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SHIFT-RELATED EFFECTS ON PSYCHOPHYSIOLOGIC PERFORMANCE IN UNDERGROUND MINEWORKERS

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INTRODUCTION

How does shiftwork influence variability in work performance? In one sense, we already know the answer to this question. There is extensive evidence that relative to day and afternoon shiftworkers, night shiftworkers tend to work at a reduced level of effectiveness, as measured both by various indices of job performance and by standard behavioral and physiological function tests (Colquhoun, 1971; Akerstedt, Patkai, and Dahlgren, 1977; Folkard and Monk, 1979). Between-shift variability in work performance thus may be explained as a consequence of circadian dissonance, in which night shiftworkers are asked to fulfill their job responsibilities in the face of depressed behavioral and physiological functioning.

Another dimension of work performance variability concerns the consistency or reliability with which a shiftworker is able to perform his/her work during the course of a shift. Possible shift-specific effects on such within-shift variability have not been closely examined. That is, night shiftworkers conceivably could be more or less consistent in performing at a reduced level across the shift, relative to the within-shift consistency in performance at a higher level displayed by workers on day or afternoon shifts. Further, there may be shift-specific differences in within-shift variability between physiological relative to behavioral measures of performance. Clearly, a comprehensive understanding of the interaction between work performance variability and the work shift must address both between- and within-shift manifestations of variability.

This report presents findings from the first phase of a study designed to compare the performance of mineworkers on rotating 8-hour shifts to that on rotating 12-hour shifts.[1] Only findings from 8-hour shifts are given.

METHOD

Subjects

Experimental subjects comprised 25 underground male workers whose work schedule was targeted for change from 8-hour to 12-hour shifts. This group worked an 8-hour schedule that

[1]We thank the British Columbia Ministry of Energy Mines and Petroleum Resources, Westmin Resources Limited, the Canadian Association of Industrial Mechanical and Allied Workers, and the Simon Fraser University Institute for Human Performance for their cooperation and assistance with this project.

rotated from the night to afternoon to day shift on a 7x2,7x2,7x3 (days on work x days off work) rotation schedule. Control subjects comprised 8 male workers on an 8-hour, nonrotating, straight day, 5x2 shift schedule (all weekends off). Table 1 summarizes subject characteristics.

Experimental Design

Separate experimental stations for behavioral and physiological testing were installed on the 1927-foot level of the mine. Replicate start of shift and end of shift testing for each subject was administered for the following dependent measures:

Behavioral Performance Testing

A personal computer (PC) based behavioral test battery, adapted from a version developed by Rosa and Colligan (1988), was employed. The battery consists of 6 parts: (1) a series of subjective response questions; (2) a pursuit tracking task; a grammatical reasoning task with (3) and without (4) random noise distraction; (5) a choice reaction time task; and (6) a repetitive finger tapping task. A total of 23 subjective and objective performance measures are derived from the behavioral battery test results, as summarized in Table 2.

Submaximal Exercise Testing

Physical fatigue was measured by use of a submaximal exercise stress test. Ergomedic Model 818E Monark bicycle ergometers were used, following a procedure for submaximal exercise testing originally described by Astrand and Rhyming (1954).

The third (highest) work load on the cycle was selected such that the highest submaximal heart rate achieved approximated 140 beats per minute (bpm). Each subject was asked to complete replicate start of shift and end of shift testing on alternate days during their work week. Estimated maximal aerobic capacity (VO_{2max}) levels for each subject were derived using the Astrand and Rhyming (1954) nomogram, based on the highest heart rate achieved at the highest submaximal work load. Estimates for two measures of aerobic capacity are cited in this report: (1) total maximal oxygen consumption (VO_{2max}), in ml O_2/min; and (2) maximal oxygen consumption per unit body weight (VO_{2max}/kg), in ml O_2/min/kg. Also cited are the recovery heart rates at 1 and 2 minutes (HR-R1 and HR-R2), calculated (Equation 1) relative to total recovery from the HR measured at the highest work load (HR-WL3) to the unloaded HR (HR-UL):

$$\text{HR-R1 \{HR-R2\}} = \frac{[(1\ \{2\}\ \text{min recovery HR}) - (\text{HR-UL})] \times 100}{[(\text{HR-WL3}) - (\text{HR-UL})]} \qquad (1)$$

Pulmonary Function Testing

The objective was to indirectly assess possible acute effects of exposure to airborne contaminants. A Collins 9-liter spirometer was used to administer three forced vital capacity (FVC) maneuvers (Collins, 1957; Ruppel, 1982) during each test session. Three measures of pulmonary function are cited in this report: (1) FVC, in liters (BTPS); (2) $FEV_{1.0}$, in liters (BTPS); and (3) the $FEV_{1.0}$/FVC ratio (no units).

Table 1. Subject characteristics.

GROUP	CREW	SHIFT	DAYS OF DATA COLLECTION	N	AGE (YEARS) MEAN	RANGE
EXPERIMENTAL (rotating)	7x2D	Day	5	12	35.0	20 - 61
	7x2N	Night	7	6	35.2	19 - 55
	7x2A	Afternoon	7	7	33.7	21 - 50
CONTROL (nonrotating)	5x2D	Straight days	5	8	35.0	27 - 49

Table 2. Dependent measures derived from behavioral performance testing.

VARIABLE	DEFINITION	UNITS	
	SUBJECTIVE VARIABLES		
ALERT	How alert do you feel right now?	1=not	9=extreme
EFFICIENT	How efficient do you feel right now?	"	"
FRIENDLY	How friendly do you feel right now?	"	"
GROUCHY	How grouchy do you feel right now?	"	"
HARD	How hard did you work during last hour?	"	"
LIVELY	How lively do you feel right now?	"	"
SLEEPY	How sleepy do you feel right now?	"	"
SSS	Stanford Sleepiness Scale	"	7=extreme
THINK	How able are you to think clearly right now?	"	9=extreme
WORK	How able are you to work hard right now?	"	"

VARIABLE	DEFINITION[1]	UNITS
	OBJECTIVE VARIABLES	
GRW-DRT	Grammatical Reasoning w/noise distraction (RT)	msec
GRW-DSD	Grammatical Reasoning w/noise distraction (SD)	msec
GRW-DERR	Grammatical Reasoning w/noise distraction (# errors)	errors
GRN-DRT	Grammatical Reasoning w/out noise distraction (RT)	msec
GRN-DSD	Grammatical Reasoning w/out noise distraction (SD)	msec
GRN-DERR	Grammatical Reasoning w/out noise distraction (# errors)	errors
CHOICERT	True/False Choice Reaction Time (RT)	msec
CHOICESD	True/False Choice Reaction Time (SD)	msec
CHOICERR	True/False Choice Reaction Time (# errors)	errors
CHOICEMISS	True/False Choice Reaction Time (# misses)	misses
TRACKRMS	Pursuit Tracking Task (root mean square)	pixels
TAPALTN	Two-Finger Tapping (# alternations)	taps
TAPLAPS	Two-Finger Tapping (# lapses in responding)	lapses

[1]RT=reaction time (msec); SD=standard deviation of RT (msec)

<u>Work Food and Sleep Diary</u>

Shortly before and shortly after their sleep period, subjects are asked to record entries in a Bureau-developed diary (Duchon and Keran, 1990) pertaining to work, eating, and sleep activities, plus self-reports of subjective mood and health complaints using a discrete 5-part scale. This report cites start of day and end of workday levels for 5 subjective diary measures: alertness, sleepiness, grouchiness, feeling relaxed, and an overall mood scale derived from these four items.

Statistical Analysis

For each dependent measure specified above, analysis of variance (ANOVA) with repeated measures was applied for the four subject groups by time of testing. For each subject and each measure, the replicate start of shift values were averaged for this analysis, as were the replicate end of shift values. Fisher product moment correlation coefficients between start of shift and end of shift levels for each dependent measure also were computed, again using the replicate averages. A PC-based statistical package (SPSS, 1990) was used for the analysis.

RESULTS

Between-Group Variability, by Shift and Time of Testing

ANOVA was used to evaluate for significant ($p<.05$) main effects of shift (S) (i.e., subject group) and of time of testing (T) (i.e., start versus end of shift), and for the interaction (SxT) of the main effects, on between-group performance variability. For a given variable: (1) a significant main effect of shift indicates that the means differ across the four shifts; (2) a significant main effect of time of testing indicates a consistent change in means from start to end of shift, regardless of the shift worked; and (3) a significant interaction indicates that the different subject groups show differences in the pattern of the time of testing effect.

ANOVA results for all dependent measures are summarized in Table 3. Among the pulmonary function and ergometry measures, only the $FEV_{1.0}/FVC$ ratio shows a significant effect of shift ($F_{3,21}=3.90$, $p<.05$); the primary difference in mean values for this ratio is between the 7x2A group (82.8%) and the 5x2D group (68.8%).

For the five subjective diary responses, there are two significant SxT interactions: HOW SLEEPY ($F_{3,10}=3.91$, $p<.05$) and HOW RELAXED ($F_{3,10}=10.46$, $p<.005$). There are no significant differences at the start of shift for HOW SLEEPY; however the night shift group reported being more sleepy at the end of shift than did the other groups. By end of shift, the 7x2N and 7x2D groups reported being more RELAXED, the 5x2D group reported being less RELAXED, and the 7x2A group reported no change, relative to start of shift.

Results for the subjective measures on the performance battery show four significant effects: SxT interaction effects for HOW GROUCHY ($F_{3,29}=4.24$, $p<.05$) and HOW SLEEPY ($F_{3,29}=4.08$, $p<.05$); also a main effect of shift ($F_{3,29}=3.05$, $p<.05$) for the HOW SLEEPY question; and a main effect of time of testing ($F_{1,29}=74.56$, $p<.001$) for the question HOW HARD DID YOU WORK DURING THE LAST HOUR.

For the question HOW GROUCHY, the 7x2A group reported an increase, the 7x2D group reported a decrease, and the 7x2N and the 5x2D groups reported no change in this measure, from start to end of shift.

Figure 1 depicts the pattern of change among the four subject groups from start to end of shift for the question HOW SLEEPY. Relative to the other groups, the night shift group reported being slightly more sleepy at start of shift, and substantially more sleepy by end of shift. The other groups

Table 3. Significant ANOVA results (p<.05 marked by *) for dependent measures, by main effects (SHIFT and TIME of test) and by SHIFT by TIME (S x T) interaction.

-------PULMONARY FUNCTION------

VARIABLE:	SHIFT	TIME	S x T
FVC			
$FEV_{1.0}$			
$FEV_{1.0}/FVC$	*		

---------------ERGOMETRY--------------

VARIABLE:	SHIFT	TIME	S x T
VO_{2max}			
VO_{2max}/kg			
HR-R1			
HR-R2			

-------------------DIARY-------------------

VARIABLE:	SHIFT	TIME	S x T
ALERT			
SLEEPY			*
GROUCHY			
RELAXED			*
MOOD			

------PERFORMANCE BATTERY-----

SUBJECTIVE VARIABLES:	SHIFT	TIME	S x T
ALERT			
EFFICIENT			
FRIENDLY			
GROUCHY			*
HARD		*	
LIVELY			
SLEEPY	*		*
SSS			
THINK			
WORK			

OBJECTIVE VARIABLES:	SHIFT	TIME	S x T
GRW-DRT			
GRW-DSD			
GRW-DERR			
GRN-DRT		*	
GRN-DSD			
GRN-DERR			
CHOICERT		*	
CHOICESD			
CHOICERR			
CHOICEMISS			
TRACKRMS			
TAPALTN			
TAPLAPS		*	

showed either no change or a decrease in sleepiness (7x2D group) from start to end of shift.

For the objective measures of behavioral performance, three significant main effects of time of testing are observed. For the GRAMMATICAL REASONING WITH NO AUDITORY DISTRACTION task, three of the four groups have faster reaction times at end of shift than at start of shift ($F_{1,28}=5.81$, $p<.05$). However, as shown in Figure 2, reaction times for the night shift group on this task remain almost constant from start to end of shift.

On the CHOICE REACTION TIME task, as shown in Figure 3, all groups have slower reaction times at the end of shift than at the start of shift ($F_{1,29}=5.01$, $p<.05$). Figure 3 also shows that night shift workers perform slowest on this task among all four groups at both start and end of shift, although the main effect for shift is not statistically significant.

For the TWO-FINGER TAPPING task, all groups have fewer lapses in responding at end of shift relative to start of shift ($F_{1,29}=4.80$, $p<.05$). A lapse is defined as failing to press the alternate finger within 385 msec.

<u>Within-Subject Variability in Performance</u>

A second goal of this study is to examine the consistency in objective and subjective measures of performance for individual subjects across the shift, as it may be influenced by different shift schedules. To address this question, correlation coefficients for mean start and end of shift scores for each subject were determined for each dependent measure. A significant coefficient ($p<.05$) for a given measure indicates high within-subject consistency (or low variability) for that measure across the shift. Examining the number and pattern of significant correlations across all of the different measures provides a general profile of within-subject performance consistency across the shift.

Table 4 summarizes the significant correlations found between start and end of shift mean values for the different dependent measures. For the pulmonary function and ergometry measures, all three of the rotating shift groups are somewhat comparable, in terms of the number of significant correlations observed. However, no significant correlations are observed for the 5x2D control group. A possible explanation for this latter finding is that only two replicate values for each of the physiological measures were collected for this group.

Table 4. Significant correlations ($p<.05$ marked by *) between start and end of shift mean values for different dependent measures, by subject group.

PULMONARY FUNCTION

	SHIFT			
VARIABLE:	7X2N	7x2A	7x2D	5x2D
FVC	*	*	*	
$FEV_{1.0}$	*	*	*	
$FEV_{1.0}/FVC$				

ERGOMETRY

	SHIFT			
VARIABLE:	7X2N	7x2A	7x2D	5x2D
VO_{2max}	*	*	*	
VO_{2max}/kg	*	*	*	
HR-R1		*	*	
HR-R2			*	

DIARY

	SHIFT			
VARIABLE:	7X2N	7x2A	7x2D	5x2D
ALERT				
SLEEPY		*		
GROUCHY	*	*		
RELAXED	*	*	*	
MOOD	*	*		

PERFORMANCE BATTERY

SUBJECTIVE	SHIFT			
VARIABLES:	7X2N	7x2A	7x2D	5x2D
ALERT	*	*		*
EFFICIENT	*		*	*
FRIENDLY	*			*
GROUCHY		*		*
HARD				
LIVELY	*			*
SLEEPY		*		*
SSS	*			
THINK	*	*	*	*
WORK	*			

OBJECTIVE	SHIFT			
VARIABLES:	7X2N	7x2A	7x2D	5x2D
GRW-DRT	*		*	*
GRW-DSD			*	
GRW-DERR	*		*	*
GRN-DRT	*	*	*	
GRN-DSD		*	*	
GRN-DERR	*	*	*	*
CHOICERT		*	*	*
CHOICESD		*		
CHOICERR			*	*
CHOICEMISS				
TRACKRMS		*	*	*
TAPALTN		*	*	
TAPLAPS	*		*	*

For the subjective diary responses, the 7x2N and 7x2A groups display more consistency across the shift than do the 7x2D and 5x2D groups.

Results for the performance battery indicate that all but the 7x2D group are consistent across the shift for many of the subjective measures. A different pattern is observed for the objective measures. All groups are consistent across the shift for many of the measures derived from the two cognitive performance tasks (i.e., GRAMMATICAL REASONING WITH and WITHOUT AUDITORY DISTRACTION). Conversely, the day and afternoon shift groups (both rotating and control) are consistent for many of the measures derived from the three psychomotor tasks (i.e., CHOICE REACTION TIME; PURSUIT TRACKING; AND TWO-FINGER TAPPING), but the night shift group is not.

CONCLUSIONS

The first question addressed is whether shift and time of testing affect performance levels. This question has been asked in many previous shiftwork studies of other types of workers. Most have been survey questionnaire studies, some have assessed only objective performance, and some have been laboratory studies. Very few have combined into a single field study measures of physiological, behavioral, and subjective performance. A weakness of the present study is the relatively low and unequal number of workers in each subject group, ranging from 6 in the 7x2N group to 12 in the 7x2D group, which tends to reduce statistical power of the analysis.

In general, most measures of performance do not differ significantly among day, afternoon, and night shiftworkers. The most consistent finding, from subjective responses on both the diary and the behavioral battery, is that night shift workers report feeling more sleepy relative to workers on the other shifts. Because this difference is more pronounced at the end relative to the start of shift, there is a significant SxT interaction for this item. Aligned with this observation are findings that both grammatical reasoning and choice reaction times are slower for the night shift group at end of shift, relative to the other groups (Figures 2 and 3).

A second goal of this study is to examine how consistency of within-subject performance may be affected by shift. Consistency is defined here as correlated performance between start and end of shift. Significant correlation implies low variability across the shift, which may be expected a priori on objective tests of both cognitive and psychomotor skill, as well as physiological functioning. For the objective behavioral tasks, this expectation appears to be upheld for both day and afternoon workers. There is less consistency across the shift among night shift workers for psychomotor behavioral tasks, as well as for heart rate recovery. It seems reasonable to suggest that this phenomenon may have a circadian basis, although further study is needed to substantiate this possibility.

Collectively, the findings cited in this report raise intriguing questions about the possible effects of extended workdays on underground mining work. If sleepiness is increased, reaction time slowed, and psychomotor performance more variable among night shift workers on 8-hour shifts, a reasonable prediction is that these effects will be exacerbated by 12-hour shifts. The second phase of this study will assess this prediction.

REFERENCES

Akerstedt, T., Patkai, P. and Dahlgren, K., 1977, Field studies of shiftwork II: temporal patterns in psychophysiological activation in workers alternating between night and day work. Ergonomics, 20, 621-631.

Astrand, P.O. and Rhyming, I., 1954, A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during submaximal work. Journal of Applied Physiology, 7, 218-221.

Collins, W.E., Inc., 1957, Clinical Spirometry (Boston: Warren E. Collins, Inc.).

Colquhoun, W.P., 1971, Circadian variations in mental efficiency. In Biological Rhythms and Human Performance, edited by W.P. Colquhoun (New York: Academic Press), pp. 39-107.

Duchon, J. and Keran, C., 1990, The adjustment to a slowly rotating shift schedule: are two weeks better than one? In Proceedings of the Human Factors Society (Santa Monica: Human Factors Society), pp. 899-903.

Folkard, S. and Monk, T.H., 1979, Shiftwork and performance. Human Factors, 21 483-492.

Rosa, R.R. and Colligan, M.J., 1988, Long workdays versus restdays: assessing fatigue and alertness with a portable performance battery. Human Factors, 30(3), 305-317.

Ruppel, G., 1982, Manual of Pulmonary Function Testing. Third Edition (St. Louis: Mosby).

SPSS Inc., 1990, SPSS Reference Guide (Chicago: SPSS, Inc.).

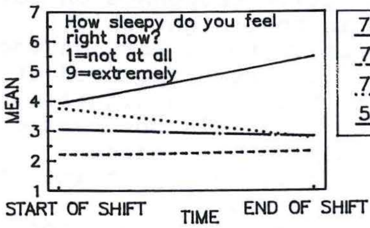

Figure 1. Start to end of shift changes by subject group for the question, "How sleepy do you feel right now?"

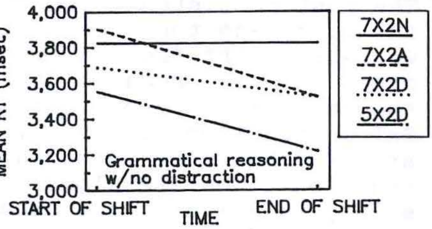

Figure 2. Start to end of shift changes by subject group for reaction time on the grammatical reasoning task with no distraction.

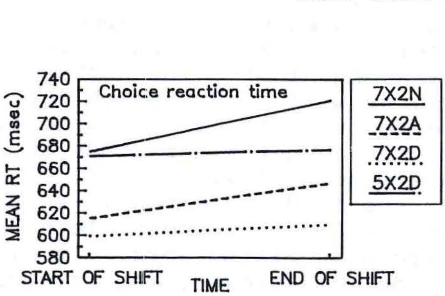

Figure 3. Start to end of shift changes by subject group for true/false choice reaction time.

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