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See COMMENTARY page 730

Dynamic Blood Pressure Changes and Recovery Under Different Work Shifts in Young Women

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BACKGROUND
Some studies have reported that shift work can affect blood pressure (BP), but few have studied recovery from BP changes occurring during different shifts.

METHODS
We recruited 16 young female nurses working rotating shifts and six working the regular day shift. All received repeated ambulatory BP monitoring (ABPM) during their workdays and following day off.

RESULTS
Our linear mixed-effect model showed that both systolic and diastolic BPs were significantly decreased during sleeping period and significantly increased while on working period, on a work day, but increased during sleeping period after a night shift or evening shift. BP measurements that changed after evening shift usually returned to baseline on consecutive off-duty day after day shift, but they did not completely return to baseline after a night shift ($P < 0.05$). We also found 69% of those working rotating shifts had at least changed once in dipper/nondipper status. The rates of change in dipper/nondipper status between work day and off-duty day were 33, 44, 50, and 38% for nurses worked in outpatient clinic, night shift, evening shift, and day shift, respectively.

CONCLUSION
Shift work is significantly associated with BP and possibly dipper/nondipper status in young female nurses. Except for those working night shifts, BP levels returned to baseline the off-duty day after day shift. We recommend that potential influence of shift work be considered when evaluating a person's BP.

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Shift work may have different effects on health.[1] There are documented associations between shift work and increased cardiovascular morbidity and mortality.[2–6] Over the past 20 years, studies have reported that shift work has an effect on cardiovascular functions, including heart rate (HR) variability, circadian rhythm, and blood pressure (BP).[7–12] Most studies comparing BP changes have based their results on data collected on different groups of shift workers and the nonshift workers. However, studies of 24-h BP changes have found genetic predisposition to play a major role in circadian rhythm.[13,14] Therefore, the results of the above studies may be confounded by genetic disposition and/or familial factors. What we do not know is how changes in BP measurement would be affected by shift work in the same group of subjects.

In this study, we performed repeated ambulatory BP monitoring (ABPM) on the same group of subjects as they rotated shifts to evaluate dynamic BP changes. BP recovery patterns were assessed by comparing BP measured over two consecutive days—a work day and the following off-duty day. In addition, we observed the effects of shift work on circadian pattern in our study subjects.

METHODS

Subjects. The subjects of this study were recruited from a municipal hospital with 600 beds and 330 nurses located in Taipei, Taiwan. To recruit subjects who worked different shifts, we recruited eight nurses working in the intensive care units and eight working in the internal medicine ward. We also recruited eight nurses from the same hospital's outpatient clinic (OPC) to represent a group working a regular day shift for comparison. To prevent potential confounding from housework and child care at home, all study subjects were unmarried and not caring for children.

Subjects were excluded from this study if they had thyroid dysfunction, diabetes mellitus, hypertension, history of cardiovascular diseases (stroke, coronary arterial disease, and myocardial infraction), a body mass index >25 kg/m^2, were pregnant, current smokers, or taking any contraceptive pills or sleeping pills. Their eligibility was confirmed by reviewing their medical records. The protocol of this study was approved by the Institutional Review Board of that hospital before the research began. Written informed consent was obtained from all participants.

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Study design. Most nurses worked three different shifts: day (from 8 AM to 4 PM), evening (from 4 PM to 12 midnight), and night (from 12 midnight to 8 AM). Because nurses in this hospital were required to stay in one shift for a full month before changing to another shift and each subject was asked to complete the study within 3 months from when they started it, the order in which the shifts were to be rotated was not specified. Thus, the order in which shifts were worked was unrelated to any known factors except each subject's preference, making it, we assume, quasirandom or no order effect. Recordings were not taken until 2 weeks of acclimatization to a new shift. Because nurses at this hospital worked four consecutive working days followed by 1 day off (off-duty day), the tests were usually performed after three working days on the fourth day of the work week and the following day off. During these two consecutive days, each subject underwent 48 h both ABPM and Holter monitorings simultaneously. All the nurses working rotating shifts received three 2-day ABPM and Holter monitorings, 1 day of monitoring for each of the three different shifts and consecutive off-duty days. The OPC nurses, all working days only, underwent one session of recording. All nurses were required to come about 15 min before going on duty to have the monitoring devices applied to their bodies. The devices were pre-set to begin monitoring at the aforementioned time for each shift. Actual waking time and sleeping time durations during their ABPM examinations were obtained from the notes kept by the study subjects.[15] Body mass index was derived from body weight and body height for each subject.

In this study, we performed repeated ABPM on rotating shift workers and one session of measurement on day shift only OPC workers to evaluate dynamic BP changes in these subjects that occurred during the three different shifts and day shift only. We focused mostly on the dynamic BP changes associated with shift work and the recovery patterns in the following off-duty day. The data of 48-h Holter monitoring were not analyzed in this report.

A total of 24 eligible nurses were recruited. Two OPC nurses dropped out. To control for potential seasonal effects, this study was conducted from March to June 2005, a time of year that Taipei temperatures range between 18 and 24 °C.[16,17]

Twenty-four hour monitoring of arterial BP. The ABPM was recorded with a noninvasive, automated oscillometric device, Dynapulse 5000A (Pulse Metric, San Diego, CA). An appropriate cuff, 51.5 × 14.3 cm in size, was placed on the participant's left arm (all participants were right dominant). The investigator calibrated the device every month and took five calibrated readings simultaneously using a standard mercury sphygmomanometer at the time the subjects were fitted with the device. Subjects were requested to hold their left arm in a natural position at heart level whenever a reading was being taken wherever they were and whatever they were doing. The usual default daytime monitoring was set from 8 AM to 11 PM and night time from 11 PM to 8 AM the next day. During the daytime, BP measurements were taken every 15 min, and during the night time every 30 min. In this study, we would accumulate 6 (OPC nurses) plus 48 (=16 × 3 in rotating shifts) times of these monitoring data, and obtain about 156 observations of BP measurements for every 2-day monitoring from each subject included in the final analysis. Nondipper status was defined as a <10% decrease in systolic BP (SBP) from awake to asleep.

Statistical analysis. In order to take into account of the repeated measurements in two consecutive days taken for each subject, a linear mixed-effect model was conducted.[18] Because BP continuously changed within a person and repeated measurements were made during BP monitoring, we could not treat such measurements as fully independent within a person. In other words, there were autocorrelations for every BP measurement within a subject and such measurements were treated as a "random effect" within that person, whereas all other major determinants or explanatory variables of BP, including sleep (vs. awake), working (vs. nonworking), work day (vs. off-duty day), work units, and different shifts, were called "fixed effects" and also included in this model. Specifically, the mixed model included a response variable as a function of explanatory variables and an error term with a covariance structure. SBP, diastolic BP (DBP), mean arterial pressure ((MAP = DBP + 1/3 (SBP − DBP)) and HR are the response variables considered in the analysis. The first binary explanatory variable was work day. That is, work day equals to 1 if the measurement was taken during the work day; work day equals to 0 if otherwise. Hence, the coefficient of the variable represents the mean response difference between work day and off-duty day among all the subjects. The work day was further divided into three time periods: the working period, covering 8 h at work, and the nonworking period, and the sleeping period, together covering the remaining 16 h. The off-duty day was also divided into three corresponding periods: 8 h corresponding to the working period the previous work day, and the other 16 h corresponding to nonworking and sleeping periods. The next two binary explanatory variables were similarly defined as working period (vs. nonworking) and sleeping (vs. awake). Two binary work shift variables were defined for night (vs. day) and evening (vs. day). The rest of the variables included work units (intensive care unit/internal medicine ward/OPC) for adjustment and possible interactions between sleep, work day, and shifts.

As a result of repeated measurements taken from each subject, a covariance structure was specified for the error term in the mixed-effect model. A reasonable covariance structure for these serial correlated measurements was an autoregressive order 1 model. The procedure PROC MIXED in SAS was used to fit this model (version 8.2; SAS Institute, Cary, NC). A P value <0.05 was considered significant.

RESULTS

The age, height, weight, and body mass index of nurses working in the different units were compared by rank sum tests. We found no significant difference in age, height, weight, and body mass index between the shift workers and the day

Table 1 | Basic characteristics of the study subjects

	Day shift only ($n = 6$)	Rotating shift ($n = 16$)	*P* value (rank sum test)
Female gender	100%	100%	
Age (years)[a]	27 (26–33)	27 (26–28)	0.52
Height (cm)[a]	162.5 (152–167)	160 (158–164)	0.90
Weight (kg)[a]	49.5 (48–54)	54 (50–57)	0.08
Body mass index (kg/m^2)[a]	19 (18–20)	21 (19–22)	0.08
Smoking (%)	0	0	
Alcohol drinking (%)	0	0	

[a]Data are expressed as median (interquartile range).

Table 2 | Regression coefficients and s.e. resulted from construction of linear mixed-effect model

Dependent variable / Independent variable	SBP (mm Hg)	DBP (mm Hg)	MAP (mm Hg)	HR (per min)
Intercept	112 (2)**	61 (1)**	78 (1)**	72 (2)**
Sleep vs. awake	−13 (1)**	−9 (1)**	−11 (1)**	−8 (1)**
Working period vs. nonworking period	7 (1)**	5 (1)**	5 (1)**	5 (1)**
Work day vs. off-duty day	5 (1)**	4 (1)**	4 (1)**	−1 (1)
Work unit				
ICU vs. OPD	2 (2)	1 (2)	1 (1)	6 (2)*
IMW vs. OPD	1 (2)	2 (2)	2 (1)	2 (2)
Work shift				
Night vs. day	−1 (1)	−1 (1)	−1 (1)	−2 (1)*
Evening vs. day	−2 (1)*	−1 (1)	−1 (1)	−3 (1)**
Interaction term				
Sleep × night shift	5 (1)**	4 (1)**	5 (1)**	3 (1)*
Sleep × evening shift	5 (1)**	4 (1)**	4 (1)**	1 (1)
Sleep × work day	−1 (1)	−2 (1)	−1 (1)	−1 (1)
Work day × night shift	1 (1)	−2 (1)	−1 (1)	3 (1)*
Work day × evening shift	2 (1)	1 (1)	1 (1)	2 (1)
R^2	0.258	0.248	0.296	0.238

DBP, diastolic blood pressure; ICU, intensive care unit; IMW, internal medicine ward; MAP, mean arterial pressure; OPC, outpatient clinic; SBP, systolic blood pressure.
*$P < 0.05$; **$P < 0.001$.

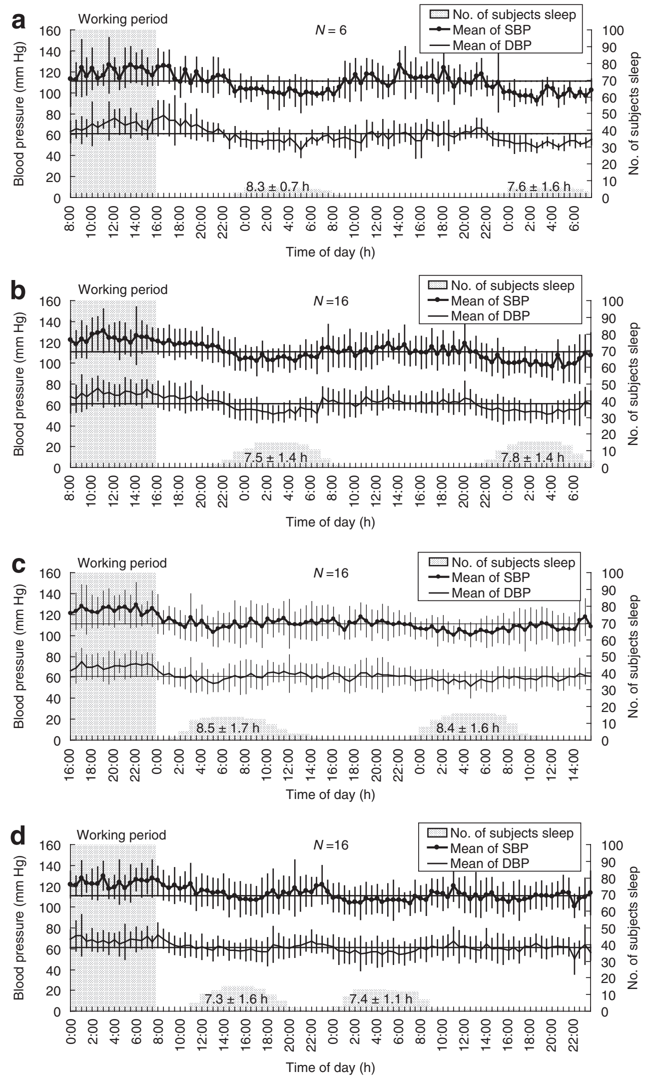

Figure 1 | Dynamic changes of blood pressures (BPs) in each shift and the sleeping duration over two consecutive days. (**a**) Outpatient clinic, (**b**) day shift, (**c**) evening shift, (**d**) night shift. The two parallel lines in the middle of each panel indicate the average systolic and diastolic BPs (111 and 61 mm Hg, respectively) based on measurements obtained from six nurses working at outpatient clinic. Durations (in hour) of sleeping periods are shown at the floor of each panel as mean ± s.d., while the height of the shadow represents number of subjects who were asleep corresponding to each time period.

workers (**Table 1**). As can be seen in **Table 2**, using a linear mixed-effect model and adjusting for other variables, we found significant decreases of SBP, DBP, and MAP in the nurses during sleeping periods, significant increases while they were at work, significant increases for the whole day in which they had worked, and significant increases during sleeping periods after a night shift or evening shift (all $P <$ 0.001). Although nurses working in the intensive care unit had a significantly greater increase in HR than those working in OPC, they had no significant increase in any of the BP measurements; however, we did find a significantly greater decrease in HRs in nurses when they were working the night shift and evening shift than when they were working the day shift. In addition, we followed the dynamic changes of BP and sleeping periods over two consecutive days (**Figure 1**). The two parallel lines in each panel of **Figure 1** represent the means of SBP and DBP based on data taken from the six OPC nurses as the reference. **Figure 1a,b** shows the similarity of dynamic BP changes for both working and off-duty days between day shift and regular OPC services. The BP changes appeared less dipped during the sleeping period immediately after evening and night shifts compared with the day shift and OPC services, but the dipping pattern seemed to appear during the sleeping periods of the off-duty days, which helps to visualize the results of the linear mixed-effect model in

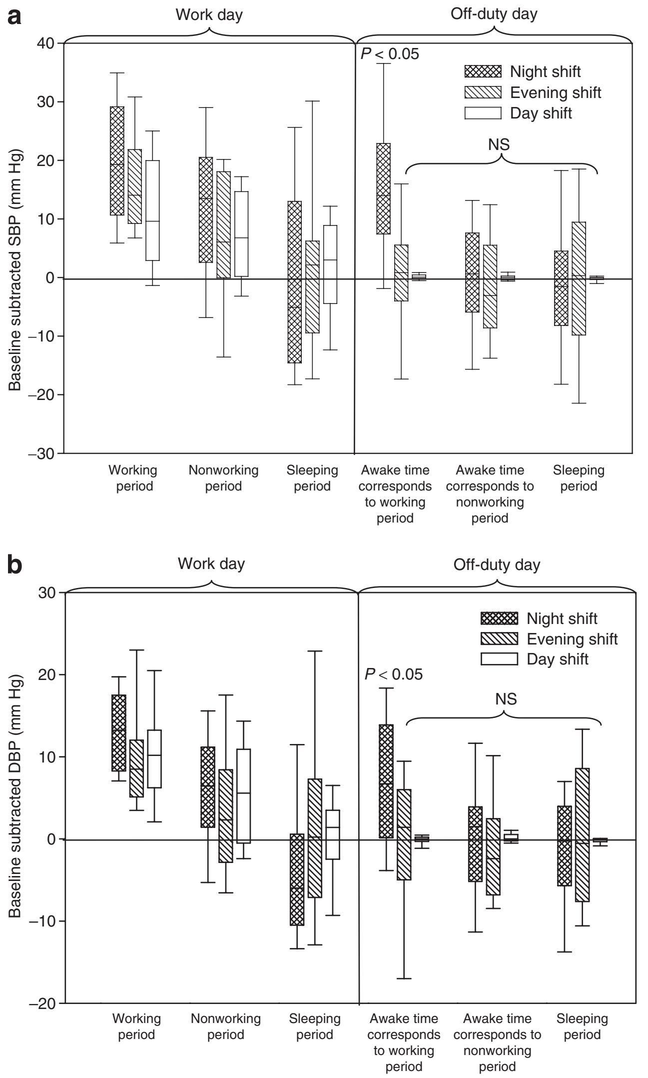

Figure 2 | The recovery of blood pressure (BP) from different shifts was defined as the BP return to the baseline, which is the hourly mean of off-duty day after a day shift for each subject. Each BP measurement was subtracted from the hourly mean to obtain the differences or deviations from baseline. The distributions of all such differences were collected for each period under three shifts and plotted as the median, box plots of 25th and 75th percentiles, and 10th to 90th percentiles. (**a**) Change of systolic BP (SBP). (**b**) Change of diastolic BP (DBP).

Table 2. There was no significant difference in how long they slept between these 2 days for all shifts, though the interval between the two sleep periods were shorter in the night shift than other two shifts and day shift only.

We analyzed the recovery of the SBP and DBP changes the following off-duty day by the shift they worked. The ABPM actually measured BP four times per hour between 8 AM and 11 PM and two times per hour between 11 PM and 8 AM. The hourly means calculated for each off-duty day after a day shift was considered the baseline for each subject. In this way, we obtained a total of 24 baseline hourly means for each subject. Then, each measurement taken in each subject within a particular hour was subtracted from her own baseline hourly mean to obtain the differences or deviations from the mean, allowing us to obtain a distribution of deviations for every subject at each hour. The different hours in these 2 days were categorized into working, nonworking, and sleeping periods in work day, and awake time corresponds to working and nonworking periods and sleeping period in off-duty day, and all data were stratified by three different shifts for comparison. The distributions of these deviations, including the median, 25th and 75th percentiles, and 10th to 90th percentiles for the three corresponding periods of all nurses working three shifts, are plotted in Figure 2. To make the baseline more stable and facilitate our comparison of deviations from this baseline, we also included BP data from the six nurses working day shifts only in the OPC. We found that BP changes that occurred in young female nurses after day and evening shifts usually returned to baseline level after one consecutive off-duty day, but the recovery of BP that occurred after night shift were incomplete by the same time.

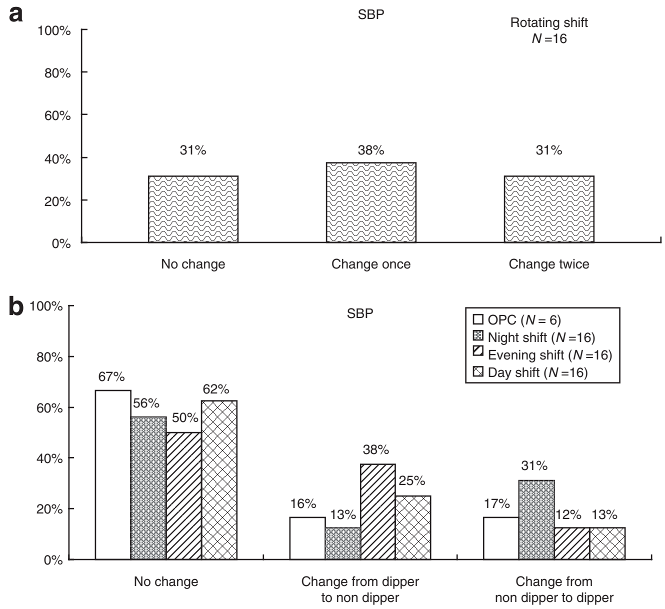

Figure 3 | Change of dipper/nondipper status. (**a**) Frequency of change in dipper/nondipper status according to rotating three different shifts. (**b**) Frequency of change in dipper/nondipper status between the work day and the following off-duty day stratified by day shift only and three different shifts. OPC, outpatient clinic, day shift only; SBP, systolic blood pressure.

Interchange between dipper and nondipper status during rotating shifts was common. Among the 16 nurses working three different shifts, there were a total of 48 shifts for analysis. We used dipper/nondipper (D/ND) status of the day shift in nurses working rotating shifts as the reference state, D-D-D or ND-ND-ND indicating no change of this status; D-ND-ND or ND-D-D indicating change twice; D-D-ND, D-ND-D or ND-D-ND, ND-ND-D change once. Compared with the reference state, 69% had at least changed once in dipper/nondipper status between the three different shifts. The percentage of each change is summarized in Figure 3a. However, the rates of change in dipper/nondipper status between work day and off-duty day were 33, 44, 50, and 38% for OPC nurses, night shift, evening shift, and day shift, respectively (Figure 3b).

DISCUSSION

In this study using repeated measurement to self-compare BP, we have shown that BP may not only increase during working periods, on a work day, but also during sleeping periods after a night shift or evening shift (**Table 2**). We have also shown that BP recovery from night shift levels remained incomplete after 1 day of no work or full rest (**Figure 2**).

Although previous studies have reported on the hemodynamic effects of shift work, few have controlled for the potential confounding of genetic effect. Our study corroborates the findings of some of these reports[11,12,19] and differs somewhat from others.[20–21] Although the small size of our sample and its highly selective age range of young women (aged 25–35 years) may limit the generalization of its findings, the repeated measurement/self-comparison design of this study may help control for potential confounding by other risk factors not considered by previous studies and provide a more accurate picture of the magnitude of shift effect on the hemodynamic changes (**Table 2**). In addition, we used a standard cuff size for all subjects and calibrated the measuring device five times to further minimize the possibilities of measurement errors.[22] Our findings suggest that the potential influence of shift work should be taken consideration when evaluating a person's BP.

Because there might be less interference from abnormal circadian rhythm when ABPM is measured on an off-duty day following day shift, we adopted these measurements as a baseline values when comparing recovery patterns (**Figure 2**). Comparing BP recovery to this baseline on different off-duty days following day shifts, evening shifts and night shifts, we found that the recovery that occurred on the off-duty day following a night shift to be incomplete. A similar finding has also been reported by another study which found that reaction time could not be fully recovered the next off-duty day following a night shift.[23] During our interviews with the study subjects, many complained of fatigue after night shift, which might explain the shorter interval between the two sleep times after the night shift (**Figure 1d**). More investigations are needed to determine whether two off-duty days might be needed for night shift workers to recover from the changes in BP they experience while at work.

Other studies have found an association between increased physical activity during work,[24] disturbance of circadian rhythm during the night and evening shifts and increased BP and HRs,[11,12,19] which was also demonstrated in this study during the working period and sleeping period on days that a nurse worked a night shift (**Table 2**). The increased HRs found in the intensive care unit nurses may have resulted from increased physical activity and/or mental stress associated with such units. In this hospital, the clinical workloads were lower during evening and night shifts than in the day shift. This might have contributed to the mild yet significant lower HRs we found in evening and night shift workers.

We found shift differences in interchange patterns in dipper/nondipper status (**Figure 3**), a finding previously reported by another study.[19] Dipper/nondipper status is largely thought to be genetically predetermined,[13] as has been shown in a monozygotic twin study,[14] but such changes have also been reported to be influenced by individual physical activity,[25] sleep quality,[26] nocturnal urination,[27] and sleeping posture.[28] In this study, we used the same subjects to compare these measurements at different times. By doing so, we could compare the effects of shift work while controlling for individual characteristics. All nurses belonged to the same race/ethnicity and age range, were in the normotensive state, did the same work, had the same working environment, had the same time to adapt to each shift, and had the same sleeping patterns. Under these circumstances, as much as 69% of change at least once in dipper/nondipper status occurred between the three rotating shifts (**Figure 3a**), suggesting that shift might have a significant effect on changes in dipper/nondipper status.

The nonchange rates of dipper/nondipper status for OPC and three different shifts between work day and the consecutive off-duty day were <70%, which representing reproducibility in ABPM without shift work.[29,30] The nonchange rates in this study, namely, 50–67% in **Figure 3**, indicate a possible shift work effect. Nevertheless, due to the relatively small sample size, we must be careful not to make any strong inference about the effects of shift on dipper/nondipper status.

In conclusion, in young female nurses working rotating shifts, SBP and DBP were elevated during working periods, on work days, and in sleeping periods following a night or evening shift. SBP and DBP elevated during day and evening shifts returned to baseline after a full day off-duty. They did not return completely to baseline the day following a night shift. The shift a nurse works might induce a change in dipper/nondipper status. On the basis of the findings of this study, at least 2 days off-duty days may be needed to recover completely from BP increases that occur while working a night shift, though further research is needed to confirm this.

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