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Field study confirms the belief that keeping busy helps control room operators sustain alertness during the night shift

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Abstract

Control room operators in a nuclear power plant participated in this on-site study to test the belief that keeping busy helps sustain alertness. Since circadian rhythms strongly affect alertness, the study was designed to account for different times of the 24-hour day.The participating reactor operators worked rotating 8-hour shifts in the control room. Every 20 minutes they reported their alertness and their workload during the preceding period. These ratings were obtained throughout three of each shift, for a total of nine shifts and 560 pairs of ratings. Reduced alertness ratings (2 and 3 on the 9-point alertness scale) occurred only during the early morning hours. For these hours, results indicated a significant positive relationship between alertness and workload, with lower alertness ratings tending to occur following 20 minutes of low workload.

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*Keywords:*Nuclear power; Reactor operators; Process operators; Alertness; Shiftwork; Workload

1. Introduction

A common belief is that keeping busy contributes to alertness, while having little to do is monotonous and leads to boredom and a reduced state of alertness. If this is true, jobs involving safety-critical mental performance should be designed to avoid periods with very low workload. Such jobs are found in many 24-hour operations such as nuclear power plants, petroleum refineries, and chemical processing plants. To test that belief, this study was undertaken to see if the alertness of control room operators is affected by the preceding level of activity.

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Extensive laboratory studies have established that an individual's alertness varies throughout the 24-hour day. If the person works a rotating shift schedule, alertness can vary substantially both between shifts and within a single shift. Variability of alertness may not be a major concern so long as alertness is adequate for performing the work. However, the public and employees at industrial plants should be concerned about an employee in a safety-critical position having a bout of very low alertness. This is primarily a concern during the night shift due to our natural circadian cycle supporting higher alertness during daylight and lower during dark hours. There have been numerous instances of industrial disasters stemming from operational perturbation that arose during the night shift, and operators misdiagnosed the problem and/or chose an ineffective course of action [1].

Because night shifts are unavoidable in 24-hour operations, steps for avoiding low alertness begin with understanding risk factors for reduced alertness. The first and foremost is the natural circadian cycle. Extensive research has firmly established the pattern of daily variation in physiological functions including body temperature and state of alertness. Both body temperature and alertness are lowest during the early morning hours, from about 0300 h until about 0600 or 0700 h [2–6]. A second widely recognized risk factor is inadequate sleep [4,6,7,8]. People who work night shifts often find it challenging to get enough hours of quality sleep during their non-work time [7]. A third risk factor for reduced alertness is having chemicals in the body that depress the central nervous system (CNS). Both medicinal sedatives and alcohol depress the CNS and reduce alertness. An individual with a depressed CNS may feel less alert than normal and may be predisposed to a substantial loss of alertness if combined with a sleep deficit and the trough of their circadian cycle. A fourth contributor to reduced alertness is the length of time at work [9]. This factor reflects the tendency to become fatigued after approximately 15-16 hours of being awake. A fifth risk factor for reduced of alertness may be having periods in which there is little to do but watch the clock.

A common situation where two of these risk factors occur together is when people are working during the early morning hours and having little to do. Jensen [10] likened the early morning hours to a container partially filled with water. The water level—representing alertness level—has a natural drain that opens during the early morning hours. In order to maintain the desired water level, more water must be added to counteract the drain. In the analogy, adding water corresponds to providing some sort of stimulation to help the operators counter the natural drain on alertness that occurs due to the circadian cycle. Being busy is thought to be one form of stimulation.

In order to test the belief that staying busy helps sustain alertness, the project design had to account for the potentially confounding effects of time within the 24-hour day and individual differences in alertness when a shift started. To account for time of day, shifts were split in half for data analyses. To account for individual differences, alertness was measured relative to the individual's perceived state of alertness when the shift began, rather than to an absolute scale of alertness. The individual's alertness at the beginning of the shift served as a surrogate for the personal factors that could affect their ability to sustain alertness throughout a shift.

The word "busy" has multiple definitions and usages. What it means in this project matches the first definition in the American Heritage Collegiate Dictionary, "engaged in activity; occupied" [11]. In order to obtain relevant measurements, a minimally intrusive self-rating scale of workload was employed. Thus, the specific purpose of the study was to determine if there is a positive relationship between alertness and workloadThis was examined for different parts of the 24-hour day.

2. Methods

2.1. Study Sample

A power generation company made one of their nuclear power plants available for this project. The plant used a rotating 8-hour shift schedule. The shift rotations followed a 42 day pattern: six day shifts, two days off, seven evening (swing) shifts, two days off, seven night shifts, two days off, five day shifts as relief operators, two days off, five day shifts for training, and four days off. The nine work shifts identified in Table 1 were selected for data collection. The nine shifts consisted of three day shifts (0700 to 1500 h), three evening shifts (1500 to 2300 h), and three night shifts (2300 to 0700 h). All seven days of the week were included.

Another aspect of the sampling strategy concerned the number of days a crew had been working a particular shift. Because the crews rotated shifts, an attempt was made to schedule data collection so that for each shift there would be a fair representation of work early in the rotation, during the middle of the rotation, and near the end of the rotation. This resulted in the following sampling strategy. For the night shift, data collection was for the first, third, and seventh nights of the 7-night rotation. For the day shift, data collection was for the first, fourth, and sixth days of the 6-day rotation. For the evening shift, data collection was for the first, fourth, and sixth evenings of the 7-evening rotation.

Table 1.Work shifts in study sample.

	Sat.	Sun.	Mon.	Tue.	Wed.	Thur.	Fri.
Night Shift	■		■				■
Day Shift	■		■		■		
Evening Shift		■		■		■	

Minimum crews for the control room consisted of a Shift Supervisor, a Crew Foreman, a Shift Technical Advisor, and three licensed Reactor Operators (ROs). There were three work stations for ROs in the control room. At the beginning of each shift in the study, the individual RO assigned to each workstation was invited to participate in the project.

2.2. Procedures

When the investigator met with a crew of ROs for the first time, he explained the purpose of the project, it was funded by the U. S. Nuclear Regulatory Commission, and it was not part of their job. The investigator asked for their voluntary participation. All but one agreed to participate and all participants signed an informed consent form. None of the participants withdrew during the study.

The on-site investigator, and author of this paper, was in the control room throughout each of the nine shifts in the study sample. Twenty minutes after the shift started, and every 20 minutes thereafter, the investigator laid a rating form on the desk of each RO. Their instructions were to fill it out right away if it would not interfere with work, otherwise wait until they had a brief break in their work. The investigator collected the forms soon after the ROs completed their ratings. The last form was distributed approximately 20 minutes before the end of the shift, i.e., 0640 h, 1440 h, or 2240 h.

2.3. Self-rating instruments

The participating ROs used the self-rating forms in Figure 1 to report their workload during the preceding 20 minutes and their present alertness relative to how alert they felt at the beginning of the shift. The workload scale in the upper half of Figure 1 is based on the rating scale developed by Ames and George for use by the U.S. Air Force Flight Test Center (AFFTC) [12]. It is generally called the AFFTC workload estimate scale [13]. It has also been called ARWES for Air Force Workload Estimate Scale [14]. This single-scale AFFTC instrument was selected because it suited this project in two ways: (a) its apparent face validity for use by ROs to estimate how busy they were for the past 20 minutes, and (b) its minimal intrusiveness compared to multidimensional scales used for diagnosing the sources of high workload [15]. The AFFTC scale is an integration of three aspects of workload: level of activity, demands of the system, and time available. In the highest rating category, "unsafe" is added as a fourth aspect. The workload scale in Figure 1 was the same as the AFFTC scale, with one exception. The highest activity level category in the original AFFTC word set was "Overloaded; System unmanageable; Essential tasks undone; Unsafe." For this project, the word "Unsafe" was replaced with "Safety concerns." This modification was made because of a belief that the ROs, unlike test pilots, would feel reluctant to use the highest activity level category if it included the word "Unsafe." By substituting the phrase "safety concerns" an RO who had an extremely busy period could check the highest category without declaring the plant unsafe. The workload levels were assigned values from zero to 12.

RATINGS OF WORKLOAD AND ALERTNESS

Workload

Please rate your workload during the past 20 minutes.

__ Nothing to do; No system demands
__
__ Light activity; Minimum demands
__
__ Moderate activity; Easily managed; Considerable spare time
__
__ Busy; Challenging but manageable; Adequate time available
__
__ Very busy; Demanding to manage; Barely enough time
__
__ Extremely busy; Very difficult; Non-essential tasks postponed
__
__ Overloaded; System unmanageable; Essential tasks undone; Safety concerns

Present Alertness Level

Compared to my alertness when this shift started, my present alertness is:

9	
8	Very much more
7	
6	Slightly more
5	← Alertness at beginning of shift
4	Slightly less
3	
2	Very much less
1	

Fig. 1.Self-rating form.

The lower half of the rating form had the alertness rating scale [16]. The word sets used in the scale (i.e., very much less, slightly less, slightly more, very much more) have been found to cause no confusion as to order [17]. These word sets were assigned the numerical values 2, 4, 6, and 8, respectively. Prior investigations established the equality of intervals between the numbered word sets [17,18]. To use this group of words properly, a reference point in the middle was needed. The reference chosen was the individual's alertness at the beginning of the shift. This rating was assigned a value of five. Thus, the rating scale was used to measure the individual's change in alertness as the shift progressed.

3. Results

Figure 2 shows the distribution of the 560 alertness ratings. The most frequent alertness rating was 5; indicating alertness had not changed from the beginning of the shift. Values of 6 and 7 were also very common, indicating a feeling of increased alertness after the start of the shift. Based on personal observations while in the control room, ratings of 2 and 3 indicate the RO was struggling to stay awake.

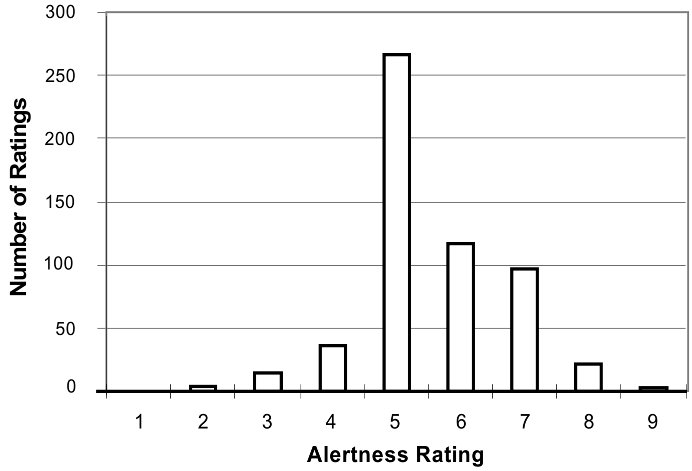

Fig. 2.Histogram of 560 alertness ratings.

3.1. Alertness differences by shift

Alertness ratings were examined for each half shift using Minitab software. Descriptive statistics are shown in Table 2. The largest mean values were for the two halves of the day shift. The lowest mean was for the second half of the night shift. The Kruskal-Wallis test for medians indicated significant differences (H = 76; p = 0.000). A one-way ANOVA indicated significant differences in means (F = 19.7; p = 0.000). The Tukey multiple comparison test for differences in means indicated the following groups with significantly different means.

A. Most Alert:
- Day first half (mean = 5.94)
- Day second half (mean = 6.26)

B. Mid-range Alertness
- Evening first half (mean = 5.49)
- Evening second half (mean = 5.45)
- Night first half (mean = 5.46)

C. Least Alert
- Night second half (mean = 4.83)

Table 2.Descriptive statistics and linear regressions of alertness related to workload for half shifts.

	Descriptive Statistics			Linear Regression Results			
Shift	Half	N*	Mean Alertness	Alertness Intercept	Workload Coefficient	T	Probability
Day	1st	88	5.94	6.634	-0.160	-2.70	0.008
Day	2nd	84	6.26	6.693	-0.120	-1.66	0.101
Evening	1st	100	5.49	5.245	0.086	2.25	0.027
Evening	2nd	94	5.45	5.027	0.193	3.02	0.003
Night	1st	99	5.46	5.835	-0.109	-1.63	0.105
Night	2nd	95	4.83	4.033	0.368	3.29	0.001

* Number of pairs of observations in each half shift. Total N = 560.

The lowest ratings were at level 2, indicating "very much less" alert than at the beginning of the shift. There were four ratings in this category. Ratings of 3 were somewhat more frequent (N = 15). Together the ratings of 2 and 3 constituted 3.4 percent of all ratings.

There were 19 alertness ratings of 2 or 3. All of these occurred during the night shift. The earliest of these was at 0300 h. Table 3 shows the number of 2 and 3 ratings in 1-hour periods. These low ratings came from three different crews observed throughout the night shift.

Table 3.Hourly distribution of lowest alertness ratings.

	Number of Alertness Scores		
Time Period	Alertness = 2	Alertness = 3	Row Total
0220-0300	0	1	1
0320-0400	1	4	5
0420-0500	0	3	3
0520-0600	1	4	5
0620-0640	2	3	5
Total	4	15	19

To examine alertness trends within shifts, average ratings on the alertness scale were computed for each hour. For example, the first hour of the day shift was 0700 to 0800 h. Alertness ratings obtained at 0720, 0740 and 0800 h were averaged. For the last hour of the shifts, two alertness ratings were obtained and averaged, e.g., those at 1420 and 1440 h for the day shift. These hourly average alertness levels are plotted in Figure 3. The day shift shows a trend of rising alertness for the initial two hours followed by a consistent alertness level for the remainder of the shift. This pattern was closely followed by all three crews studied during the day shift. The evening shift shows an unchanging level of alertness throughout. This pattern was closely followed by all three crews in the study sample. The night shift shows alertness level above 5 for the first three hours, very near 5 for three hours, and below 5 for the last two hours. The three crews that worked the night shift during the study followed the same trend only for the first 6 hours of the shift. Their alertness trends diverged during the last 2 hours.

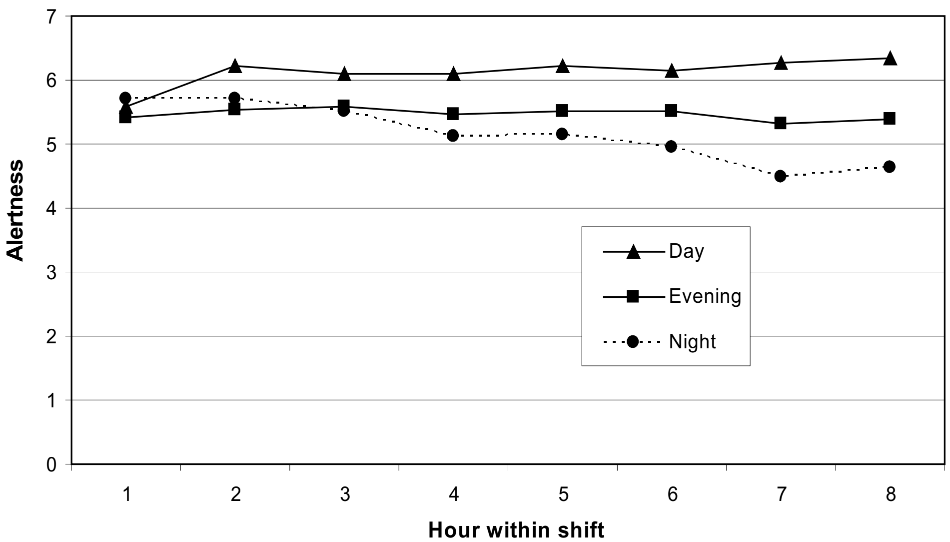

Fig. 3.Hourly trends in mean alertness ratings for each shift.

3.2. Alertness influenced by workload and half shift

Of the 19 alertness ratings considered low (2 or 3), 17 were associated with a workload rating in the low range (0 to 3). The other two low alertness ratings were associated with activity level rated at level 5. Therefore, two factors appear to explain 17 of the 19 (89.5%) low alertness ratings:

1. Time of day between 0300 and 0640 h, and
2. Workload rated in the 0 to 3 range.

The results of linear regression analyses between self-rated levels of alertness (A) and workload (W) are presented in Table 2. Considering the slopes and *p* values, the strongest relationships were for the second half of the night shift, followed by the second half of the evening shift. Two other half shifts with statistically significant regressions were the first half of the day shift and first half of the evening shift.

4. Discussion

4.1. Methods and Limitations

One strength of the methodology was having experienced ROs as the source of data. Two advantages over using a questionnaire survey are strong context validity of the ratings due to being recorded on-site during shifts, and minimal reliance on the memory of participants [18]. The sampling plan was constructed to include all three shifts, different crews, and a fair distribution of when the shift occurred during a shift rotation. This approach facilitated analyzing data between and within shifts.

The AFFTC workload scale was acceptable to the ROs and provided suitable data for this project. In that regard, I agree with Hendy et al. [15] and Pickup et al. [13] that multiple scale methods are necessary only if one wants to diagnose the role of different factors in creating the overall workload. Diagnosis was not sought in this project. Additionally, multidimensional workload scales are more intrusive than single dimensional scales. Similarly, Pickup et al. (2005) considered various workload scales for use in railroad operations [13]. They concluded that the multidimensional scale methods would be too intrusive for their needs in the railroad industry. For this project on RO's, getting permission from the power plant was not assured. By designing the study for minimal intrusiveness, the plant management was willing to authorize the study and the operators were willing to participate. It is not known if this level of cooperation could have been achieved had operators been asked to provide six or more workload-related rating plus one for alertness every 20 minutes instead of two.

The alertness scale was anchored to the individual participant's alertness when the shift began. This approach allowed for differences in how the individual felt when starting the shift. An operator, who felt tired when the shift began, could still rationally provide ratings above the anchor point (five) due to changes that occurred during the shift. Thus, the relative nature of the alertness scale helped control for individual differences in state of alertness by personalizing this potentially confounding factor.

An apparent limitation of this project was obtaining all data at a single plant. As a result, generalizations to other types of 24-hour operations should be made cautiously. The findings about alertness varying during different shifts are as expected, and consistent with the shiftwork literature. One difference is that this field study did not find a mid-afternoon dip in alertness.

The finding about alertness declining during the early morning hours is consistent with prior studies and supports the view that the participating ROs were both able to recognize the decline and willing to share that feeling through their ratings. Thus, in spite of the study being limited to a single plant, there is no apparent reason to believe the ROs in this facility were somehow not representative of control room operators in many other plants with 8-hour rotating shifts.

4.2. Conclusions

The project was undertaken to test the belief that keeping busy helps sustain alertness. The specific purpose was to determine if there is a positive relationship between alertness and workload, with lower alertness ratings tending to follow 20 minutes of lower workload. Thiswas clearly determined for the second half of the night shift and less clearly confirmed for the second half of the evening shift. A significant positive relationship was found for the first half of the evening shift—although significant, I regard this as meaningless due to the relatively flat slope of the regression line.Thus, the primary conclusions from this field study is that during the second halves of the night and evening shifts, lower ratings of alertness tend to occur following 20-minute periods of low workload. It is, therefore, a wise management practice to facilitate control room operator alertness by keeping them busy with work or other kinds of stimulating activities.

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