional area at both the rib cage and abdominal levels. Plethysmographs were calibrated to enable measurement of lung volume changes regardless of the relative displacements caused by rib cage or abdominal expansion.

Cardiac Response. Subjects wore disposable, surface-mounted electrodes (Lead II configuration) to record heart rate. The R waves of the amplified electrocardiogram were discriminated by an R wave detector (Model HR-934, CWE Corporation). A computer-interfaced digital clock (CTM05, Metrabyte Corporation) measured the time in milliseconds (± 1 ms) between consecutive R waves. Two cardiac measures were calculated for each work period: (1) mean interbeat interval; and (2) heart rate variability (standard deviation of interbeat intervals).

Synchronization. For each work period, an algorithm (Porges et al., 1980) was used to quantify the degree of synchrony between (1) cardiac response and the work rhythm, and (2) breathing response and the work rhythm. In addition, a second related method was used to quantify the degree of synchrony among all three measures (breathing response, cardiac response, and the work rhythm). Briefly, these algorithms provide a single summary statistic varying between 0 and 1 (anal-

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[2]Line lengths of 3–13 characters resulted in induced work rhythms ranging from about .1 Hz to .5 Hz for the average data entry typist (i.e., keying at a rate of 8,000 keystrokes/hour). These line lengths were selected to induce work rhythms at, above, and below the breathing frequency of adults engaged in sedentary work (typically 15 breaths/min or .25 Hz).

ogous to a squared-correlation coefficient) quantifying the extent that frequencies (and phase relationships) are common (or shared) among the comparison measures, with high values indicating a high degree of synchrony.

In preparation for the preceding synchronization analyses, the rhythm components of each measure (breathing response, cardiac response, and the work rhythm) were identified through frequency (Fourier) analysis. This analysis required that each measure be collected in a time series format. The (5-Hz) time series for *breathing response* was obtained by sampling the sum of plethysmograph outputs at a rate of five samples per second. The 5-Hz time series for *cardiac response* was obtained by sampling values of the interbeat interval. The 5-Hz time series for the *work rhythm* was obtained by sampling for carriage returns.

Signal-processing techniques were then used to identify and remove unwanted trends in the time series for cardiac response, and also in the time series for breathing response.[3]

Mood States. A mood survey was computer-administered to the subjects immediately after each 40-min work period. Subjects were instructed to indicate "how they were feeling during the work period they had just completed." The mood survey contained 18 statements about mood state, for example, "I was feeling energetic." Subjects rated each statement on a 5-point scale: hardly at all (1), a little (2), some (3), a lot (4), a great deal (5). Most of these items were selected from the Profile of Mood States (McNair, Lorr & Droppleman, 1971). Responses to these items were combined additively to produce scale scores for Tension, Fatigue, and Irritation. Cronbach's alpha for the Tension, Fatigue, and Irritation scales were .83, .90, and .95, respectively.

Two additional measures of affective state, Boredom and Perceived Stress, were based on responses to single items ("I was feeling bored"; I was feeling stressed").

Procedure

The experiment was conducted in a simulated office environment. Data were collected for 2 work days following a day of practice and orientation. Although subjects shared a common work area, talking was not permitted and no visual contact among coworkers was possible.

Each day of the experiment consisted of three 40-min work periods in the morning and three 40-min work periods in the afternoon. Each work period consisted of two 20-min trials separated by a rest pause whose length was controlled by the subject. Subjects took 10-min breaks away from the workstation between work periods. Subjects received no performance guidelines other than "to put in a good day's work."

[3]Trends related to blood pressure and body temperature changes (Bohrer & Porges, 1982) were removed from the time series for cardiac response through use of a cubic polynomial moving average (Kendall, 1973). The same technique was applied to the time series for breathing response to remove trends caused by shifts in posture.

Data Analysis

Multiple regression analysis was used to test if the synchronization measures could predict mood state or physiological response (mean interbeat interval, heart rate variability) in the corresponding work period. The effects of the synchronization measures were tested independently, hence for each of the outcome variables (a total of 7), three regression analyses were performed.

In addition to the synchronization measure, each multiple regression model also contained a variable corresponding to the predominant work rhythm in each condition (i.e., the work rhythm frequency of maximum power). The purpose of including this variable in the regression model was to control for effects due to changes in the work rhythm alone (as opposed to synchronization) from confounding the evaluation of the effects of synchronization on mood state and cardiac response. A predictor was also included to control for effects of the subject-controlled pause between the two 20-min trials in each 40-min condition (the length of this subject-controlled pause was shown to affect the operator's mood state and physiological response in prior research; see Henning, Sauter, Salvendy, & Krieg, 1989).

"Dummy variables" corresponding to "subjects" (total=$N-1$ variables, i.e. 1 variable for all but 1 of the N subjects) and "work period" (total=11 variables, i.e., 1 variable for all but 1 of the 12 work rhythm conditions) were also included in the multiple regression to adjust for subject differences (e.g., age and data-entry experience) and time-related trends (due to time-of-day and between-day differences across the 12 conditions in the 2-day study), respectively.

The regression model was as follows:

Response measure = Synch + Wmax + Break T + [S codes] + [T codes]

where	Synch	is the synchronization score being evaluated;
	Wmax	is the predominant work rhythm;
	Break T	is the length of the subject-adjusted rest pause (in $\log_e$−s) between the two 20-min trials in each 40-min condition;
	[S codes]	are N-1 variables to adjust for subject differences in a repeated measures design; and
	[T codes]	are 12-1 variables to adjust for time-of-day and day-to-day differences across the 12 conditions administered over the 2-day study.

RESULTS

As expected, the task-induced work rhythm varied across conditions in response to task manipulations, with predominant work-rhythm frequencies ranging from .1 Hz to .7 Hz. Synchronization scores varied between low values of .20 to high values of .65, with a mean value of about .32.

Results of the regression analyses are summarized in Table 1. Each cell of the table contains parameter estimates and the error variance explained (partial r^2) for each regressor. The results for the dummy variables (subject and time-related trends) are not shown because they are secondary to the focus of this study, and also for reasons of economy.

Regression analysis revealed that high levels of work-breathing synchronization were predictive of longer interbeat intervals [i.e., reduced heart rate, $t(178) = 3.37, p < .001$; partial $r^2 = .060$] and increased heart rate variability [$t(178) = 2.74, p = .0067$; partial $r^2 = .041$]. However, work-breathing synchronization was not predictive of mood state.

High levels of work-cardiac synchronization were predictive of reduced Boredom [$t(149) = -3.44, p < .001$; partial $r^2 = .073$] and reduced Fatigue [$t(149) = -2.37, p = .019$; partial $r^2 = .036$]. However, work-cardiac synchronization was not a significant predictor of the physiological response measures.

High levels of work–breathing–cardiac synchronization were predictive of longer interbeat intervals [i.e., indicating reduced heart rate, $t(178) = -3.30, p = .0012$; partial $r^2 = .058$], and reduced Boredom [$t(149) = -2.38, p = .019$; partial $r^2 = .037$].

DISCUSSION

The results of this study provide evidence that synchronization between the work rhythm and short-cycle biorhythms can benefit worker well-being. High levels of work-breathing synchronization were associated with reduced heart rate and increased heart rate variability, indicating reduced psychological demand and stress (Weber et al., 1980). Additionally, an association between high levels of work-cardiac synchronization and reduced Boredom and Fatigue in this study suggests that the task was more engaging and less tiring when work-cardiac synchronization was present. Finally, when all three measures (breathing and cardiac responses, and the work rhythm) were synchronized, heart rate was lower and boredom was reduced.

A number of mechanisms could explain the positive effects seen here when work rhythms and physiological rhythms became synchronized. Floru, Cail, and Elias (1985) suggest that the passive nature of sedentary, computer-based work may make it difficult for the worker to maintain a level of arousal necessary to perform the task effectively. It is possible that entrainment of physiological rhythms to the work rhythm can prevent a decline in arousal because physiological responses are more stable over the work spell (e.g., heart rate maintained at a constant level).

Another possibility is that synchronization between the work rhythm and respiratory rhythms may make the task inherently more predictable. Because a worker can consciously or unconsciously monitor his or her breathing pattern, synchronization of respiratory rhythm to the rhythm of work would enable events

Table 1. Summary of the Separate Regression Analyses

PREDICTORS	Boredom r^2	Boredom b	Fatigue r^2	Fatigue b	Irritation r^2	Irritation b	Stress r^2	Stress b	Tension r^2	Tension b	H IBI r^2	H IBI b	H var r^2	H var b
Work-Breathing Synchronization	n.s.		n.s.		n.s.		n.s.		n.s.		.060***	311	.041**	49.1
Wmax														
Break T													.031*	2.99
Work-Cardiac Synchronization	.073***	−3.88	.036*	−12.6	n.s.		n.s.		n.s.		n.s.		n.s.	
Wmax														
Break T			.050**	1.97										
Work-Breathing-Cardiac Synchronization	.037*	−3.48	n.s.		n.s.		n.s.		n.s.		.058**	256.6	n.s.	
Wmax														
Break T	.032*	.335												

Note. Break T is the variable rest period within each condition (in $\log_e$−s); Wmax is the work rhythm frequency of maximum power; r^2 is the partial error variance explained; b is the parameter estimate (slope).

* $p < .05$. ** $p < .01$. *** $p < .001$.

in the work cycle to be anticipated, eliminating a known source of stress in human-computer interaction, that is, uncertainty or unpredictability (Kuhmann, Wolfram, Schaefer, & Alexander, 1987; Martin & Corl, 1986; Planas & Treurniet, 1988; Schleifer & Amick, 1989).

The importance of synchronization also can be described in cybernetic terms. According to Smith and Smith (1987), physiological and behavioral systems of the body are integrated in a closed-loop, feedback-regulated fashion. A work rhythm that promotes work-physiological synchronization may facilitate efficient tracking of metabolic and biomechanical demands by the cardio pulmonary control systems, thereby reducing the physiological cost of work.

The results of this study have implications for the human factors design of repetitive work. A number of methods for promoting work-physiological synchronization can be considered. Foremost among these is to design repetitive tasks to provide the worker with a greater degree of control over the work rhythm. One problem with many physical tasks, however, is that the work rhythm can seldom be varied without affecting the rate that work is performed. In the case of a task involving repetitive lifting, for example, an increase in the frequency of the work rhythm requires a corresponding increase in work output.

Unlike most physical tasks, the inherent flexibility of information or computer work provides the potential for the work rhythm to be controlled independently of work output. In a repetitive task, for example, control over the work rhythm could be provided to the operator in much the same manner as in this study, that is, by providing control over the amount of information processed in each work cycle.

A second possibility would be to utilize measures of the operator's mood state, or possibly physiological data, as inputs to a control system that would automatically adjust task parameters to regulate the work rhythm. Given the increased availability of computer-processing power at "intelligent" terminals and PC workstations, implementation of a sophisticated operator tracking system of this type now appears feasible.

A third, more administrative approach would use work-scheduling techniques to minimize the negative impact of work rhythms that are incompatible with a worker's biorhythms. When it is not possible and/or practical to redesign the job itself, job rotation could be used to minimize exposure to a particular work rhythm, that is, operators would rotate among several tasks so that a single, potentially stressful work rhythm would not be sustained for a prolonged period.

Further research would be useful to determine if tasks designed along these lines would promote work-physiological synchronization resulting in improved worker well-being.

CONCLUSION

This study examined temporal interactions between physiological rhythms and the periodicity of repetitive work. Results suggest that worker well-being may be benefited when repetitive computer work is designed to promote synchronization between the work rhythm and short-cycle biorhythms.

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