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Association of occupational noise exposure and shift work with non-alcoholic fatty liver disease: a cross-sectional study of male workers in the Chinese automobile manufacturing industry

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ABSTRACT

Objective This study aimed to determine the relationship between occupational noise, shift work and non-alcoholic fatty liver disease (NAFLD) in male workers in the automobile manufacturing industry.

Design Cross-sectional study.

Setting This study was carried out at the Guangzhou Twelfth People's Hospital using data from April to September 2022.

Participants A total of 4672 eligible participants were included in the study.

Primary and secondary outcome measures Diagnosis of NAFLD was made using ultrasound. Noise was detected according to the Measurement of Physical Factors in the Workplace-Part 8: Noise. Environmental noise intensity was assessed using an EDGE personal noise dosimeter manufactured by CASELLA (UK). The working status of workers was investigated by questionnaire.

Results The OR of NAFLD was 1.39 (1.03, 1.88) in the cumulative noise exposure (CNE)≥95 group compared with CNE<85 group. Improved risk of NAFLD in workers with shift work compared with those without shift work (OR=1.35, 95% CI: 1.09, 1.68). As stratified analyses showed, the ORs of NAFLD prevalence related to occupational noise and shift work exposure appear to be increased in young workers. When both shift work and noise exposure work are present simultaneously, the synergy index between them was 0.47 (95% CI: 0.25, 0.89). Combined effects analysis revealed that the OR of NAFLD was 2.02 (95% CI: 1.34, 2.99) in CNE≥95 and cumulative length of night shifts work>2920 hours.

Conclusion Occupational noise exposure may be an independent risk factor for NAFLD. It may synergistically affect disease when combined with night shift work, particularly among younger workers. These findings underscore the importance for companies to prioritise the management and training of younger workers, along with targeted occupational health education initiatives, as crucial measures for reducing the incidence of NAFLD.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ In this study, a cross-sectional survey was used to analyse the effects of occupational noise exposure and shift work on non-alcoholic fatty liver disease.
⇒ Data were collected by trained investigators, and health examinations were provided to the participants by professional physicians.
⇒ The questionnaire items on working hours, lifestyle, diet, etc, were designed simplistically and may be difficult to assess comprehensively.
⇒ Due to the cross-sectional survey, there may be observational bias and causality cannot be elucidated either.

INTRODUCTION

In recent decades, there has been a progressive increase in the incidence of non-alcoholic fatty liver disease (NAFLD), leading to a significant burden of morbidity and mortality associated with liver-related disorders.[1 2] Anticipating future trends, researchers project a continued rise in the prevalence of NAFLD, while expecting a stable or possibly decreasing prevalence of other chronic liver diseases.[3] In China, the prevalence of NAFLD has notably increased in the past decade, rising from 18% to 29.2%. Industrialisation and changes in lifestyle have contributed to this rise, resulting in a 10% increase in national incidence.[4] Recent studies have highlighted the rapid increase in NAFLD prevalence among adolescents.[5]

The development of NAFLD is influenced by various factors, including age, gender, type 2 diabetes, metabolic syndrome, its components and family history of fatty liver.[6–10] Age and gender also play significant roles in the onset of NAFLD. The increasing prevalence of NAFLD can be attributed to population ageing, where age-related visceral fat accumulation may contribute to the secretion of inflammatory factors.[7 8] Unhealthy dietary habits, including high-fat diets, and unhealthy lifestyles such as late-night activities have also been associated with an increased risk of NAFLD.[11–13] Furthermore, occupational factors in the workplace, such as noise exposure and shift work, may influence the risk of NAFLD. Previous research has demonstrated a significant dose-response relationship between cumulative noise exposure (CNE) and the detection rates of fatty liver, lending support to the notion that noise may act as a risk factor for fatty liver.[14] Shift work is a prevalent practice in various industries, including manufacturing, pharmaceutical and service sectors. It not only disrupts normal circadian rhythms directly but is also closely linked to sleep disorders, leading to insulin resistance and stress reactions, causing physiological disruptions and harm to health.[15–17] These disturbances can disrupt glucose and lipid metabolism, which is a significant contributing factor in elevating the risk of NAFLD.[18]

Workers in the automotive manufacturing industry frequently endure prolonged occupational noise exposure and may also be required to engage in shift work. Despite this, few investigations have specifically examined the impact of shift work and noise on NAFLD within the context of this workforce. Consequently, our study aims to investigate the effects of occupational noise exposure and shift work on NAFLD among male workers in the automotive manufacturing industry. By focusing on this specific population, the study intends to provide a theoretical foundation to implement measures to protect against occupational hazards.

METHODS

Study design and population

From April to September 2022, a cross-sectional study was conducted among male workers at an automobile manufacturing company in Guangzhou for an occupational health examination. Participants with incomplete medical examination or questionnaire data, female workers, individuals taking antiretroviral drugs and those with a history of cancer, excessive alcohol intake, hepatobiliary disease, blood system diseases or renal failure were excluded. Ultimately, a total of 4672 eligible participants were included in the study.

NAFLD diagnosis and collection of information on covariates

Trained physicians conducted the occupational health examination in accordance with a standardised protocol. Diagnosis of NAFLD was made using the criteria proposed by Farrell *et al*.[19] Blood was drawn from the fasting subjects to measure haemoglobin (HGB) and fasting plasma glucose (FPG) levels. Blood pressure (BP) was measured using the omron HEM-7071 electronic BP monitor three times, each time at an interval of 1 min, and the average of the three measurements was taken as the individual BP value. BP was classified according to the 2018 Chinese Guidelines for the Prevention and Treatment of Hypertension. The FPG normal range is 3.9–6.1 mmol/L. According to the Guidelines for the Prevention and Control of Overweight and Obesity in Chinese Adults, our study included body mass index (BMI)<24 kg/m^2 and BMI≥24 kg/m^2 as dichotomous variables in the multivariate logistic regression model.

Referring to previous research and consulting multiple experts in the field of occupational health to revise and improve it continuously, we used a self-designed questionnaire to investigate.[20] The questionnaires were administered face to face by trained investigators to acquire participants' information, including dietary habits, lifestyle, occupational information and medical history. Finally, investigators checked the completed questionnaires to detect errors promptly. We investigated the average number of working days per week for workers to assess working hours and determine whether it is considered long working hours. Long working hours are defined as working more than 40 hours per week.[21] Simultaneously, we made inquiries regarding the exposure statuses of other occupational hazard factors, so as to guarantee that the exposures to other occupational factors like dust and benzene series (mainly refers to benzene, toluene and xylene) were beneath the occupational exposure limits (OELs) stipulated in the 'Occupational exposure limits for hazardous agents in the workplace—Part 1: Chemical hazardous agents' (GBZ 2.1-2019). Classification of dietary habits: high-salt foods mainly include pickled vegetables, ham and bacon, etc[22 23]; high-fat foods, including chips, chocolate, animal offal and fried foods; late evening snack is defined as an additional meal arranged after 21:00. According to the frequency of eating within a week, they are divided into four groups: seldom, 1–2 times per week, 3–4 times per week and >4 times per week. Smoking is defined as a consistent consumption of at least one cigarette per day for a duration of more than 6 months. Alcohol consumption is defined as a regular pattern of drinking at least once a week for a period of 1 year or longer. According to the duration of sleep, they were divided into three groups: <6 hours (short-sleep duration), 6–8 hours (moderate-sleep duration) and >8 hours (long-sleep duration).[24]

Noise exposure assessment

Our study followed the 'Measurement of physical factors in the workplace—Part 8: Noise' (GBZ/T189.8-2007) for noise detection. Environmental noise intensity was assessed using an EDGE personal noise dosimeter manufactured by CASELLA (UK). Each monitoring point was measured three times, and the average value was taken as the measurement result. In this study, noise exposure was evaluated using the normalisation of continuous A-weighted sound pressure level equivalent to 8-hours per day (LAeq, 8h), and work exposed to noise is defined as those operations involving the presence of hearing-impairing, health-hazardous or otherwise hazardous

Table 1 Basic characteristics of population in different disease states (n, %)

Characteristics	Non-alcoholic fatty liver disease		Total	P value
	No (n=3309)	Yes (n=1363)	(n=4672)	
Age (years), n (%)				<0.001
≤29	2649 (80.1)	698 (51.2)	3347 (71.6)	
≥30	660 (19.9)	665 (48.8)	1325 (28.4)	
Education, n (%)				0.009
Senior secondary and below	1888 (57.1)	720 (52.8)	2608 (55.8)	
Higher education	1421 (42.9)	643 (47.2)	2064 (44.2)	
Smoking status (cigarettes per day), n (%)				<0.001
Non-smokers	1741 (52.6)	729 (53.5)	2470 (52.9)	
1–5	618 (18.7)	198 (14.5)	816 (17.5)	
6–10	599 (18.1)	239 (17.5)	838 (17.9)	
>10	351 (10.6)	197 (14.5)	548 (11.7)	
Fruit and vegetable (times per week), n (%)				0.002
Seldom	262 (7.9)	89 (6.5)	351 (7.5)	
1–2	1961 (59.3)	752 (55.2)	2713 (58.1)	
3–4	653 (19.7)	297 (21.8)	950 (20.3)	
>4	433 (13.1)	225 (16.5)	658 (14.1)	
Late evening snack (times per week), n (%)				0.024
Seldom	747 (22.6)	361 (26.5)	1108 (23.7)	
1–2	1863 (56.3)	735 (53.9)	2598 (55.6)	
3–4	386 (11.7)	137 (10.1)	523 (11.2)	
>4	313 (9.5)	130 (9.5)	443 (9.5)	
Body mass index (kg/m^2), n (%)				<0.001
<24	3001 (90.7)	555 (40.7)	3556 (76.1)	
≥24	308 (9.3)	808 (59.3)	1116 (23.9)	
Sleep duration (hours), n (%)				<0.001
<6	592 (17.9)	303 (22.2)	895 (19.2)	
6–8	2574 (77.8)	1023 (75.1)	3597 (77.0)	
>8	143 (4.3)	37 (2.7)	180 (3.9)	
Blood pressure (mm Hg), n (%)				<0.001
Normal	1374 (41.5)	306 (22.5)	1680 (36.0)	
High-normal	1890 (57.1)	963 (70.7)	2853 (61.1)	
Hypertension	45 (1.4)	94 (6.9)	139 (3.0)	
ECG, n (%)				<0.001
Normal	1392 (42.1)	824 (60.5)	2216 (47.4)	
Abnormal	1917 (57.9)	539 (39.5)	2456 (52.6)	
Fasting plasma glucose (mmol/L), n (%)				<0.001
Normal	2887 (87.2)	1001 (73.4)	3888 (83.2)	
Abnormal	422 (12.8)	362 (26.6)	784 (16.8)	
Haemoglobin (g/L), n (%)				0.005
Normal	2586 (78.2)	1013 (74.3)	3599 (77.0)	
Abnormal	723 (21.8)	350 (25.7)	1073 (23.0)	
Long working hours				<0.001
No	1375 (41.55)	685 (50.26)	2060 (44.09)	
Yes	1934 (58.45)	678 (49.74)	2612 (55.91)	

Continued

Table 1 Continued

Characteristics	Non-alcoholic fatty liver disease		Total	P value
	No (n=3309)	Yes (n=1363)	(n=4672)	
Dust				0.015
No	2990 (90.36)	1262 (92.60)	4252 (91.01)	
Yes	319 (9.64)	101 (7.41)	420 (8.99)	
Benzene series				0.02
No	2828 (85.46)	1200 (88.04)	4028 (86.22)	
Yes	481 (14.54)	163 (11.96)	644 (13.78)	
Shift work				<0.001
No	808 (24.42)	206 (15.11)	1014 (21.70)	
Yes	2501 (75.58)	1157 (84.89)	3658 (78.30)	
Work exposed to noise				0.045
No	1239 (37.44)	468 (34.34)	1707 (36.54)	
Yes	2070 (62.56)	895 (65.66)	2965 (63.46)	
Cumulative length of night shift work (hours)	1100 (511–2560)	2190 (1090–4380)	1460 (730–2920)	<0.001
Cumulative noise exposure (dB(A)·year)	86.9 (83.1–91.1)	89.8 (85.2–93.3)	87.8 (83.6–91.9)	<0.001
Seniority in shift work (year), median (IQR)	3.0 (1.50, 6.50)	6.0 (3.95, 12.0)	4.0 (2.0, 8.0)	<0.001
Seniority in work exposed to noise (year), median (IQR)	3.00 (1.30, 7.00)	7.90 (2.75,13.50)	3.8 (1.50, 8.33)	<0.001

sound, and LAeq, 8h≥80 dB(A) for at least 1 year. Meanwhile, CNE was used to quantify the noise exposure level of the study participants and is calculated as CNE=$L_{Aeq,8h}$+10 log*T*, where *T* indicates the years of noise exposure and the CNE unit is dB(A)·year.

Assessment of shift work

The International Labour Organization defines shift work as extending the working day to 24 hours by alternating between different workers and/or teams.[25 26] Night shift work is defined as work occurring between 00:00 and 05:00.[26 27] The cumulative length of night shift work was calculated in hours during data processing. In this study, the two main types of shift patterns for workers are two shifts system and three shifts system.

In addition, according to the sampling methods and technical requirements in the 'Specifications of air sampling for hazardous substances monitoring in the workplace' (GBZ 159-2004), collect samples of dust, benzene, toluene and xylene in the air of workplaces. In accordance with the requirements of the 'Determination of dust in the air of workplace—Part 1: Total dust concentration' (GBZ 192.1-2007) and 'Occupational exposure limits for hazardous agents in the workplace—Part 1: Chemical hazardous agents' (GBZ 2.1-2019), we conduct fixed-point sampling and detection on representative operating posts for dust, benzene, toluene and xylene in the air.

Statistical analyses

Subject staff verified data daily to ensure unique ID codes for each individual and timely identification of missing key data and logical errors. R (V.4.2.1) was used for all statistical analyses. Continuous variables that followed normal distribution were presented as mean±SD, and were compared by t-test. Mann-Whitney U test was used to compare continuous variables with skewed distribution in the form of median with interquartile ranges. The χ^2 test was used to compare categorical variables, which have been expressed as numbers (percentages). The relationship between shift work, occupational noise and NAFLD was analysed using a multivariate logistic regression model, with night shift hours and CNE included in the regression model as categorical variables, respectively, as well as the joint effect of both was analysed in relation to NAFLD. Referring to the national criteria (GBZT229.4-2012), CNE is divided into four groups: <85, 85–, 90– and 95–. Cumulative length of night shift work is grouped by quartiles using the first quartile as a reference. Previous studies have considered adolescents and young adults to be the group aged 15 years and older, with the cut-offs at 24, 29 and 39 years being difficult to determine and some studies considering 18–24 years as late adolescence.[28] We stratified the age into two groups ≤29 and ≥30 for analysis. To provide more clarity on the effect of CNE on the illness of workers in different age groups, we subdivided younger workers at age 29 into two groups (≤24 and 25–29 years old).[29 30] All tests were two-sided, and α=0.05 was considered statistically significant.

Patient and public involvement

Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

RESULTS

Basic information about the study population

A total of 5928 questionnaires were distributed, out of which 4791 valid questionnaires were returned, resulting in a valid response rate of 80.8%. After excluding individuals who did not meet the study's inclusion criteria and those with incomplete occupational health screening results (n=119), the final sample size included for analysis was determined. Overall, 4672 workers with complete information on occupational health examination and questionnaires were included in the study according to the inclusion and exclusion criteria. The mean age of the study population was (26.8±5.0), with different prevalence rates for workers in the ≤29 and ≥30 years age groups (p<0.001), with a total of 1363 workers with NAFLD and a prevalence of 29.2%. There were 3658 (78.3%) shift workers, with different prevalence of NAFLD in different shift work situations (p<0.001). Meanwhile, 2965 (63.5%) noise workers had a statistically significant difference in prevalence in different noise exposure scenarios (p<0.05). Cumulative length of night shift work and CNE vary by disease state (all p<0.05). A summary of the sample characteristics is presented in table 1. The results of univariate analysis of drinking status, high-salt foods, high-fat foods, physical activity and importance of noise protection equipment are presented in online supplemental table 1.

Relationship between occupational noise exposure and NAFLD

The impact of work exposed to noise on NAFLD is demonstrated in table 2. Compared with those that did not, no statistically significant relationship between work exposed to noise and NAFLD (OR=0.92, 95% CI: 0.78, 1.09) was found. Table 3 and online supplemental table 2 present the ORs and 95% CIs for the effect of occupational noise exposure on NAFLD. Stratified analysis indicated that the association between CNE and NAFLD was not statistically significant in both those aged ≤29 and ≥30 years (see online supplemental table 1); By reference to CNE<85, the OR of NAFLD was 1.39 (95% CI: 1.03, 1.88) in the CNE≥95 group. Table 3 shows further stratification by age, and among those ≤24 years of age, the OR of NAFLD in the CNE≥95 group was 2.97 (95% CI: 1.18, 6.95).

Relationship between shift work and NAFLD

The effect of shift work on NAFLD is shown in figure 1. Compared with those without shift work, the OR of NAFLD among workers with shift work was 1.35 (95% CI: 1.09, 1.68). Stratified analysis showed that shift work was a risk factor for NAFLD among those aged ≤29 years (OR=1.46, 95% CI: 1.15, 1.87). Similarly, in comparison with cumulative length of night shift work≤730 hours, rising cumulative length of night shift work was associated with a higher risk of NAFLD, with ORs (95% CIs) of 1.43 (1.14, 1.79), 1.44 (1.15, 1.81) and 1.64 (1.23, 2.17), respectively. Among those aged ≤29 years, increased cumulative length of night shift work was also a risk factor for NAFLD, with ORs (95% CIs) of 1.66 (1.30, 2.11), 1.52 (1.17, 1.98) and 2.41 (1.50, 3.84) respectively.

Relationship between the interaction of work exposed to noise and shift work and NAFLD

To further explore the combined effects of noise exposure work and shift work, we analysed the interaction between them. The results are shown in table 4. When both shift work and noise exposure work are present simultaneously, the excess relative risk of relative excess risk due to interaction was −0.43 (95% CI: −1.00, 0.14), the attributable proportion due to interaction (AP) was −0.31 (−0.69, 0.07) and the synergy index between them was 0.47 (95% CI: 0.25, 0.89).

Table 2 Association of work exposed to noise with non-alcoholic fatty liver disease

	Model 1		Model 2	
Work exposed to noise (yes or no)	**OR (95% CI)**	**P value**	**OR (95% CI)**	**P value**
Total				
No	Ref			
Yes	0.97 (0.83, 1.15)	0.754	0.92 (0.78, 1.09)	0.356
Age				
≤29 years				
No	Ref			
Yes	1.07 (0.87, 1.31)	0.537	0.98 (0.79, 1.21)	0.826
≥30 years				
No	Ref			
Yes	0.84 (0.63, 1.11)	0.212	0.83 (0.63, 1.11)	0.212

Model 1: adjust for age, smoking and drinking status, fruit and vegetable, high-salt foods, high-fat foods, late evening snack, body mass index, sleep duration, physical activity, blood pressure, ECG, fasting plasma glucose, haemoglobin.
Model 2: based on model 1, adjust for importance of noise protection equipment, long working hours, dust, benzene series, shift work.

Table 3 Relationship between cumulative noise exposure and non-alcoholic fatty liver disease in different age groups

Cumulative noise exposure (dB(A)·year)	Model 1		Model 2	
	OR (95% CI)	P value	OR (95% CI)	P value
Total				
<85				
85–	1.20 (0.97, 1.48)	0.087	1.12 (0.90, 1.39)	0.320
90–	1.16 (0.93, 1.45)	0.191	1.08 (0.85, 1.36)	0.536
95–	1.48 (1.10, 1.99)	0.009	1.39 (1.03, 1.88)	0.033
Age				
≤24 years				
<85	Ref			
85–	1.07 (0.77, 1.48)	0.676	0.96 (0.68, 1.35)	0.810
90–	1.00 (0.64, 1.52)	0.988	0.86 (0.54, 1.34)	0.512
95–	3.18 (1.29, 7.31)	0.008	2.97 (1.18, 6.95)	0.015
25–29 years				
<85	Ref			
85–	1.14 (0.80, 1.62)	0.480	1.14 (0.78, 1.66)	0.505
90–	1.11 (0.76, 1.62)	0.603	1.08 (0.73, 1.62)	0.690
95–	1.01 (0.55, 1.81)	0.963	1.07 (0.57, 1.95)	0.825

Model 1: adjust for age, smoking and drinking status, fruit and vegetable, high-salt foods, high-fat foods, late evening snack, body mass index, sleep duration, physical activity, blood pressure, ECG, fasting plasma glucose, haemoglobin.
Model 2: based on model 1, adjust for importance of noise protection equipment, long working hours, dust, benzene series, shift work.

Combined effects of occupational noise and shift work in association with NAFLD

The combined effects of occupational noise and cumulative length of night work on NAFLD are shown in table 5. After adjusting for variables, the association with NAFLD was statistically significant for all groups at cumulative length of night shift work>2920 hours and CNE≥85 compared with CNE<85 and cumulative length of night shift work≤730 hours. The OR of NAFLD was greatest at 2.01 (95% CI: 1.34, 2.99) when the cumulative length of night shift work>2920 hours and CNE≥95. Furthermore, we analysed the relationships between occupational noise, shift work and NAFLD in different states of benzene series exposure as well (see online supplemental table 3).

DISCUSSION

To summarise, our study included a total of 4672 male workers in the automotive manufacturing industry, investigating the impact of occupational noise and shift work on NAFLD through a cross-sectional survey. The majority of the company's employees are subjected to a high workload, with 63.5% working in noise and 78.3% working in shifts, which is significantly higher compared with other occupations such as teachers and white-collar workers.[31] Night work has been categorised by the International Agency for Research on Cancer as 'possibly carcinogenic to humans' (Group 2A),[32] prompting growing concerns about its adverse effects on health. The prevalence of NAFLD in this survey was 29.2%, a rate close to the combined prevalence estimate of NAFLD reported by Fan *et al*.[11 33–35] Among those exposed to noise and those not exposed, the prevalence of NAFLD is 30.2% and 27.4%, respectively. After adjusting for relevant variables, multifactorial logistic regression analysis revealed that increased CNE was the significant risk factor associated with NAFLD. This may be because the biological effects of noise are cumulative and the effects of a single noise exposure are not sufficient to cause health damage to the organism. However, the more repeated exposures and the longer the exposure period, the more pronounced the cumulative effects will be when the effects are not eliminated.[36 37] Associations between CNE and NAFLD vary across age groups. An increase in CNE is a risk factor for NAFLD among workers under 24 years of age. This suggests that short-term exposure to high-intensity noise may contribute to the development of NAFLD in this population. Possible factors that may contribute to this association include the inadequate use of noise protective equipment among young workers or exposure to noise outside of the occupational setting. The effect of noise on NAFLD in younger workers should be further explored. This indicates that enterprises should strengthen training and occupational health education for young workers, which is important to reduce the occurrence of NAFLD. Shins, Saeha *et al* have shown that chronic exposure to road traffic noise was associated with an increased incidence of diabetes and hypertension in Toronto.[38] Du *et al* found that noise exposure could lead to disorders

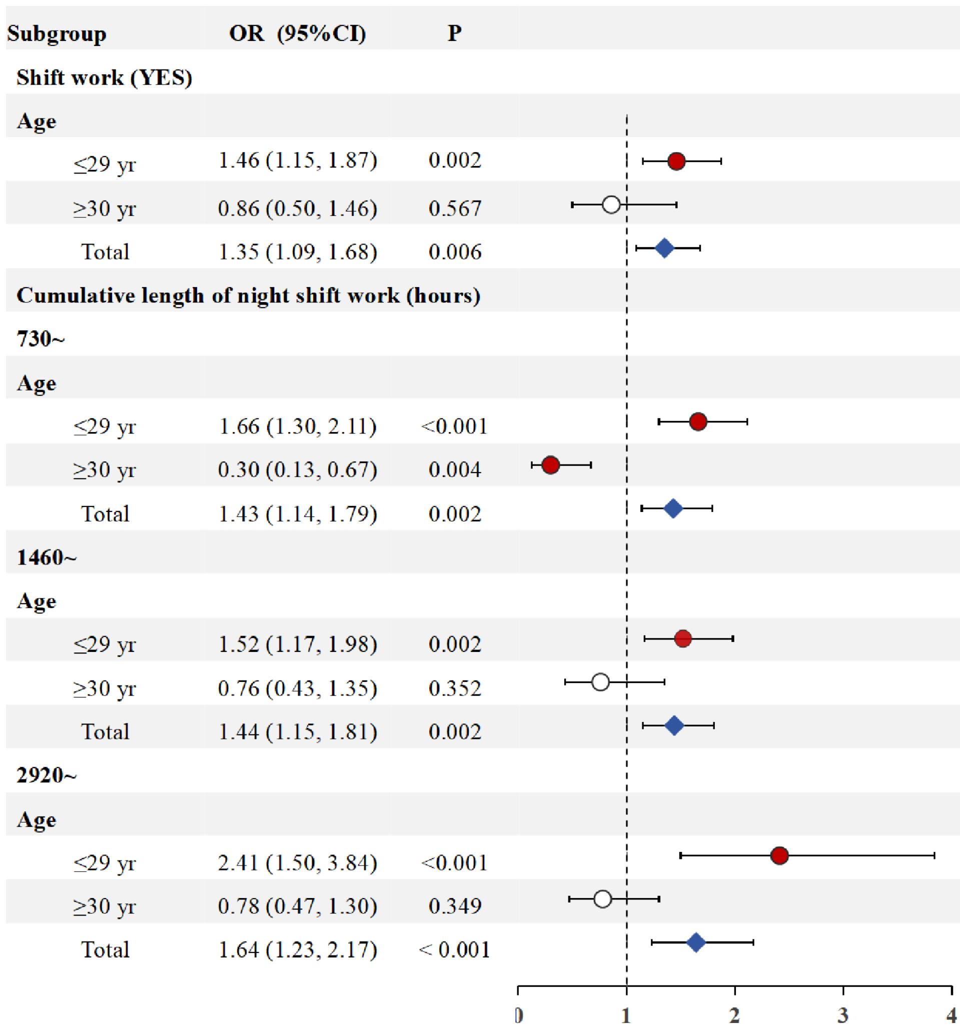

Figure 1 Relationship between shift work and non-alcoholic fatty liver disease. Adjust for age, smoking and drinking status, fruit and vegetable, high-salt foods, high-fat foods, late evening snack, body mass index, sleep duration, physical activity, blood pressure, ECG, fasting plasma glucose, haemoglobin, importance of noise protection equipment, long working hours, dust, benzene series, work exposed to noise.

of glucolipid metabolism in mice through inhibition of the AKT pathway mediated by the biological clock gene BMAL1.[39] The experiment by Evans *et al* also demonstrated significant changes in serum alanine transaminase (ALT) levels across test groups, suggesting that noise can lead to liver dysfunction.[40] It can be seen that noise may be the basis for the formation of NAFLD by promoting insulin resistance and disorders of glucolipid metabolism in the body, resulting in metabolic abnormalities in the body. These studies also indirectly support our findings.

Table 4 Relationship between the interaction of work exposed to noise and shift work and non-alcoholic fatty liver disease

		Total				
Work exposed to noise (yes or no)	Shift work (yes or no)	OR (95% CI)	Relative excess risk due to interaction	Attributable proportion	Synergy index	$P_{interaction}$
No	No	Ref	−0.43 (−1.00, 0.14)	−0.31 (−0.69, 0.07)	0.47 (0.25, 0.89)	0.112
	Yes	1.60 (1.19, 2.17)				
Yes	No	1.21 (0.83, 1.75)				
	Yes	1.38 (1.05, 1.83)				

Adjust for age, smoking and drinking status, fruit and vegetable, high-salt foods, high-fat foods, late evening snack, body mass index, sleep duration, physical activity, blood pressure, ECG, fasting plasma glucose, haemoglobin, importance of noise protection equipment, long working hours, dust, benzene series.

Table 5 Association of cumulative noise exposure and cumulative length of night shift work with non-alcoholic fatty liver disease

Cumulative noise exposure (dB(A)·years)	Cumulative length of night shift work (hours)			
	≤730	730–	1460–	2920–
	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
<85	Ref	**1.49 (1.04, 2.12)***	1.27 (0.82, 1.94)	1.34 (0.64, 2.76)
85–	0.88 (0.6, 1.27)	**1.45 (1.05, 1.99)***	**1.61 (1.14, 2.26)****	**1.99 (1.29, 3.07)****
90–	1.24 (0.76, 1.97)	1.31 (0.85, 1.99)	**1.41 (1.00, 1.98)***	**1.54 (1.08, 2.21)***
95–	1.98 (0.89, 4.26)	1.61 (0.72, 3.48)	1.67 (0.95, 2.88)	**2.01 (1.34, 2.99)*****

*p<0.05, **p<0.01, ***p<0.001.
Bold values are p<0.05.
Adjust for age, smoking and drinking status, fruit and vegetable, high-salt foods, high-fat foods, late evening snack, body mass index, sleep duration, physical activity, blood pressure, ECG, fasting plasma glucose, haemoglobin, importance of noise protection equipment, long working hours, dust, benzene series.

In this study, the prevalence of NAFLD was 20.3% and 31.6% among auto manufacturing workers not involved in shift work and those who did, respectively, with a higher prevalence among workers in shift work, similar to the findings of Golabi *et al*.[11] We observed that shift work and an increase in cumulative length of night shift work were identified as risk factors for NAFLD. We also examined the relationship between shift work and NAFLD across different age groups. Specifically, among workers below 29 years of age, engaging in shift work was found to significantly increase the risk of NAFLD. This indicates the presence of specific physiological adaptations that contribute to this heightened risk. Similarly, we found that an extended cumulative length of night shift work was a significant risk factor for NAFLD in workers below 29 years of age. These findings emphasise the importance of appropriate management strategies to mitigate the adverse effects of shift work on NAFLD among younger workers. Previous epidemiological studies have consistently demonstrated a link between shift work and NAFLD. For instance, a 4-year cohort study conducted among Chinese railway workers reported a higher incidence of NAFLD in individuals engaged among shift work.[11] Similarly, a cross-sectional survey involving male steelworkers found that night shift workers had an increased risk of NAFLD compared with those working day shifts.[15] Wang *et al* further supported the association between night shifts and NAFLD by demonstrating the impact of disrupted circadian rhythms, due to delayed sleep, on the incidence of NAFLD.[41] These findings are in line with our results. Sun *et al* also revealed the association between sleep deprivation, increased cortisol levels and insulin resistance, further highlighting the possible mechanisms underlying the relationship between sleep disruption and NAFLD.[42] Our study identified a significant association between occupational noise exposure, shift work and an increased risk of developing NAFLD among workers. This association may be explained by the potential mechanisms through which both noise exposure and shift work contribute to the development of insulin resistance, a key factor in the pathogenesis of NAFLD. Insulin resistance disrupts lipid metabolism, leading to elevated lipase activity and subsequent overproduction of triglycerides and free fatty acids. Consequently, an excessive amount of free fatty acids enters the liver, promoting increased lipid synthesis and deposition within hepatic cells. This lipid accumulation interferes with hepatocyte transport capacity, resulting in hepatocyte apoptosis and the accumulation of fat, ultimately leading to NAFLD development.

It should be noted that some participants in this study were simultaneously exposed to benzene series (mainly benzene, toluene and xylene). The study by Yun-Hee Cho *et al* showed that exposure to chemicals such as benzene, toluene and xylene could significantly increase the risk of NAFLD.[43 44] In obese populations, benzene exposure is positively correlated with liver injury, and systemic inflammation increases with the exposure to benzene and toluene, indicating that benzene and toluene exposure have certain potential impacts on steatohepatitis.[45] These effects may result from the activation of cell death, the induction of oxidative and endoplasmic reticulum stress and the disruption of metabolism, which are caused by the dysfunction of xenobiotic and endobiotic receptors.[46] After detection, we found that the concentrations of benzene series in the researchers' workplaces were all lower than the OELs stipulated in the 'Occupational exposure limits for hazardous agents in the workplace—Part 1: Chemical hazardous agents'. To ensure the reliability of the results, we also analysed the relationships between occupational noise, shift work and NAFLD under different benzene series exposure conditions. The results showed that in the absence of benzene series exposure, occupational noise exposure and shift work were still risk factors for NAFLD.

This study contributes to a relatively uncommon and innovative exploration of the association between occupational noise exposure, shift work and their combined effect on NAFLD among male workers in the automotive manufacturing industry. Based on the study findings, we

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propose several recommendations for relevant management departments. It is advised to scientifically and reasonably organise the working system, promote the implementation of flexible working arrangements and minimise the cumulative length of night work. Furthermore, improving the production process to control or eliminate noise sources, such as installing sound insulation and vibration dampers, is recommended. Additionally, establishing and enhancing occupational health supervision, strengthening the management of occupational health and facilitating regular occupational health check-ups for workers are crucial measures to safeguard worker health. These recommendations hold significant practical importance in protecting the health of workers.

However, it has to acknowledge the limitations of our study. Due to the cross-sectional nature of the survey, there may be observational bias and causality cannot be elucidated either. To address these limitations, we are in the process of establishing a cohort study among workers in the automotive manufacturing industry. In future studies, we plan to use individual noise dosimeters to more accurately measure workers' noise exposure, enabling a more robust analysis of the association between these occupational factors and disease outcomes.

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Contributors ZJ, YZ and ZWa conceived and designed the study. ZWa provided administrative support. ZJ, CxQ, WyM, ZWe and ZWa provided study materials. ZJ, YZ, CxQ, KyW, JwZ and JC collected and assembled data. YZ, RY, YxG, JL and CpY analysed and interpreted the data. YZ, ZJ and YxG wrote the manuscript. ZWa and JwZ approved the final manuscript. The guarantor of the study is ZWa, who accepts full responsibility for the finished work and the conduct of the study, has access to the data and controls the decision to publish.

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