

# Work Schedule and Task Factors in Upper-Extremity Fatigue

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We tested the combined effects of work schedule and task factors on upper-extremity fatigue in the laboratory during 8-h and 12-h shift schedules. Participants performed a simulated manual assembly task at three repetition rates and three torque loads and self-adjusted their work cycle duration to maintain fatigue at moderate levels. Work cycle durations decreased with increases in both load level and repetition rate. Fatigue was observed more quickly with increasing time on shifts and during night shifts compared with day shifts. Work schedule effects were most apparent at lighter workloads, with minimal differences at higher workloads. The highest fatigue levels were observed during 12-h night shifts, with similar levels reached by the end of both the week of 8-h night shifts and the week of 12-h day shifts. Overall durations were 20%–30% shorter than in previous short-term studies, which was likely a result of the more realistic work schedules used in this study. Results from this study could be applied to the design of work-rest schedules for manual tasks involving the upper extremities.

## INTRODUCTION

Workers performing manual tasks involving the upper extremities often develop painful symptoms that can reduce work capacity and increase sick leave (Anderson, 1984). These symptoms arise from excessive fatigue in muscles that are repetitively or excessively loaded. The extent of the problem in industry has indicated a need for practical job assessment methods so that tasks can be designed to minimize the risk of contracting a soft tissue disorder.

Toward this end, Putz-Anderson and Galinsky (1993) adapted psychophysical methods, used to characterize manual lifting (e.g., Ayoub, Bethea, & Deivanayagam, 1978; Ciriello, Snook, Blick, & Wilkinson, 1990; Snook, 1978), to the study of manual assembly tasks involving the upper extremities. Unlike lifting studies that varied weight or position, however, Putz-Anderson and Galinsky required participants to adjust the duration of the work

cycle in response to given levels of task demand. Adjusting cycle duration circumvented the difficulties involved in changing physical variables that are not modified easily in actual assembly tasks.

In a series of studies, Putz-Anderson and Galinsky (1993) demonstrated that participants could adjust the duration of their work cycle consistently in response to task factors such as shoulder-arm load, tool weight, vertical reach, and repetition rate, and in response to various criteria of perceived fatigue or discomfort. Increases in any of these parameters resulted in decreases in work cycle duration. The strongest observed effects were those of repetition rate (39%–45% of variance), load (21%–36% of variance), and perceived criterion of fatigue/discomfort (21% of variance).

The present study extended these findings by testing the effects of two work schedule factors – time of day and length of workshift – on judgments of perceived exertion in elevated

manual work. Given that the original studies required workers to perform the task for only 3–5 h during the daytime, the extent to which the results generalize to workdays of 8 h or longer, or to work at atypical times of day is not clear. It is important to consider these parameters because the frequent use of 24-h operations (Mellor, 1986) and the growing popularity of work shifts longer than 8 h (Rosa, 1995) could increase the probability of fatigue-related injuries (for reviews, see Folkard & Monk, 1985; Rosa & Colligan, 1992). Indeed, several studies have demonstrated that both physiological functions and exercise capacity are diminished at night (e.g., Cabri, De Witte, & Clarys, 1988; Cohen & Muehl, 1977; Ilmarinen, Ilmarinen, Korhonen, & Nurminen, 1980; Wojtczak-Jaroszowa, 1977; Wojtczak-Jaroszowa & Banaszekiewicz, 1974). However, studies of the effects of time of day or length of work period on manual work are rare.

In studies of manual lifting, acceptable loads have been estimated from observation periods of 0.5–4 h (e.g., Ayoub et al., 1978; Ciriello et al., 1990; Legg & Pateman, 1984; Snook, 1978), or from a single 8-h workday (Fernandez, Ayoub, & Smith, 1991; Legg & Myles, 1981; Legg & Patton, 1987; Louhevaara, Hakola, & Ollila, 1990; Mital, 1983; Yu & Lu, 1990; Zhu & Zhang, 1990). Within a given study, no direct comparisons have been made to work shifts of different length (except in Waersted & Westgaard, 1991). Consequently, the present study was conducted to examine the relative contribution of work schedule parameters (time of day and length of work shift) and task parameters (applied force and repetition rate) to upper-extremity fatigue from manual work. It was hypothesized that reductions in activation-arousal, physiological work capacity, and psy-

chological motivation, which are associated with night work or extended work shifts, would combine with physical factors intrinsic to the manual task to decrease the acceptable work durations observed in previous work.

**METHOD**

**Work Schedules**

In this study the 8-h schedule was the typical 5-day workweek, whereas the 12-h schedule was a 4-day week. Separate groups of participants on each schedule worked one week of day shifts (7:00 a.m.–3:30 p.m. or 7:00 p.m.–7:30 p.m.) and one week of night shifts (11:00 p.m.–7:30 a.m. or 7:00 p.m.–7:30 a.m.) in counterbalanced order (see Figure 1).

**Participants**

Eight women and eight men (ages 21–40) were recruited through newspaper advertisements requesting experienced shift workers. Equal numbers of men and women were assigned randomly to each work schedule (see Figure 1). Selection criteria included at least six months' experience both with manual assembly tasks and shift work within two years preceding the experiment, good health, normal sleep, no history of drug or alcohol abuse, right-hand dominance, normal or corrected vision, caffeine intake not exceeding the equivalent of three cups of coffee per day, and tobacco use of no more than half a pack of cigarettes per day. Women participants were excluded if they were pregnant. Health criteria were determined by a physician's examination.

None of the participants had worked night shifts for at least two weeks prior to the study. Informed consent was obtained, and all participants received hourly compensation, including a night shift differential, for their participation.

		Day													
		M	T	W	T	F	S	S	M	T	W	T	F		
8-h Shifts	Order A (N=2M,2F):	D	D	D	D	D	r	r	N	N	N	N	N	N	
	Order B (N=2M,2F):	N	N	N	N	N	r	r	D	D	D	D	D	D	
12-h Shifts	Order A (N=2M,2F):	D	D	D	D	r	r	r	N	N	N	N			
	Order B (N=2M,2F):	N	N	N	N	r	r	r	D	D	D	D			

D = Day Shift; N = Night Shift; r = Rest Day

Figure 1. 8-h and 12-h work schedules.

## Work Task and Auxiliary Measurements

*Manual work task.* Load (i.e., force applied by the operator) and repetition rate (i.e., number of work cycles per unit of time) were examined in a replication of the task developed by Putz-Anderson and Galinsky (1993). During each 70-min session, three trials were conducted for each of nine factorial combinations of load (10%, 20%, and 30% maximum voluntary contraction) and repetition rate (10, 20, and 30 motions/min), yielding 27 trials per session. Trial order was randomized for each participant within each session.

The task was performed on a Baltimore Therapeutic Equipment (BTE) work simulator that was configured to simulate elevated manual assembly for a seated operator. The BTE consists of a variable-resistance exercise head with attached crankshaft and control console that was used to vary load level, record the trial duration, and time a 1-min rest break between trials. A rigid plastic tool handle with a comfortable pistol grip attached to a pointer was affixed to the crankshaft. In front of the tool handle, two plates were secured to a pole at approximately eye and waist levels. The participant, while seated behind and to the left of the tool handle, used the right hand to move the pointer in a vertical arcing motion to contact the top and bottom plates successively. Tool movement was paced by auditory and visual signals that were controlled by a timer.

The psychophysical measure of fatigue was the duration of continuous operation of the assembly task during each trial. Participants determined duration by terminating each trial when they perceived that shoulder or arm fatigue had reached a criterion of “somewhat strong” exertion (Level 4) on the Borg CR-10 scale (Borg, 1982, 1990). This scale was developed specifically to express muscular exertion, not cardiovascular effort as in the original Borg scale. Consequently, participants monitored their musculoskeletal discomfort as a function of manual work involving the arm and shoulder, and adjusted their work cycle duration accordingly.

*Auxiliary fatigue tests.* Before and after each work session, 20 min of fatigue measures were collected (see Rosa & Colligan, 1988).

For brevity, only results from the Yoshitake Questionnaire for Subjective Symptoms of Fatigue (Yoshitake, 1978) and the Corlett-Bishop body parts map (Corlett & Bishop, 1976) are presented. The Yoshitake scale has 30 phrases describing fatigue to which the participants responded “yes” or “no” in relation to how they felt at that moment. The scale was scored as the total number of positive responses. Current feelings of local muscle discomfort and soreness were rated for each location on the Corlett-Bishop body parts map using the Borg CR-10 scale.

## Procedure

*Training day.* All procedures were accomplished at the Sleep/Performance Laboratory of the Department of Veterans Affairs Medical Center in Dayton, Ohio. Training was conducted at least one week prior to the study. Participants first warmed up by arm-cranking on a Monark Rehab Trainer at 25 rpm and 25 w output for 5 min or until criterion Level 7 on the Borg CR-10 scale was reached. Anthropometric measures were then taken to establish a comfortable working height. Based on these measures, the chair and handle position on the BTE were adjusted to 90% of maximum reach at the upper plate that was to be contacted with the tool handle during the manual assembly task. Maximum voluntary contractions (MVCs) were then established by averaging six trials of peak torque on the BTE. During each trial, participants used their right arm to press upward as hard as possible for 3 s while gripping the immobile tool handle of the BTE, which registered the static force level for each trial. To average positional differences in mechanical advantage, three trials were conducted at chest height and three at shoulder height. There were 2 min of rest between trials.

After a 5-min rest, participants practiced the simulated manual assembly task by pacing to a series of lights and tones and also practiced using the Borg CR-10 scale. During these trials participants were instructed to attain near-maximum work cycle durations at each load/rate combination by sustaining exertion to a criterion of “very, very strong” (Level 10) on the Borg CR-10 scale. These near-maximum durations served as comparison levels (i.e.,

perceptual anchors) for the experimental days when the participants worked to a criterion of “somewhat strong” (Level 4). They rested for at least 5 min between trials.

*Experimental routine.* The daily order of activities is shown in Figure 2. Scheduled activity totaled 7.5 h for the 8-h shifts and 11.17 h for the 12-h shifts. Each day was separated into 110-min sessions consisting of 70 min of the manual task preceded and followed by 20 min of auxiliary fatigue measures. Any free time at the end of a manual work session was occupied with a monotonous, low-load card-sorting task using the nonwork hand. This task was used so that participants had no incentive to complete the manual task too quickly in order to obtain a longer rest break. The ergometer warm-up was the same as the procedure performed on the training day.

**Data Analyses**

Differences in work durations across schedules were compared with balanced analyses of variance (ANOVAs). One ANOVA examining the extremes of each work schedule was balanced by eliminating Day 3 of the 8-h schedule and the two midshift work sessions of the 12-h work schedule. The other ANOVA controlled time of day and day of the week by eliminating Day 5 of the 8-h schedule and the final two work sessions of the day shift and the first two work sessions of the night shift on the 12-h schedule. The design of both ANOVAs was 2 schedules (8-h vs. 12-h) × 4 days × 2 shifts (day vs. night) × 4 work sessions × 3 load levels × 3 repetition rates, with repeated measures on all factors except work schedule. All ANOVAs collapsed over the counterbalanced order of day- and night-shift weeks. Only those results that were significant in both between-schedule ANOVAs are reported using the minimum *F* value. Significant effects were explored further with ANOVAs calculated separately for the 8-h and 12-h schedules. These repeated-measures ANOVAs had factors for shift, day, session, load level, and repetition rate. Data from all days or sessions within a particular schedule were used in these ANOVAs. Omega-squared estimates of the proportion of accountable variance were calculated for all ANOVA factors (Hays, 1981).

ANOVAs examining schedule effects on the subjective scales were balanced similarly, resulting in a design of 2 schedules (8-h vs. 12-h) × 4 days × 2 shifts (day vs. night) × 5 daily test times, with repeated measures on all factors except schedule. Significant effects were explored further with separate ANOVAs within each schedule.

**RESULTS**

**Manual Task**

Work cycle durations for each load level and repetition rate are shown in Table 1. Duration decreased as load level or repetition rate increased, which was supported by main effects for load level,  $F(2, 28) = 29.95, p < 0.001$ , and repetition rate,  $F(2, 28) = 48.66, p < 0.001$ .

CLOCK TIME	ACTIVITY
0700–0710	Ergometer Warm-up
0710–0730	Auxiliary Fatigue Tests (CB,YQ)
0730–0840	MANUAL WORK
0840–0900	Auxiliary Fatigue Tests (CB,YQ)
0900–0910	Break
0910–0930	Auxiliary Fatigue Tests
0930–1040	MANUAL WORK
1040–1100	Auxiliary Fatigue Tests (CB,YQ)
1100–1130	Meal Break
1130–1150	Auxiliary Fatigue Tests
1150–1300	MANUAL WORK
1300–1320	Auxiliary Fatigue Tests (CB,YQ)
1320–1330	Break
1330–1350	Auxiliary Fatigue Tests
1350–1500	MANUAL WORK
1500–1520	Auxiliary Fatigue Tests (CB,YQ)
***END 8-HOUR SHIFT***	
1520–1530	Break
1530–1550	Auxiliary Fatigue Tests
1550–1700	MANUAL WORK
1700–1720	Auxiliary Fatigue Tests (CB,YQ)
1720–1750	Meal Break
1750–1810	Auxiliary Fatigue Tests
1810–1920	MANUAL WORK
1920–1940	Auxiliary Fatigue Tests (CB,YQ)
***END 12-HOUR SHIFT***	

*Figure 2.* Sequence of activities for 8-h and 12-h shifts. Only day shift is shown, but the same sequence occurred during the 8-h night shift starting at 11:00 p.m. and the 12-hour night shift starting at 7:00 p.m. CB and YQ indicate the Corlett-Bishop scale and the Yoshitake Questionnaire for Subjective Symptoms of Fatigue, respectively.

**Table 1:** Psychophysically Determined Work Cycle Durations (s) for Each Combination of Load Level and Repetition Rate (standard deviations in parentheses).

Load Level (% MVC)	Repetition Rate (motions/min)			Mean
	10	20	30	
10	115 (69)	82 (42)	63 (30)	87 (54)
20	77 (35)	53 (22)	40 (18)	57 (30)
30	51 (25)	37 (22)	30 (20)	39 (24)
Mean	81 (54)	57 (35)	44 (27)	

Differences between loads were largest at the lowest rate and smallest at the highest rate, as indicated by the interaction of load with rate,  $F(4, 56) = 7.57, p < 0.001$ .

Duration as a function of session time for 8-h and 12-h day and night shifts is shown in Figure 3 for each load level and in Figure 4 for each repetition rate. Several interactions between task and work schedule were apparent:

1. Differences between loads or rates were greater during day shifts compared with night shifts, as indicated by interactions of shift with load level,  $F(2, 28) = 3.90, p < 0.04$ , and with repetition rate,  $F(2, 28) = 4.25, p < 0.003$ .
2. The decrease across sessions was greatest at the 10% MVC level and at the 10 motions/min rate, as indicated by the Load  $\times$  Session interaction,  $F(6, 84) = 8.01, p < 0.001$ , or Rate  $\times$  Session interaction,  $F(6, 84) = 3.05, p < 0.01$ .
3. The decrease across sessions was greater during night shifts compared with day shifts, as indicated by the Shift  $\times$  Session interaction for load,  $F(3, 42) = 5.04, p < 0.005$ , and repetition rate,  $F(3, 42) = 5.04, p < 0.005$ .
4. For repetition rate, the decrease across sessions was greatest during the night shift at the 10 motions/min rate, as indicated by the Rate  $\times$  Shift  $\times$  Session interaction,  $F(6, 84) = 3.70, p < 0.003$ .

Duration across consecutive 8-h and 12-h day and night shifts is shown in Figure 5. For 8-h shifts, duration decreased more quickly across nights compared with days, reaching the lowest point during the fourth and fifth nights. For 12-h shifts, durations across nights were consistently lower than days until the final shift.

On the final shift, durations were similar during the 8-h night, 12-h day, and 12-h night but clearly longer during the 8-h day. These results were supported by a Schedule  $\times$  Shift  $\times$  Week-day interaction,  $F(3, 42) = 5.95, p < 0.002$ .

Omega-squared values indicated that the majority of variance was attributable to task effects. Load level and repetition rate accounted for 20% and 13% of variance, respectively, whereas work schedule parameters, including shift, workday, work session, and interactions, accounted for 5% of variance.

### Subjective Fatigue and Discomfort

Corlett-Bishop discomfort ratings in the neck, back, and right shoulder, arm, wrist, and hand increased significantly across both 8-h and 12-h shifts (all  $ps < 0.01$ ). Ratings in each body area ranged from one or less (little or no discomfort) prior to the first session to four or less (moderate discomfort) after the final session. No remarkable differences were observed with respect to work schedule, shift, or workday.

In the Yoshitake scale, a mean of three symptoms was reported at the beginning of day shift, which increased to five symptoms by the end of the day. At night, a beginning mean of two symptoms increased to nine by the end of the shift. The day versus night difference at the end of the shift was supported by a Shift  $\times$  Test Time interaction,  $F(4, 56) = 11.22, p < 0.001$ . No overall work schedule or consecutive shift differences in the Yoshitake scale were observed.

### DISCUSSION

Task results replicated those of previous studies (Putz-Anderson & Galinsky, 1993). Workers consistently reduced their work cycle durations in response to increases in both load level and repetition rate so that discomfort levels remained within acceptable limits. Low to moderate ratings of subjective discomfort on all shifts verified that the workers avoided overexertion. Durations in the present study, however, were 20%–30% shorter than in previous studies at all task levels. Estimates of proportion of accountable variance were also lower. These shorter durations and smaller

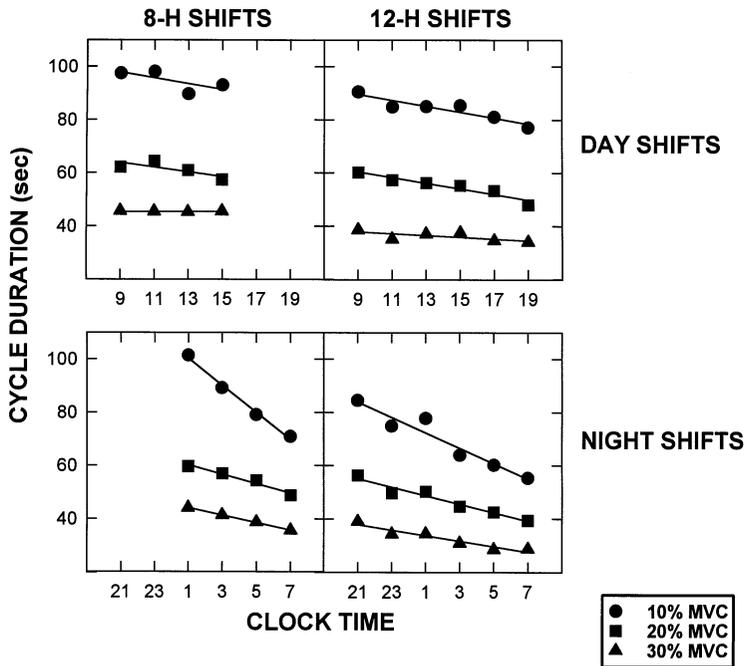


Figure 3. Work cycle duration for each load level as a function of work session time for 8-h and 12-h day and night shifts.

effect magnitudes were likely a result of more realistic work schedules.

The previously observed interaction of load level with repetition rate (Putz-Anderson & Galinsky, 1993) was also replicated. Differences in duration between force levels at the highest repetition rate were 30%–40% shorter than those differences at the lowest repetition rate. The consistency of this interaction across studies emphasizes the potentiating effect of these task factors in combination. High levels of force induced rapid fatigue even at low repetition rates, whereas high repetition rates did not allow adequate recovery time between work trials even at low levels of applied force. Therefore, lowering the levels of either task factor independently may not alleviate the potential for the other task factor to produce cumulative trauma.

The results for work schedule expand on those of previous studies. Workers became fatigued more quickly with increasing time on a shift and were more fatigued during night compared with day shifts, as indicated by both work cycle durations and self-reports. These differences, however, were more apparent at easier task levels, for which longer durations

were observed during day compared with night, and greater decreases in duration were observed with time on shift. The result of lower fatigue during day shifts at easier task levels is consistent with previous time-of-day studies using physical tasks that were minimally taxing and performed briefly (e.g., Cabri et al., 1988; Cohen & Muehl, 1977; Ilmarinen et al., 1980; Wojtczak-Jaroszowa, 1977; Wojtczak-Jaroszowa & Banaszekiewicz, 1974). The brevity of those studies, however, makes them less representative of actual work conditions than the more continuous work task used in the present study. At the difficult task levels in the present study, few day versus night or time-on-shift differences were apparent. The addition of higher task loads emphasizes their potential to overwhelm the influence of other interacting factors such as work schedule.

Overall differences in cycle duration with respect to the 8-h or 12-h schedules were relatively independent of task factors, but length of shift did interact with time of shift and number of consecutive shifts. The lowest fatigue levels were maintained across a week of 8-h day shifts, whereas the highest fatigue levels were observed during the week of 12-h night

shifts. Similar fatigue levels were reached by the end of the week of 8-h night shifts and 12-h day shifts. These results are in contrast to our work site evaluations of 8-h and 12-h shift schedules, for which the shortened workweek of the 12-h schedule offset some fatigue from the longer shift (Rosa, Colligan, & Lewis, 1989; Rosa, 1991; Rosa & Bonnet, 1993). In those studies, however, workers performed mentally demanding sedentary tasks as opposed to the physically demanding task of the present study.

In conclusion, the psychophysical technique employed in the present study demonstrates that workers can monitor musculoskeletal fatigue and adjust their work durations to avoid overexertion. Moreover, the technique is sensitive to both phasic changes in fatigue factors, such as the trial-by-trial differences in task load, and tonic changes, such as the differences between day and night and length of shift. Given this sensitivity, simultaneous examination of both task and schedule factors allows for comparison of their magnitudes of effect, which may provide a groundwork for effective intervention in jobs at risk for overex-

ertion injuries. It is clear from the present results that task factors carry a higher immediate risk of overexertion, as they accounted for two to four times more variance than work schedule factors.

Offhand, this substantial difference suggests that an intervention aimed at reducing overexertion should adjust task factors first by, for example, lightening the load, reducing the repetition rate, shortening the work cycle, or allowing more recovery time between cycles. We caution, however, that such a recommendation is limited by our data to sitting workers performing a task involving the shoulders, arms, and hands. Tasks requiring more body movement such as lifting, carrying, walking, or climbing could produce higher levels of tonic fatigue, which suggests that the work schedule would carry greater weight in producing overexertion in those situations.

Even within the context of the present task performed in the sitting position, a 12-h/4-day schedule appeared to produce more fatigue than an 8-h/5-day schedule, especially during a night shift. Therefore, it is suggested that if night or extended work shifts are used, then

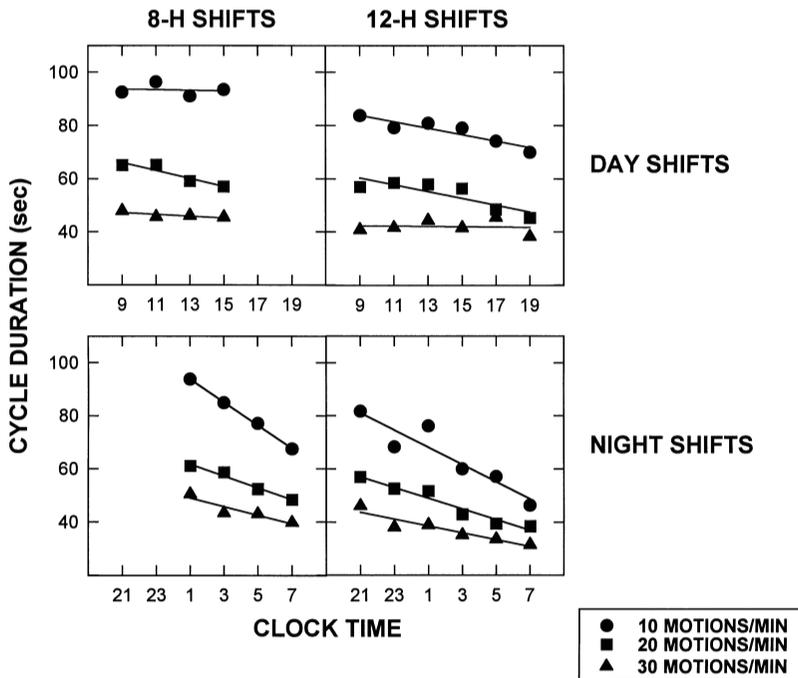


Figure 4. Work cycle duration for each repetition rate as a function of work session time for 8-h and 12-h day and night shifts.

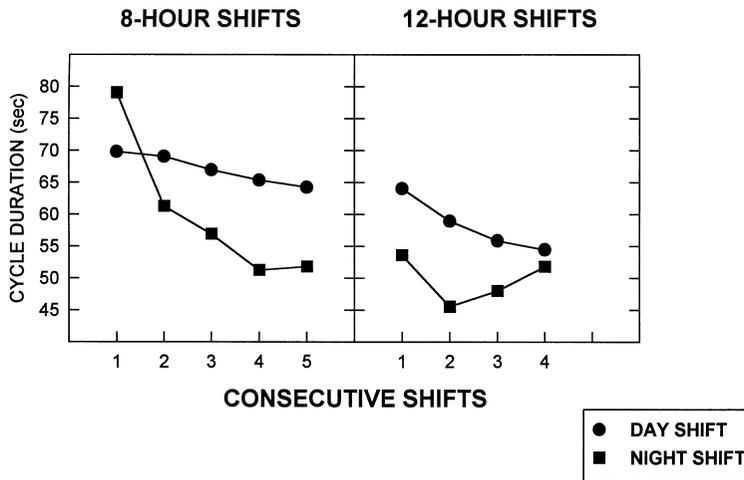


Figure 5. Work cycle duration as a function of day of the work week for 8-h and 12-h day and night shifts.

shorter work cycles or more frequent rest periods than those provided on 8-h day shifts should be considered. Work site verification of these suggestions are needed, however, before definitive recommendations can be made.

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