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Original article

Association Between Shift Work and Metabolic Alterations: Possible Contributing Factors

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ABSTRACT

Background: Shift work (SW) can contribute to metabolic disorders affecting biological rhythms, inducing sleep deprivation, decreasing the resting metabolic rate, and changing dietary habits and eating behaviors. This study aims to assess the relationship of SW on physical and metabolic parameters, including the metabolic syndrome (MetS), and the contributing role of sleep quality, chronotype, chrononutrition, and the Mediterranean diet.

Methods: Shift and nonshift workers underwent medical examinations and lab tests. MetS was diagnosed using the National Cholesterol Education Program's Adult Treatment Panel III criteria. The Pittsburgh Sleep Quality Index, Chrononutrition Profile, Morning-Eveningness, and Prevention through Mediterranean Diet questionnaires were used to explore factors potentially affecting the development of metabolic disorders.

Results: Shift ($n = 172$) and nonshift workers ($n = 177$), primarily employed in healthcare and social activities and in the education and administrative sectors, were enrolled. Mean systolic blood pressure levels were significantly higher in shift workers compared to the daytime counterpart (121.0 ± 12.9 vs. 117.5 ± 13.2 mmHg, $p = 0.013$). MetS was significantly more frequent in the former group (25.6% vs. 13.7%, $p = 0.006$). Higher percentages of shift workers compared to daytime workers, had poor quality of sleep (37.8% vs. 27.1%, $p = 0.033$), an evening chronotype (14% vs. 6.8%, $p = 0.010$), and high adherence to the Mediterranean diet (65.7% vs. 43.5%, $p < 0.001$), while no differences emerged for the chrononutrition profile. SW represents a risk factor for MetS, although its development results from the interaction of personal lifestyle, dietary habits, chronotype, chrononutrition, sleep quality, and occupational factors.

Conclusion: In the perspective of the *Total Worker Health*® approach to workplace safety, health, and well-being, such an interplay should be addressed.

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1. Introduction

Shift work (SW) is defined as an "organization of daily working hours in which different teams work in succession to cover more or all of the 24 h" [1]. It is commonly found in various industries and services to provide the flexibility needed to optimize productivity and enhance business competitiveness in developed countries. According to the Sixth European Working Conditions Survey of the EU-28, 19% and 21% of workers were engaged in night and SW, respectively [2]. Similarly, in the United States of America, the National Health Interview Survey reported that approximately 26% of workers were involved in shift work, which included evening, night, or rotating shifts [3].

However, a wide variety of negative impacts of SW and night work (NW) on the workers' psychophysical health have been reported, including cardiovascular and metabolic problems [4–6]. Evidence demonstrated that a significantly increased risk of metabolic syndrome (MetS) was associated with "ever being exposed to SW" or with "rotating SW" [7,8]. Focusing specifically on night shift workers, the prevalence of MetS among workers who have been engaged in night shifts for 10 years (or more) was 37.5% and 50% higher compared to diurnal workers [9].

SW could contribute to metabolic disorders by disrupting the synchronization between biological and environmental rhythms, inducing sleep deprivation, decreasing the resting metabolic rate, physical activity, daily energy expenditure during night shifts and in response to dinner, and by causing changes in dietary habits and behaviors [10,11]. While existing research on eating behaviors has primarily focused on the qualitative and quantitative aspects of nutrition, there is limited information on the timing of food intake and its impact on MetS [12]. In this regard, some authors argue that in SW and NW the temporal alteration of the eating window makes it difficult to consume healthy foods, reduces the sense of satiety, and increases the desire to binge eat, thus favoring the development of metabolic disorders [13]. Additionally, SW has been reported to have negatively impacted adherence to the Mediterranean diet due to disrupted sleep patterns and potential shifts in eating habits, with workers with an evening chronotype demonstrating significantly lower Mediterranean diet adherence than those with a morning chronotype [14]. Given the well-established protective role of the Mediterranean diet against cardiometabolic disorders, its inclusion in the analysis provides important insight into lifestyle-related risk factors that may exacerbate the impact of SW on metabolic health.

Therefore, the aim of this study was to comprehensively assess the relationship between SW and physical and metabolic parameters, including MetS, by comparing workers engaged in SW with those not engaged in SW. Our findings could be helpful in identifying key areas to address to mitigate the risks associated with SW and to promote the health of workers employed in such schedules.

2. Materials and methods

2.1. Investigated population

A cross-sectional study was conducted between June 2023 and August 2024. Workers aged between 18 and 65 years, not-engaged (fixed daily shift workers) or engaged in SW at the time of the survey and for at least six months beforehand were enrolled on a voluntary basis among the employees referring to the Occupational Medicine Unit of the University Hospital "Federico II", in Naples, Italy, for their mandatory health surveillance medical examinations. SW was intended as a "*any method of organizing work in shifts whereby workers succeed each other at the same workstations according to a certain pattern, including a rotating pattern, and which may be continuous or discontinuous, entailing the need for workers to work at different times over a given period of days or weeks*" [15]. According to the Directive 2003/88/EC [16], a "night worker" was defined as "a *worker, who, during nighttime, works at least three hours of his daily working time as a normal course,*" where "nighttime" was defined as "*any period of not less than seven hours as defined by national law, including the timeframe between midnight and 05:00.*" All participants were adequately informed about the study aims, and they were asked to provide their written informed consent to participate.

2.2. Clinical and occupational features

In addition to the anamnestic phase of the medical examination, a dedicated form, administered by the medical staff, was used to obtain detailed information on patients' demographic data and individual lifestyle habits (e.g., smoking and alcohol use) that may play a role as possible risk factors for metabolic disorders. During the physical examination, abdominal circumference was measured at the level of the navel, and systolic and diastolic blood pressure were recorded. Workers were also subjected to hematochemical tests, carried out after a fasting period of at least 12 hours, for the determination of the parameters needed to diagnose MetS: glucose, triglycerides, and high-density lipoprotein (HDL) cholesterol levels. In this regard, the MetS diagnosis was made based on the National Cholesterol Education Program's Adult Treatment Panel III criteria, when at least three of the following five criteria were present: increased waist circumference ($\geq$102 cm and $\geq$88 cm in men and women, respectively), high triglyceride levels ($\geq$150 mg/dL or ongoing hypotriglyceride-lowering therapy), low HDL cholesterol levels ($<$40 mg/dL and $<$50 mg/dL in men and women, respectively, or pharmacological treatment in course for hypoalphalipoproteinemia), high blood pressure levels ($\geq$130/85 mmHg, or ongoing pharmacologic treatment for hypertension), and fasting blood glucose $\geq$100 mg/dl (or pharmacologic treatment for hyperglycemia) [17]. Additionally, glucose tolerance was classified on the basis of fasting plasma glucose (FPG) levels [18]. Subjects were grouped as normal glucose tolerance (FPG $<$100 mg/dl), prediabetes (impaired fasting glucose with FPG 100–125 mg/dl), and diabetes (FPG $\geq$126 mg/dl). The proportion of subjects undergoing pharmacological treatment for metabolic conditions was also analyzed. By considering treatment status, the analysis provides a more accurate interpretation of metabolic health indicators, distinguishing between controlled conditions due to medication and untreated or subclinical manifestations. Regarding occupational data, the sectors of employment and type of engagement were assessed using the International Standard Industrial Classification of All Economic Activities to categorize the productive field of employment, with breakdown according to sex [19]. Occupational risks experienced during specific job tasks, with specific attention paid to SW and night SW, as well as the workers' fitness for work were also evaluated.

2.3. Adherence to the mediterranean diet: the prevention through mediterranean diet questionnaire

The Mediterranean diet has been reported as a key factor for a low cardiovascular disease's incidence and mortality observed in Mediterranean countries [20–22]. The prevention through Mediterranean Diet questionnaire has been employed to assess the adherence to the Mediterranean diet as a possible contributing aspect in the relationship between SW and MetS development [23]. The questionnaire consists of 14 items addressing the use of extra virgin olive oil, butter or margarine, the number of portions of vegetable, fresh and dried fruit, red and white meat, fish, legumes, sweets, and wine consumed over a week. A score of 1 or 0 is assigned to each item and the prevention through Mediterranean Diet questionnaire final score is calculated as follows: 0–5, lowest adherence; 6–9, average adherence; ≥10, highest adherence [24].

2.4. Chrononutrition: the chrononutrition profile–questionnaire

Chrononutrition refers to the timing of food intake with respect to our circadian rhythms. The chrononutrition profile–questionnaire (CP-Q) assesses general chrononutrition behaviors and preferred timing of food intake such as breakfast skipping, largest meal, evening eating, evening latency, night eating, and eating window [25,26]. Through 18 items, the questionnaire assigns a score between 0 and 2 to each of the 6 distinct chrononutrition behaviors [27]. The total score can vary from 0 to 12: values between 0-4, 5-8, and 9-12 indicate a good, intermediate, and low chrononutrition profile, respectively [25].

2.5. Sleep quality: Pittsburgh sleep quality index

The Pittsburgh Sleep Quality Index is a 19-item questionnaire designed to assess seven components of sleep quality complaints over the past month, including subjective sleep quality and sleep disturbances [28]. The items are divided into 7 components, which evaluate the subjective sleep quality, sleep latency, sleep duration, habitual sleep effectiveness (meaning the percentage of time in bed in which one sleeps), sleep disorders, use of sleeping medication, and daytime dysfunction. Each element is rated on a scale from 0 to 3 points, where a score of "0" indicates no difficulties and a score of "3" indicates severe difficulties. The overall Pittsburgh Sleep Quality Index score is obtained by summing the scores of the seven components, and scores higher than 5 suggest poor sleep quality [29].

2.6. Chronotype: Morning-eveningness questionnaire

Chronotype refers to an individual's internal circadian rhythmicity, which influences preferred times for performing various activities such as sleeping or engaging in physical activity [30]. The Morning-Eveningness Questionnaire is 19 items, self-reported questionnaire used to assess the preferred time of day to perform activities and categorizes subjects into "morning" type" (individuals who prefer sleeping and waking up early as well as planning their activities early), "evening type" (individuals who prefer sleeping and waking up late as well as planning their activities later in the day), or "intermediate type" [31]. Each item of the questionnaire provides a point system that is summed to obtain a final score classifying participants along a continuum of chronotype. The total scores fall within a range between 16 and 86. A score ≤41, between 42 and 58, and ≥59 indicated evening, intermediate, and morning types, respectively [32,33].

3. Statistical analysis

The statistical analysis was primarily descriptive and exploratory as the study was conducted on a convenience sample including all eligible and available subjects. No a priori power analysis was performed to determine the sample size. Therefore, the main objective of the study was to collect preliminary data to generate hypotheses for future research. Continuous variables were presented as mean ± standard deviation (SD), while categorical variables were expressed as absolute and relative frequencies. Comparisons between groups were performed using the student's t-test for continuous variables, and the chi-square test was used for categorical variables. A multivariable logistic regression model was performed to assess the association between SW and MetS, adjusting for potential confounders that were significant at the univariate analysis. All statistical tests were conducted with a two-sided significance level of 0.05. Statistical analyses were carried out using R statistical software.

4. Results

4.1. Characteristics of study participants

Four hundred workers were invited to participate in the study. Out of these, 349 participants (87.2%) agreed to attend, with 172 (49.3%) engaged in SW and 177 (50.7 %) working fixed schedules. Overall, a total of 197 (56.4%) workers were male, and the mean ± SD age of the participants was 41.9 ± 13.6 years (Table 1). Concerning lifestyle habits, 53% of the total population were nonsmokers, 63.6% reported occasional alcohol use, and 51% reported not performing sport activities. With regard to educational levels, 245 workers (70.2%) held a university or postgraduate degree, while 103 workers (29.5%) had completed high school. Significant differences emerged between workers engaged in SW or not, particularly concerning age and gender. Specifically, the

Table 1
Characteristics of the study participants and differences between shift and nonshift workers. Significant values are marked with bold type.

	Study population (n = 349)	Shift workers (n = 172)	Nonshift workers (n = 177)	p
Age (Mean ± SD)	41.9 ± 13.6	40.2 ± 11.7	43.5 ± 15.1	**0.028**
Sex *n* (%)	—	—	—	**0.018**
Female	152 (43.6%)	64 (37.2%)	88 (49.7%)	—
Male	197 (56.4%)	108 (62.8%)	89 (50.3%)	—
Sport *n* (%)	—	—	—	0.785
Yes	171 (49.0%)	83 (48.3%)	88 (49.7%)	—
No	178 (51.0%)	89 (51.7%)	89 (50.3%)	—
Smoker *n* (%)	—	—	—	**0.012**
Yes	163 (46.7%)	92 (53.5%)	71 (40.1%)	—
No	186 (53.3%)	80 (46.5%)	106 (59.9%)	—
Alcohol consumption *n* (%)	—	—	—	**0.004**
Yes- habitual	23 (6.6%)	16 (9.3%)	7 (4.0%)	—
Yes- occasional	222 (63.6%)	107 (62.2%)	115 (65.0%)	—
No	104 (29.8%)	49 (28.5%)	55 (31.1%)	—
Educational level *n* (%)	—	—	—	**<0.001**
Primary/Secondary school	1 (0.6%)	0 (0.0%)	1 (0.3%)	—
High school diploma	103 (29.5%)	39 (22.7%)	64 (36.2%)	—
University degree	175 (50.1%)	126 (73.2%)	49 (27.7%)	—
Post-graduate degree	70 (20.1%)	7 (4.1%)	63 (35.6%)	—

mean ± SD age of shift workers was significantly lower compared to that of the nonshift employees (40.2 ± 11.7 vs. 43.5 ± 15.1 years, $p = 0.028$), and a significantly greater portion of shift workers were in the 25-34 year age range (51.7%) compared to those in daily activities (15.9%) ($p < 0.001$). Similarly, the percentage of males was significantly higher in the SW group (62.8% vs. 50. 3%; $p = 0.018$). Among the workers engaged in SW, there was also a significantly higher percentage of smokers (53.5% vs. 40.1%, p = 0.012) and alcohol users (71.5% vs. 69%, $p = 0.004$), as well as a significantly greater percentage of subjects with a university degree or postgraduate qualification (77.3% vs. 63.3%, $p < 0.001$) (Table 1).

4.2. Occupational features

Among the group of workers engaged in SW, 126 (73.2%) reported having a permanent contract, compared to 115 (65%) in the group of daily employees. Most shift workers were employed in healthcare and social work activities (80.2%; 35.4% females and 44.8% males), whereas daily workers were predominantly found in the education (50.3%; 23.8% females and 26.5% males) and administrative (22.1%; 13.6% females and 8.5% males) sectors (Table 2). This difference was also reflected in the diverse occupational risk factors reported by the two groups. Indeed, among the SW group, 101 (58.7%) were also involved in NW, 137 (79.6%) were exposed to biological risk factors, and 94 (54.6%) reported exposure to ionizing radiation. In contrast, 128 (72.3%) of daily workers reported using a video terminal unit for more than 20 hours per week and were exposed to prolonged and sustained awkward postures.

4.3. Physico-clinical parameters and questionnaire scores

In term of physical and health parameters, no significant differences emerged between shift and fixed daily shift workers with respect to abdominal circumference and diastolic blood pressure values, (Table 3), whereas systolic blood pressure levels were significantly higher in shift workers (121.0 ± 12.9 vs. 117.5 ± 13.2 mmHg, $p = 0.013$). Regarding haemato-chemical parameters, no significant differences were observed in triglycerides and HDL cholesterol levels. However, the mean ± SD of glucose value resulted significantly higher in those employees engaged in fixed scheduled work activities compared to shift workers (94.0 ± 23.6 vs. 79.7 ± 15.1 mg/dl, respectively; $p < 0.001$). Consistent with these findings, categorizing FPG levels according to American Diabetes Association criteria revealed a significantly different distribution between shift workers and those on fixed schedules. A higher proportion of nonshift workers fell into the prediabetes (17.0%) and diabetes (2.9%) categories compared to shift workers, whose corresponding rates were 12.2% and 0.0%, respectively, while a greater percentage of shift workers fell within the normal range (87.8%) than their fixed-schedule counterparts (80.1%). This pattern may be influenced by the substantially higher proportion of shift workers receiving diabetes treatment (15.7%) compared to nonshift workers (3.4%, $p < 0.001$). With regard to the prevalence of the MetS, it was notably greater among shift workers, with 25.6% compared to 13.7% in fixed daily workers ($p = 0.006$). After adjustment for potential confounders (age, sex, smoking status, alcohol consumption, and educational level), SW remained significantly associated with MetS (OR, 2.35, 95% CI, 1.19−4.80, $p = 0.016$).

Concerning the potential mechanisms underlying these alterations, a significantly higher percentage of shift workers ($n = 65$; 37.8%) had poor quality of sleep compared to 48 (27.1%) of those engaged in routine daily schedule ($p = 0.033$). With regard to chronotype, there was a significant difference between the two investigated groups ($p = 0.010$). Among shift workers 45, (26.2%) were identified as morning types, 103 (59.9%) as intermediate types, and 24 (14%) as evening types, whereas among fixed daily shift workers, the distributions was 69 (39.0%) morning types, 96 (54.2%) intermediate types, and 12 (6.8%) evening types. Concerning the chrononutrition profile, no significant differences ($p = 0.447$) emerged between the two groups (Table 4). Surprisingly, when assessing adherence to the Mediterranean diet, shift workers exhibited a significantly better profile ($p < 0.001$) since 113 (65.7%), 47 (27.3%) and 12 (7.0%) subjects reported a high, average, and low adherence, while among the fixed daily shift workers 77 (43.5%), 85 (48.0%), and 15 (8.5%) participants were classified in the same categories, respectively. Interestingly, a subgroup analysis in which Mets prevalence was analyzed with respect to the involvement in NW failed to reveal differences in this group compared to shift workers not operating at night. Indeed, no significant differences in the number of diagnosed MetS cases could be determined between night-shift workers (25; 24.8%) and shift-employees not working at night (19; 26.8%) ($p = 0.766$).

5. Discussion

Previous research has shown that occupational factors such as SW, excessive sitting-time, and sedentary occupations significantly increased the risk of MetS [9,34,35]. However, a comprehensive investigation of possible contributing factors has not yet been conducted. In this context, our study represents a first attempt to address the prevalence of physico-chemical alterations, including the development of MetS, in workers engaged and not engaged in SW, also evaluating the role of various parameters, such as sleep quality, chronotype, chrononutrition, and adherence to the Mediterranean diet.

Our results confirmed a higher prevalence of MetS in shift workers, primarily employed in the healthcare sector, compared to fixed daily shift workers, who were most involved in educational and administrative roles. Importantly, the association between MetS and SW remained statistically significant even after adjusting

Table 2
Sectors of employment of the study participants and differences between shift and nonshift workers

Industrial classification (ISIC)	Study population ($n = 349$)	Shift workers ($n = 172$)			Nonshift workers ($n = 177$)		
		Total number	Female subjects	Male subjects	Total number	Female subjects	Male subjects
Agriculture; forestry and fishing	9 (2.6%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	9 (5.1%)	2 (1.1%)	7 (4%)
Transportation and storage	34 (9.7%)	34 (19.8%)	3 (1.8%)	31 (18%)	0 (0.0%)	0 (0%)	0 (0%)
Administrative and support service activities	39 (11.1%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	39 (22.1%)	24 (13.6%)	15 (8.5%)
Education	89 (25.5%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	89 (50.3%)	42 (23.8%)	47 (26.5%)
Human health and social work activities	177 (50.7%)	138 (80.2%)	61 (35.4%)	77 (44.8%)	39 (22.2%)	20 (11.3%)	19 (10.9%)
Other service activities	1 (0.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.6%)	0 (0%)	1 (0.6%)

Table 3

Physical and hematochemical parameters as well as MetS criteria categorization of the study participants and differences between shift and nonshift workers. Significant values are marked with bold type.

Physical and blood parameters	Study population ($n = 349$)	Shift workers ($n = 172$)	Nonshift workers ($n = 177$)	p
Abdominal circumference (cm)	88.7 ± 10.4	89.0 ± 10.7	88.3 ± 10.1	0.529
Systolic blood pressure (mmHg)	119.2 ± 13.1	121.0 ± 12.9	117 ± 13.2	**0.013**
Diastolic blood pressure (mmHg)	76.4 ± 8.1	76.7 ± 8.5	76.1 ± 7.7	0.501
Triglycerides (mg/dl)	92.9 ± 38.9	92.9 ± 43.4	94.0 ± 23.6	0.965
HDL cholesterol (mg/dl)	55.1 ± 13.2	55.4 ± 14.1	54.7 ± 12.0	0.665
Glucose (mg/dl)	86.9 ± 21.0	79.7 ± 15.1	94.0 ± 23.6	**<0.001**
Fasting plasma glucose category	**Study population* ($n = 349$)**	**Shift workers* ($n = 172$)**	**Nonshift workers* ($n = 177$)**	**P-value**
Normal	288 (84.0%)	151 (87.8%)	137 (80.1%)	**0.031**
Prediabetes	50 (14.6%)	21 (12.2%)	29 (17.0%)	—
Diabetes	5 (1.5%)	0 (0.0%)	5 (2.9%)	—
NCEP-ATPIII MetS criteria and metabolic syndrome	**No. of subjects with positive results among the study population* ($n = 349$)**	**Shift workers* ($n = 172$)**	**Nonshift workers* ($n = 177$)**	**P-value**
Waist circumference	88 (25.4%)	42 (24.4%)	46 (26.3%)	0.689
Triglyceride levels	58 (19.3%)	39 (22.7%)	19 (14.7%)	0.084
HDL cholesterol levels	60 (19.9%)	34 (19.8%)	26 (20.2%)	0.934
Blood pressure levels	133 (38.1%)	70 (40.7%)	63 (35.6%)	0.326
Fasting blood glucose	72 (21.0%)	37 (21.5%)	35 (20.5%)	0.812
Metabolic syndrome	—	—	—	**0.006**
Yes	67 (19.7%)	44 (25.6%)	23 (13.7%)	—
No	273 (80.3%)	128 (74.4%)	145 (86.3%)	—
Therapies	**No. (%) of treated subjects among the study population* ($n = 349$)**	**Shift workers* ($n = 172$)**	**Nonshift workers* ($n = 177$)**	**P-value**
Antihypertensive	40 (11.5%)	22 (12.8%)	18 (10.2%)	0.442
Antihypercholesterolemia	49 (14.0%)	35 (20.3%)	14 (7.9%)	**<0.001**
Diabetes treatment	33 (9.5%)	27 (15.7%)	6 (3.4%)	**<0.001**

* Percentages were calculated based on the available data, excluding any missing values from the analysis.

HDL, high-density lipoprotein; MetS, metabolic syndrome; NCEP-ATPIII, National Cholesterol Education Program's Adult Treatment Panel III.

Table 4
Characteristics of the study participants and differences between shift and nonshift workers in terms of sleep quality, chronotype, chrononutrition profile, and adherence to the Mediterranean diet

Questionnaire results	Study population ($n = 349$)	Shift workers ($n = 172$)	Nonshift workers ($n = 177$)	p
PSQI (n, %)	—	—	—	**0.033**
Good	236 (67.6%)	107 (62.2%)	129 (72.9%)	—
Poor	113 (32.4%)	65 (37.8%)	48 (27.1%)	—
MEQ (n, %)	—	—	—	**0.010**
Evening	36 (10.3%)	24 (14.0%)	12 (6.8%)	—
Intermediate	199 (57.0%)	103 (59.9%)	96 (54.2%)	—
Morning	114 (32.7%)	45 (26.2%)	69 (39.0%)	—
CP-Q (n, %)	—	—	—	0.447
Good	219 (62.8%)	104 (60.5%)	115 (65.0%)	—
Intermediate	126 (36.1%)	65 (37.8%)	61 (34.5%)	—
Low	4 (1.1%)	3 (1.7%)	1 (0.6%)	—
PREDIMED (n, %)	—	—	—	**<0.001**
Average adherence	132 (37.8%)	47 (27.3%)	85 (48.0%)	—
Highest adherence	190 (54.4%)	113 (65.7%)	77 (43.5%)	—
Lowest adherence	27 (7.7%)	12 (7.0%)	15 (8.5%)	—

CP-Q, the chrononutrition profile–questionnaire; MEQ, morning-eveningness questionnaire; PREDIMED, the prevention through mediterranean diet questionnaire; PSQI, pittsburgh sleep quality index. Significant values are marked with bold type.

for potential confounding variables, including age, sex, smoking status, alcohol consumption, and educational level. This finding aligns with existing literature, especially with a recent meta-analysis that reported a significantly greater occurrence of MetS among employees in the healthcare sector [36]. Apart from glucose levels and systolic blood pressure, no other biochemical or physiological parameters showed significant differences between the two groups. Mean glucose levels were significantly higher in nonshift workers compared to shift ones. This finding is in contrast with studies reporting that SW—particularly night shifts—can impair glycemic control, alter cortisol secretion, and disrupt lipid metabolism, thereby contributing to the development of MetS [37,38]. This finding may reflect the effect of pharmacological treatments capable of controlling various conditions as also demonstrated by the significantly greater percentage of subjects treated for diabetes in the night shift work group. To account for this potential confounding factor, an analysis of the individual MetS criteria was conducted, incorporating not only the biological measurements but also the use of relevant pharmacological therapies. Although individual parameters did not differ significantly between groups, the prevalence of MetS was notably higher among shift workers. This phenomenon may occur when the diagnostic criteria are interrelated, such as in the case of central obesity and hypertension. Furthermore, this finding suggests that assessing MetS as a composite dichotomous variable (presence/absence) may provide greater statistical power than analyzing each criterion independently. In this regard, comorbidity—defined as the simultaneous presence of multiple risk factors within the same individual—can differ between groups even when the individual components do not. It is essential to recognize that the diagnostic criteria for MetS encompass not only hematological parameters but also the presence of pharmacological treatment for conditions such as hypercholesterolemia, diabetes, and hypertension. This broader diagnostic framework may explain the absence of significant differences in biological markers, which are often well-managed through therapeutic interventions despite a confirmed MetS diagnosis. Consequently, accurate documentation of ongoing treatments is crucial for a reliable diagnosis of MetS and for the interpretation of the study results. Relying solely on hematological data may lead to misclassification and obscure potential associations between occupational risk factors and the syndrome.

In the SW group, a higher proportion of individuals reported poor sleep quality, suggesting that sleep disturbances may play a significant role in the development of MetS. However, when comparing the prevalence of MetS between night shift workers and those working shifts exclusively during the day, no significant differences were observed. This finding appears to contradict the widely accepted hypothesis that circadian disruption and misalignment of endogenous rhythms induced by NW are associated with increased MetS risk [39]. Nonetheless, the possibility that the "healthy worker survival effect" influenced these results cannot be excluded. Individuals experiencing poor sleep quality due to circadian misalignment caused by NW may have opted to transition to a different work schedule that avoids night shifts, while still remaining within the SW category. This self-selection bias could attenuate the observed differences in MetS prevalence between night and day shift workers.

In the SW group, a greater percentage of evening chronotypes was present, supporting the hypothesis that working at scheduled times (e.g., in the morning shift) not in agreement with one's chronotype could be responsible for possible adverse health outcomes. Concerning chrononutrition, the lack of differences between workers engaged or not in SW supports the notion that, within this cohort, the timing of food intake did not exert a significant impact on the development of MetS. While different studies have highlighted the role of meal timing as a critical factor in metabolic regulation, the absence of significant differences in this context may reflect compensatory behavioral adaptations or interindividual variability in chronotype and dietary habits, including the adherence to the Mediterranean diet [40–42]. In this scenario, despite the increased incidence of MetS among shift workers, this group exhibited significantly greater adherence to the Mediterranean diet, a dietary pattern associated with improved metabolic and cardiovascular health outcomes, compared to the fixed daily shift workers. Such dietary behavior observed among shift workers appears to coincide with a higher prevalence of treatment for hypercholesterolemia, diabetes, and hypertension, potentially reflecting food choices driven by an increased awareness of metabolic and cardiovascular health. However, due to the cross-sectional design of the study, definitive conclusions cannot be drawn regarding causality. The interplay between lifestyle habits, chrononutrition patterns, and therapeutic management warrants further investigation through longitudinal approaches. Overall, these results highlight the importance of considering additional factors in personal life styles as well as in the occupational environment and work organization that might play a role in MetS development. The group of workers engaged in SW, in fact, comprised a greater percentage of males in a lower age range, along with a greater prevalence of smokers and alcohol consumers. A recent review, in fact, suggested a dose-response relationship between alcohol consumption and MetS occurrence [43]. In this regard, we cannot exclude that such differences in voluptuary habits could have played a role in the MetS development, potentially counteracting the protective effects of younger age and adherence to the Mediterranean diet. Moreover, the cross-sectional nature of our study does not allow us to exclude that the adherence to the Mediterranean diet could be an eating choice motivated by the workers' awareness of the metabolic or cardiovascular alterations they suffered.

Concerning the occupational environments and organization of work, it is well known that healthcare workers face a variety of occupational risk factors, including biological, chemical, physical organizational and psychosocial risk factors that may impact on their health status. Work-related stress experienced by healthcare workers, for instance, together with SW, may be responsible for the determined increase in systolic blood pressure levels. This result is in line with the growing body of research reporting the adverse effects of psychosocial work factors on blood pressure elevation and metabolic changes [44,45]. This underlines the relevance of the work environment and job organizational aspects as determinants of workers' health according to a holistic and comprehensive approach to worker safety, health, and well-being at work that arises from the interaction of occupational and extra-occupational risk factors' interaction. Consequently, the interplay of various occupational risk factors on the MetS components should be deeply investigated to define current efforts at primary prevention in workplaces that may favorably impact the cardiovascular and metabolic health of exposed workers.

Although preliminary, our findings reveal intriguing aspects that require deeper explorations in future workplace health promotion studies. Unfortunately, the small sample size and the cross-sectional nature of the study cannot provide information to support the identification of causal relationships between SW-related behaviors and MetS. Therefore, longitudinal analyses involving larger and more homogeneous samples (e.g., in terms of gender, job tasks, and level of education) are crucial to understand the causal relationship between occupational risk factors and metabolic disorders. Comparing different occupational sectors, such as healthcare and the administrative or educational roles, is valuable for highlighting critical issues, but may not lead to definitive conclusions. Indeed, investigations focused on specific occupational settings are necessary, paying close attention to the various job tasks and related risks. Furthermore, surveys assessing life-style habits, including eating and sleeping behaviors, should be as comprehensive as possible, since metabolic outcomes can result from the interaction of multiple factors.

Shift work has been identified as a significant risk factor for MetS. However, different parameters, both occupational and nonoccupational, can play a contributing role in MetS development. In this context, MetS should be investigated considering the multiple interactions between different individual, occupational, and work-related risk factors in order to define and develop updated and effective strategies for risk prevention and health promotion policies and strategies, in line with the *Total Worker Health*® model.

CRediT authorship contribution statement

Veruscka Leso: Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Pasquale Dolce:** Writing – original draft, Methodology, Formal analysis. **Marco Greco:** Writing – original draft, Data curation. **Andrea Durante:** Writing – original draft, Data curation. **Luisa Di Lauro:** Writing – original draft, Data curation. **Paola Pedata:** Writing – review & editing, Writing – original draft, Data curation. **Luca Fontana:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization. **Ivo Iavicoli:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization. The study was conducted under the supervision of Prof. Ivo Iavicoli, who served as Principal Investigator during his tenure at the University of Naples Federico II, Italy. He continued to contribute to the project through supervision as well as writing – review and editing activities under his current affiliation with the Catholic University of Sacred Heart of Rome, Italy.

Ethics statement

The Ethical Committee Campania 3 of the Campania region approved the study protocol with the protocol number 0023986/2023.

Data availability statement

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Statement on the Use of AI Tools

No artificial intelligence tools were utilized in the preparation of this manuscript.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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