ABSTRACT

Objectives This study aimed to evaluate the separate and combined effects of rotating night shift work and lifestyle factors with elevated gamma-glutamyl transpeptidase (GGT) among steelworkers.

Design, setting and participants This cross-sectional study used the baseline information from a Chinese occupational cohort. The in-service workers of the production department of Tangsteel Company who participated in the occupational health examination in Tangshan from February to June 2017 were selected as the research objects.

Main outcome measures The separate and combined effects of rotating night shift work and lifestyle factors with elevated GGT among steelworkers.

Results The information of 7031 subjects from the production department of Tangsteel Company was analysed. Results showed that the current shift workers and the workers with the duration of night shifts>19 years, the cumulative number of night shifts>1774 nights, the average frequency of night shifts≤7 nights/month and the average frequency of night shifts>7 nights/month had elevated odds of elevated GGT, compared with those who never worked night shifts, and ORs, (95% CIs) were 1.39, (1.10 to 1.75), 1.46, (1.15 to 1.86), 1.46, (1.15 to 1.85), 1.34, (1.04 to 1.73) and 1.37, (1.09 to 1.74) after adjustment for potential confounders. The independent effect of shorter sleep duration (<7 hours/day) on elevated GGT was not statistically significant. Among workers who had shorter sleep duration, the association between rotating night shift work and elevated GGT was statistically significant, but no associations were found among workers with the sleep duration of ≥7 hours/day and elevated GGT among steelworkers. In particular, the effect of rotating night shift work on elevated GGT was affected by sleep duration and other lifestyle factors.

Conclusions Rotating night shift work is associated with elevated GGT among steelworkers. In particular, the effect of rotating night shift work on elevated GGT was affected by sleep duration and other lifestyle factors.

INTRODUCTION

Shift work refers to irregular and abnormal working time arrangements, including all working hours that are outside the normal daytime ones, such as rotating night shift work. Nowadays, rotating night shift work widely exists in the service industry, manufacturing industry, medicine industry and so on, and shift workers are required to work according to different schedules. It is reported that rotating night shift work is associated with many adverse health outcomes. Rotating night shift work will disrupt the synchronisation of the endogenous environment and the external environment by breaking the original sleep/wake cycle, thus affecting the secretion of hormones and the function of the circadian rhythm system and finally endangers human health. However, there are other lifestyles that affect circadian rhythm. Sleep is an essential part of lifestyle, and lack of sleep duration is associated with
many adverse health outcomes. Studies have shown that insufficient sleep duration is associated with adverse outcomes of liver function. Gamma-glutamyl transpeptidase (GGT) is abundant in the liver and also present in the kidney, pancreas, which is one of the indicators of liver function detection. As a biochemical marker of hepatobiliary injury, the elevated GGT level is associated with pancreatic disease, fatty liver, renal failure and hepatobiliary disease.

Some studies have shown that in addition to higher hyperhomocysteinaemia (HHcy) odds, rotating night shift work could be associated with adverse effects on liver function through circadian rhythm disorder and metabolic dysfunctions by redistributions of food consumption.

Previous studies have shown that rotating night shift work is significantly associated with adverse reactions of liver function and higher levels of liver enzymes (such as alanine transaminase (ALT) and alkaline phosphatase (ALP)). However, the relationship between rotating night shift work and the level of GGT is not clear so far, and there are few related studies. In some studies, the evaluation indicators of night shift work (yes or no) ignored the important factors that may have an impact on health, such as the duration of night shifts (years) and the average frequency of night shifts (night/month), and thus concealing the real relationship between exposures and outcomes. In addition, rotating night shift work is not only related to light exposure at night, but also to sleeping duration and other lifestyle factors, and shift workers are known to sleep less than day workers. To our knowledge, no studies have focused on the combined effects of sleep duration and rotating night shift work on the level of GGT. This study aimed at exploring the relationship between rotating night shift work and elevated GGT with some indicators we have used, including duration of night shifts (years), cumulative number of night shifts (nights), average frequency of night shifts (night/month) and current shift status. In particular, we also investigated the joint effects of some lifestyle factors and rotating night shift work on elevated GGT.

**METHODS**

**Study population**

Our data comes from a cohort of occupational health effects approved by the Ministry of science and technology of China. The purpose of this cohort study is to study the impact of some occupational harmful factors on human health. The cohort study was conducted in HBIS Group’s Tangsteel Company in Tangshan city, China, and the baseline information of the cohort study was used in this study. The in-service workers in the production department of Tangsteel Company who participated in the occupational health examination in Tangshan Hongci hospital from February to June 2017 were selected as the research objects and the data used in previous publication and this study was collected from the same participants. The workers with missing blood biochemical data, shift information and covariates, as well as those taking some antiretroviral drugs, and the workers with cancer, excess alcohol intake, history of hepatobiliary disease, thyroid disease and renal failure were excluded. A total of 7661 people participated in the occupational health examination, and finally, 7031 people were included in the study. All participants gave informed consent before taking part in this study.

**Patient and public involvement**

It was not appropriate or possible to involve patients or the public in the design, or conduct, or reporting, or dissemination plans of our research.

**Blood tests and elevated GGT**

Steelworkers were required to fast for at least 8 hours before their blood can be drawn. Because the blood index of workers who have just left the night shift may change briefly, and night shift workers need to be drawn on rest days. Participants’ anterior elbow vein blood was collected and centrifuged at room temperature (3000 r/min, 15 min) immediately. All blood samples were tested in the central laboratory of Tangshan Hongci Hospital using automatic biochemical analysers (mindray, BS-800, China) within 4 hours. Elevated ALT and elevated aspartate aminotransferase (AST) were defined as ALT>40 U/L and AST>40 U/L, respectively. Elevated GGT was defined as: (GGT>60 U/L in males, GGT>40 U/L in females) according to the reference value of the central laboratory of Tangshan Hongci Hospital and other studies.

**Assessment of rotating night shift work**

Shift work (the mainly four-crew-three-shift system now and historical three-crew-two-shift system) in this study referred to rotating night shift work. Shift workers whose shift duration did not exceed 1 year and the workers who worked regular working hours at all times were defined as never rotating night shift workers. In the four-crew-three-shift system, each group has two morning shifts (08:00–16:00), two afternoon shifts (16:00–00:00), two night shifts (00:00–08:00) and then has 2 days off. In the three-crew-two-shift system, each group has a morning shift (08:00–20:00), a night shift (20:00–08:00) and then takes 1 day off. The data were collected from face-to-face interviews and then checked with the Tangsteel Company’s records. Participants were asked whether they were involved in rotating night shift work (working through 00:00 to 6:00) during their employment. If yes, they were asked about their current shift status (ever, current), shift system, number of days in each month for each shift system, start date and end date of each shift system. In this study, different exposure indicators were used to assess rotating night shift work. Duration of night shifts (years): sum of years spent in all different night shift systems; cumulative number of night shifts (nights): sum of nights spent in all different night shift systems; average frequency of night shifts (nights/month): cumulative number of night shifts (nights) divided by cumulative
According to current shift status. The difference between the different current shift status groups were statistically significantly by age, sex, working years and diabetes history. The range of age and working years of the subjects is (22.3–60.0) and (0.2–46.8), respectively. In terms of lifestyle, smoking status was statistically different among the different current shift status groups. In terms of occupational hazardous factors, exposure of high temperature, dust and carbon monoxide (CO) differed significantly among the different current shift status groups, but the differences were not statistically significant in different noise exposure groups. GGT levels and ALT levels differed significantly among the different current shift status groups, and current night shift workers were more likely to have elevated GGT and elevated ALT.

The differences in means of GGT according to current shift status were statistically significant (see online supplemental table S1). The higher exposure categories of night shift work showed an increased prevalence of elevated GGT (table 2). Subjects with elevated GGT had higher age and working years. And other basic characteristics of the study subjects according to GGT levels status were shown in online supplemental table S2.

### Statistical analyses

Continuous variables were described by means±SD and median and range (minimum, maximum), and the differences between groups were compared by independent sample t-test if the data was normally distributed. Otherwise, the rank-sum test was used to compare these continuous variables among the various groups. The categorical variables were expressed by the number of individuals (%), and χ² tests were used for comparison between groups. Multivariate unconditional logistic regression model and restricted cubic spline function (RCS) model were used to explore the relationship between different exposure indicators of night shift work and elevated GGT. For multivariate logistic regression, stepwise regression was used to select covariates. Analyses were conducted with Statistical Package for the Social Sciences (SPSS for Windows, V.19.0) software and Statistical Analysis System V.9.4 (SAS, Institute) with a two-sided significance threshold of p<0.05.

### RESULTS

#### Univariate analysis

Table 1 shows the basic characteristics of 7031 subjects according to current shift status. The difference between...
Table 1  Basic characteristics of the study subjects according to current shift status

| Characteristics                              | Total (n=7031) | Never | Ever  | Current | P value |
|----------------------------------------------|----------------|-------|-------|---------|---------|
|                                              |                |       |       |         | <0.001  |
| Sex, n (%)                                   |                |       |       |         |         |
| Male                                         | 6436 (91.5)    | 1028  | 1246  | 4162    |         |
| Female                                       | 595 (8.5)      | 127   | 134   | 334     |         |
| Smoking status, n (%)                        |                |       |       |         | 0.038   |
| Never                                        | 3069 (43.6)    | 525   | 599   | 1945    |         |
| Ever                                         | 375 (5.3)      | 56    | 95    | 224     |         |
| Current                                      | 3587 (51.1)    | 574   | 686   | 2327    |         |
| Drinking status, n (%)                       |                |       |       |         | 0.805   |
| Never                                        | 4295 (61.1)    | 712   | 833   | 2750    |         |
| Ever                                         | 150 (2.1)      | 24    | 35    | 91      |         |
| Current                                      | 2586 (36.8)    | 419   | 512   | 1655    |         |
| Physical activity (MET—hours/week), n (%)   |                |       |       |         | 0.275   |
| Low                                          | 130 (1.8)      | 17    | 26    | 87      |         |
| Middle                                       | 695 (9.9)      | 120   | 117   | 458     |         |
| High                                         | 6206 (88.3)    | 1018  | 1237  | 3951    |         |
| Sleep duration, n (%)                        |                |       |       |         | 0.986   |
| <7 hours/day                                 | 4446 (63.2)    | 618   | 825   | 3003    |         |
| ≥7 hours/day                                 | 2585 (36.8)    | 537   | 555   | 1493    |         |
| Diabetes, n (%)                              |                |       |       |         | 0.017   |
| No                                           | 6270 (89.2)    | 1007  | 1220  | 4043    |         |
| Yes                                          | 761 (10.8)     | 148   | 160   | 453     |         |
| Hypertension, n (%)                          |                |       |       |         | 0.96    |
| No                                           | 5092 (72.4)    | 808   | 996   | 3288    |         |
| Yes                                          | 1939 (27.6)    | 347   | 384   | 1208    |         |
| Dyslipidaemia, n (%)                         |                |       |       |         | 0.706   |
| No                                           | 4240 (60.3)    | 684   | 833   | 2723    |         |
| Yes                                          | 2791 (39.7)    | 471   | 547   | 1773    |         |
| Renal dysfunction, n (%)                     |                |       |       |         | 0.898   |
| No                                           | 5923 (84.2)    | 968   | 1162  | 3793    |         |
| Yes                                          | 1108 (15.8)    | 187   | 218   | 703     |         |
| BMI (kg/m²), n (%)                           |                |       |       |         | 0.426   |
| <24                                          | 2372 (33.7)    | 389   | 466   | 1517    |         |
| 24–27                                        | 3494 (49.7)    | 563   | 707   | 2224    |         |
| ≥28                                          | 1165 (16.6)    | 203   | 207   | 755     |         |
| High temperature, n (%)                      |                |       |       |         | <0.001  |
| No                                           | 3462 (49.2)    | 748   | 789   | 1925    |         |
| Yes                                          | 3569 (50.8)    | 407   | 591   | 2571    |         |
| Noise, n (%)                                 |                |       |       |         | 0.602   |
| No                                           | 53 (0.8)       | 6     | 11    | 36      |         |
| Yes                                          | 6978 (99.2)    | 1149  | 1369  | 4460    |         |
| Dust, n (%)                                  |                |       |       |         | <0.001  |
| No                                           | 2438 (34.7)    | 364   | 362   | 1712    |         |
| Yes                                          | 4593 (65.3)    | 791   | 1018  | 2784    |         |
| CO, n (%)                                    |                |       |       |         | <0.001  |

Continued
1.42, (1.12 to 1.80), 1.41, (1.11 to 1.80), 1.32, (1.03 to 1.70), 1.36, (1.08 to 1.71), respectively, after adjustment for age and sex. All of the estimates were attenuated but remained significant. The results of model 3 showed that the odds of elevated GGT were increased with the groups of the current night shift, the duration of night shifts>19 years, the cumulative number of night shifts>1774 nights, the average frequency of night shifts ≤7 night/month and the average frequency of night shifts>7 nights/month, compared with never night shift workers, and ORs, (95% CIs) were 1.39, (1.10 to 1.75), 1.46, (1.15 to 1.86), 1.46, (1.15 to 1.85), 1.34, (1.04 to 1.73), 1.37, (1.09 to 1.74), respectively, after adjustment for age, sex, smoking status, drinking status and DASH Score. Though all of the estimates were still attenuated, the results were comparable to model 1. Moreover, our study also showed that the odds of elevated GGT were increased with the groups of the current night shift, the duration of night shifts>19 years, the cumulative number of night shifts>1774 nights, the average frequency of night shifts ≤7 night/month and the average frequency of night shifts>7 nights/month, compared with never night shift workers, and ORs, (95% CIs) were 1.40, (1.10 to 1.92), 1.41, (1.02 to 1.94) and 1.40, (1.01 to 1.93), respectively, after adjusting for potential confounders (table 4).

In addition, we further stratified the analysis using smoking status, drinking status, body mass index (BMI), and physical activity and studied the interaction between rotating night shift work and the lifestyle factors. As shown in table 1, the number of ever smokers (21.1%), ever drinkers (5.3%) and high physical activity (18.2%) is small. Therefore, we combine ever smokers and never smokers, ever drinkers and never drinkers, and middle and high physical activity into one group, respectively. The association between the rotating night shift work and the elevated GGT in the two layers of current drinking

| Characteristics         | Total (n=7031) | Current shift status | P value |
|------------------------|---------------|---------------------|---------|
|                        |               | Never | Ever | Current |         |
| No                     | 3906 (55.6)   | 550 (47.6) | 739 (53.6) | 2617 (58.2) |         |
| Yes                    | 3125 (44.4)   | 605 (52.4) | 641 (46.4) | 1879 (41.8) |         |
| GGT levels, n (%)      |               |       |       |         |         |
| Normal                 | 6270 (89.2)   | 1057 (91.5) | 1233 (89.3) | 3980 (88.5) | 0.014   |
| Elevated               | 761 (10.8)    | 98 (8.5)   | 147 (10.7) | 516 (11.5)  |         |
| AST levels, n (%)      |               |       |       |         |         |
| Normal                 | 6846 (97.3)   | 1124 (97.3) | 1339 (97.0) | 4381 (97.4) | 0.705   |
| Elevated               | 187 (2.7)     | 31 (2.7)    | 41 (3.0)    | 115 (2.6)   |         |
| ALT levels, n (%)      |               |       |       |         |         |
| Normal                 | 6274 (89.2)   | 1059 (91.7) | 1253 (90.8) | 3962 (88.1) | <0.001  |
| Elevated               | 757 (10.8)    | 96 (8.3)    | 127 (9.2)    | 534 (11.9)  |         |
| Age (years), median (range) | 45.0 (22.3, 60.0) | 46.2 (22.8, 59.6) | 46.6 (23.4, 59.7) | 44.2 (22.3, 60.0) | <0.001 |
| Working years (years), median (range) | 24.4 (0.2, 46.8) | 26.3 (0.2, 43.1) | 26.5 (1.4, 42.8) | 23.8 (1.4, 46.8) | 0.002   |
| DASH Score             | 21.6±2.2      | 21.7±2.1    | 21.7±2.2    | 21.6±2.2   | 0.856   |
| ALT levels (U/L), median (IQR) | 22 (17, 31)   | 22 (17, 29) | 22 (17, 30) | 23 (17, 31) | <0.001  |
| AST levels (U/L), median (IQR) | 20 (17, 23)   | 20 (17, 23) | 20 (17, 23) | 20 (17, 23) | 0.247   |
| GGT levels (U/L), median (IQR) | 27 (19, 42)   | 27 (18, 40) | 26 (18, 40) | 28 (19, 43) | <0.001  |

Values are number of individuals (%), means±SD, and median (range). P-values are from chi-square test for categorical variables and rank-sum test for continuous variables.

ALT, alanine transaminase; AST, aspartate aminotransferase; BMI, body mass index; DASH, Dietary Approaches to Stop Hypertension; GGT, gamma-glutamyl transpeptidase; MET, metabolic equivalent of task.
status was statistically significant (see online supplemental table S6). When we used current smoking status and BMI for stratified analysis, the association between rotating night shift work and elevated GGT was statistically significant only in layers with current smoking or BMI ≥ 24 (see online supplemental tables S7 and S8). The risks of elevated GGT were increased by rotating night shift work in both stratification of physical activity (see online supplemental table S9). In addition, all the interactions between rotating night shift work and lifestyle factors on elevated GGT were not statistically significant.

**Sensitivity analyses**

Multivariate logistic regression analysis showed that the results from the population including participants taking antiretroviral drugs were comparable to those excluding participants taking antiretroviral drugs (see online supplemental table S10). In addition, the results of the logistic regression model after adjusting all potential confounding factors were comparable to those of the logistic regression model selected by the stepwise regression method (see online supplemental table S11). In order to avoid the influence of the maximum on the results of RCS curves fitting, we deleted the last 1% quantile of the duration of night shifts and the cumulative number of night shifts, and the results remained robust (see online supplemental figures S1 and S2).

**DISCUSSION**

Previous studies have used duration in rotating night shifts, night shifts per month, cumulative lifetime night shift exposure and other indicators to study the relationship between shift work and other health issues. At present, the results of this study showed that all rotating night shift work indicators (current shift status, duration of night shifts, cumulative number of night shifts and average frequency of night shifts) had a significant association with elevated GGT and elevated ALT, but not with...
The present study indicated that rotating night shift work would increase the risk of elevated GGT and elevated ALT. This is in contradiction with a previous study, which indicated that shift work is not a significant risk factor for increased serum GGT on workers of a telecommunication enterprise. The difference in exposure assessment and population characteristics may contribute to the discrepancy. Additionally, our study used different indicators to evaluate the rotating night shift work, which reduced the deviation caused by different evaluation standards to a certain extent. However, the results of our study were consistent with some research results to some extent. A study has shown that circadian rhythm disorder is associated with higher levels of GGT, and some studies have shown that the elevated level of liver enzymes (including ALT, ALP) was significantly associated with shift work. Moreover, the results of this study were supported by several previous studies, which indicated that shift work was associated with a higher risk of non-alcoholic fatty liver disease (NAFLD), since elevated GGT and elevated ALT is relevant to NAFLD. Although the underlying biological pathways have not been fully revealed, some mechanisms have been proposed.

Table 3 ORs of elevated gamma-glutamyl transpeptidase (GGT) according to different exposure metrics of night shift work

| Exposure metrics                      | Total               | Model 1          | Model 2          | Model 3          |
|--------------------------------------|---------------------|------------------|------------------|------------------|
|                                      | N (%)   | OR (95% CI) | OR (95% CI) | OR (95% CI) |
| Current shift status                 |         |             |             |             |
| Never                               | 1155 (16.4) | 1.00         | 1.00          | 1.00            |
| Ever                                | 1380 (19.6) | 1.29 (0.98 to 1.68) | 1.25 (0.95 to 1.63) | 1.27 (0.97 to 1.67) |
| Current                             | 4496 (64.0) | 1.40 (1.12 to 1.75) | 1.37 (1.09 to 1.73) | 1.39 (1.10 to 1.75) |
| Duration of night shifts             |         |             |             |             |
| Never                               | 1155 (16.4) | 1.00         | 1.00          | 1.00            |
| ≤19 years                           | 2855 (40.6) | 1.18 (0.93 to 1.50) | 1.25 (0.97 to 1.60) | 1.24 (0.97 to 1.59) |
| >19 years                           | 3021 (43.0) | 1.56 (1.24 to 1.97) | 1.42 (1.12 to 1.80) | 1.46 (1.15 to 1.86) |
| P trend                              | <0.001   |             |             |             |
| Cumulative number of night shifts    |         |             |             |             |
| Never                               | 1155 (16.4) | 1.00         | 1.00          | 1.00            |
| ≤1774 nights                        | 2948 (41.9) | 1.19 (0.93 to 1.51) | 1.26 (0.98 to 1.61) | 1.25 (0.98 to 1.60) |
| >1774 nights                        | 2928 (41.7) | 1.57 (1.24 to 1.98) | 1.41 (1.11 to 1.80) | 1.46 (1.15 to 1.85) |
| P trend                              | <0.001   |             |             |             |
| Average frequency of night shifts    |         |             |             |             |
| Never                               | 1155 (16.4) | 1.00         | 1.00          | 1.00            |
| ≤7 nights/month                     | 2132 (30.3) | 1.36 (1.06 to 1.74) | 1.32 (1.03 to 1.70) | 1.34 (1.04 to 1.73) |
| >7 nights/month                     | 3744 (53.3) | 1.38 (1.09 to 1.73) | 1.36 (1.08 to 1.71) | 1.37 (1.09 to 1.74) |
| P trend                              | <0.001   |             |             |             |
| Sleep duration                      |         |             |             |             |
| ≥7 hours/day                        | 2585 (36.8) | 1.00         | 1.00          | 1.00            |
| <7 hours/day                        | 4446 (63.2) | 1.00 (0.85 to 1.17) | 0.95 (0.81 to 1.11) | 0.90 (0.77 to 1.06) |

Model 1: unadjusted. Model 2: adjusted for age, sex. Model 3: adjusted for age, sex, smoking status, drinking status and DASH Score. DASH, Dietary Approaches to Stop Hypertension.
Rotating night shift work will affect liver repair. Lin et al. carried out a retrospective analysis on workers who had long-term shift work and found that long-term shift work poses a barrier to ALT normalisation of workers with previous abnormal liver function. Furthermore, our study showed that the association between the elevated GGT and different exposure metrics of night shift work were statistically significant only when the sleep duration < 7 hours/day. Kim et al. has found that shorter sleep duration had progressively higher odds of abnormal ALT. Lack of sleep and poor sleep quality are responsible for a large proportion of the negative effects of shift work, Hicklin and Schwander said in a study. These studies support the conclusions of this study to some extent, but it needs a lot of studies to confirm.

Finally, we found that current smoking and current drinking status increased the risk of elevated GGT. Moreover, the interactions between rotating night shift work

| Table 4 | Joint effects of different exposure metrics of night shift work and sleep duration on elevated gamma-glutamyl transpeptidase |
|---|---|---|---|---|
| Stratified variables | Total | Model 1 | Model 2 | Model 3 |
| N (%) | OR (95% CI) | OR (95% CI) | OR (95% CI) |
| Sleep duration | Current shift status | | | |
| <7 hours/day | Never | 123 (10.1) | 1.00 | 1.00 | 1.00 |
| | Ever | 361 (14.6) | 1.22 (0.85 to 1.75) | 1.20 (0.84 to 1.73) | 1.19 (0.82 to 1.72) |
| | Current | 724 (75.3) | 1.42 (1.04 to 1.92) | 1.41 (1.04 to 1.92) | 1.40 (1.03 to 1.92) |
| ≥7 hours/day | Never | 1032 (17.7) | 1.00 | 1.00 | 1.00 |
| | Ever | 1771 (20.6) | 1.39 (0.93 to 2.07) | 1.29 (0.86 to 1.94) | 1.39 (0.92 to 2.09) |
| | Current | 3020 (61.7) | 1.37 (0.97 to 1.93) | 1.31 (0.93 to 1.85) | 1.37 (0.97 to 1.95) |
| P for interaction | | 0.720 | 0.520 | 0.686 |
| Sleep duration | Duration of night shifts | | | |
| <7 hours/day | Never | 123 (10.1) | 1.00 | 1.00 | 1.00 |
| | ≤19 years | 322 (33.7) | 1.22 (0.88 to 1.69) | 1.25 (0.89 to 1.75) | 1.27 (0.90 to 1.80) |
| | >19 years | 763 (56.2) | 1.50 (1.10 to 2.05) | 1.44 (1.05 to 1.98) | 1.41 (1.02 to 1.94) |
| ≥7 hours/day | Never | 1032 (17.7) | 1.00 | 1.00 | 1.00 |
| | ≤19 years | 1951 (43.4) | 1.12 (0.77 to 1.60) | 1.23 (0.85 to 1.78) | 1.30 (0.89 to 1.90) |
| | >19 years | 2840 (38.9) | 1.74 (1.22 to 2.48) | 1.40 (0.97 to 2.02) | 1.46 (1.00 to 2.12) |
| P for interaction | | 0.338 | 0.448 | 0.289 |
| Sleep duration | Cumulative number of night shifts | | | |
| <7 hours/day | Never | 123 (10.1) | 1.00 | 1.00 | 1.00 |
| | ≤1774 nights | 420 (34.8) | 1.23 (0.89 to 1.70) | 1.25 (0.89 to 1.75) | 1.29 (0.92 to 1.82) |
| | >1774 nights | 665 (55.1) | 1.50 (1.10 to 2.05) | 1.44 (1.05 to 1.98) | 1.40 (1.01 to 1.93) |
| ≥7 hours/day | Never | 1032 (17.7) | 1.00 | 1.00 | 1.00 |
| | ≤1774 nights | 2528 (43.4) | 1.26 (0.97 to 1.63) | 1.25 (0.86 to 1.80) | 1.32 (0.90 to 1.91) |
| | >1774 nights | 2263 (38.9) | 1.43 (1.11 to 1.83) | 1.38 (0.95 to 2.00) | 1.45 (0.99 to 2.11) |
| P for interaction | | 0.351 | 0.452 | 0.267 |
| Sleep duration | Average frequency of night shifts | | | |
| <7 hours/day | Never | 123 (10.1) | 1.00 | 1.00 | 1.00 |
| | ≤7 nights/month | 361 (29.9) | 1.37 (0.99 to 1.91) | 1.37 (0.98 to 1.90) | 1.34 (0.96 to 1.88) |
| | >7 nights/month | 724 (50.0) | 1.37 (1.01 to 1.87) | 1.36 (1.00 to 1.86) | 1.36 (0.99 to 1.87) |
| ≥7 hours/day | Never | 1032 (17.7) | 1.00 | 1.00 | 1.00 |
| | ≤7 nights/month | 1771 (30.5) | 1.35 (0.93 to 1.96) | 1.25 (0.85 to 1.82) | 1.33 (0.91 to 1.95) |
| | >7 nights/month | 3020 (51.8) | 1.39 (0.98 to 1.97) | 1.35 (0.95 to 1.91) | 1.41 (0.99 to 2.01) |
| P for interaction | | 0.790 | 0.969 | 0.842 |

Model 1: unadjusted. Model 2: adjusted for age, sex. Model 3: adjusted for age, sex, smoking status, drinking status and DASH score. DASH, Dietary Approaches to Stop Hypertension.
and lifestyle factors (smoking, drinking, BMI and physical activity) on elevated GGT were not statistically significant. However, the lifestyle factors affected the association between rotating night shift work and elevated GGT. Among current smokers, people with BMI ≥24 or people with high physical activity, rotating night shift work would increase the risk of elevated GGT.

In addition, the results of this study are consistent with those of previous studies\(^8\) to some extent. Rotating night shift work is not only are associated with higher HHcy odds, but also associated with elevated GGT and elevated ALT among steelworkers.

**Strengths and limitations**

The first strength of this study is that it has a large sample size of 7031 individuals with detailed disease history, general demographic characteristics and lifestyle information, and we also considered chemical and physical risk factors in the occupational environment. In addition, we have collected in-depth rotating night shift work information for the evaluation of different exposure metrics of night shift work. However, there are some weaknesses of our study. First, this study is a cross-sectional study, which has limitations in explaining the causal relationship of rotating night shift work and sleep duration with elevated GGT. Second, because information on sleep duration and lifestyles was self-reported, the potential exists for exposure miscategorization. Thirdly, we have no authority to obtain the specific level of occupational hazards, including high temperature, noise, dust and CO, so we were unable to consider industrial dust in this study. Finally, our research object is relatively healthy steelworkers. Therefore, the results of this study are limited when they are extended to the general population.

**CONCLUSION**

In conclusion, our data indicated that current shift status, duration of night shifts, cumulative number of night shifts and average frequency of night shifts were all associated with elevated GGT and elevated ALT among steelworkers, and lifestyle factors affected the association between rotating night shift work and elevated GGT. From the perspective of occupational medical and preventive medicine, the assessment of shift schedules should be more detailed, and night shift workers should ensure enough sleep duration and quit smoking and drinking. We acknowledge the need for prospective cohort studies to confirm that rotating night shift work and these lifestyle factors are harmful to the health of the liver.

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**Data availability statement** Data are available upon reasonable request. The datasets generated and analysed during the current study are not publicly available due other analyses are proceeding but are available from the corresponding author on reasonable request.

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