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ABSTRACT

Background

[GQ2][GQ4][GQ5]In recent years, numerous large-scale manufacturing enterprises in Northeastern China have shifted from the conventional 8-h shift model to an extended 12-h shift schedule. While this change aims to improve production efficiency, prolonged working hours may lead to increased levels of occupational fatigue and pose significant risks to worker health and safety.

Objective

This study aimed to assess the physiological and subjective fatigue responses among forklift operators working 12-h shifts, with particular emphasis on differences between day and night shifts, as well as gender-based variations in fatigue susceptibility.

Methods

Ten forklift truck operators were recruited from a major tire manufacturing enterprise that had implemented a 12-h shift system. Subjective fatigue was measured through self-reported assessments, while objective indicators were captured using surface electromyography (sEMG) and electroencephalography (EEG). Data were collected at multiple time points across both day and night shifts to monitor changes in fatigue levels.

Results

Findings revealed that most operators experienced significant fatigue after 8 h of work, even when shifts extended to 12 h. Fatigue and drowsiness symptoms were more pronounced among night shift workers, with critical fatigue peaks observed between 14:30–16:00 and 2:30–4:00. Gender-based analysis showed negligible differences in daytime fatigue; however, female operators exhibited greater fatigue and drowsiness during night shifts compared to male counterparts.

Conclusions

Extended 12-h shifts are associated with considerable fatigue, especially during night work, posing potential safety concerns in industrial environments. The identification of specific fatigue-prone periods and gender-related differences underscores the need for tailored fatigue risk management strategies and evidence-based shift scheduling policies to safeguard worker well-being and operational safety.

KEYWORDS

- occupational fatigue
- work-related fatigue
- extended work hours
- EEG
- EMG
- industrial safety

Instruction

The 12-h shift system has gained increasing popularity in several European countries, particularly in regions with well-developed manufacturing industries.[1] Employees often prefer extended shifts over the conventional 8-h shift system,[2] as they believe that longer shifts provide additional rest days for leisure and personal activities, mitigate commuting-related challenges and costs, and allow for increased sleep duration to recover from night work.[3,4,5]

However, the adoption of 12-h shifts may also pose significant challenges. First, prolonged continuous work has been shown to exacerbate fatigue,[5] increase the likelihood of errors,[6] and compromise occupational safety.[1,7] A review of seven studies found that in five of them, employees working 12-h shifts reported significantly higher levels of fatigue. Second, fatigue associated with extended shifts has been implicated in several major industrial accidents, including the Chernobyl disaster, the Three Mile Island incident, and the

Exxon Valdez oil spill.[8] A systematic review further concluded that the risk of occupational injury at the end of a 12-h shift is twice as high as that at the end of an 8-h shift.[9] Additionally, prolonged working hours can adversely affect family life and childcare responsibilities, particularly for female employees, leading to increased work-family conflicts.[10]

Similar to European countries, Northeastern China traditionally employed the 8-h work shift system.[11,12] However, with the development of modern industrial facilities and environmental regulations, many large factories were relocated from urban centers to more remote areas.[13] This geographical shift resulted in longer commuting times for workers. In response to concerns over commuting costs and employee dissatisfaction with extended travel durations, some large joint ventures introduced 12-h shifts as an alternative to the traditional 8-h system. Nevertheless, the suitability of this shift model for the physiological and cultural characteristics of Chinese workers has not been thoroughly examined. Moreover, the potential impact of extended working hours on occupational fatigue and overall worker health remains largely unexplored.

Previous cases suggest that implementing a 12-h shift system may not always be sustainable. For instance, a large multinational electronics manufacturer in China abandoned the 12-h shift model after only two months due to widespread worker complaints regarding fatigue and difficulties in maintaining concentration.[4] To further investigate the feasibility of 12-h shifts, this study focused on another large-scale company in China that had implemented this system. The objective was to evaluate worker fatigue levels to better inform shift system design and optimize workforce scheduling in a 12-h shift environment.

Work-related fatigue is typically assessed through a combination of physiological and psychological indicators. Most studies on shift worker fatigue have relied on questionnaire-based evaluations.[2,4,14] However, subjective assessments alone may not fully capture workers' actual physiological states. Objective quantitative measurements are crucial to minimize bias and enhance the accuracy of fatigue assessment.

Appropriate fatigue evaluation methods should align with the specific nature of the job and the type of fatigue being measured. Surface electromyography (sEMG) is a widely used technique for assessing physical fatigue and has a longstanding history as a diagnostic tool for lower back pain. Since the 1950s, researchers have employed sEMG to analyze lumbar muscle activity under various postural and movement conditions.[15,16,17,18] Changes in sEMG signals from the erector spinae muscles have been identified as reliable indicators of lower back pain.[19,20,21] As muscle fatigue progresses, additional motor units are recruited, leading to an increase in the discharge frequency of motor units and a subsequent rise in the mean power frequency (MPF) of EMG signals. However, as fatigue intensifies, the conduction velocity of muscle fibers decreases, resulting in a decline in MPF.

Mental fatigue, on the other hand, is typically evaluated through cognitive, sensory, and neurological performance measures. Among various assessment techniques, electroencephalography (EEG) is one of the most widely utilized objective methods.[22,23,24] EEG signals are categorized into five frequency bands: delta (δ), theta (θ), alpha (α), beta (β), and gamma (γ). Studies have shown that as mental fatigue increases, delta wave activity initially rises and then declines in the frontal brain region, while theta wave activity gradually increases in the frontal, temporal, and occipital areas. Meanwhile, alpha wave activity progressively decreases in the occipital region.[25,26,27] Additionally, during the transition to sleep, delta wave power increases, and the center of alpha wave distribution shifts from the occipital to the frontal region, leading to a reduction in alpha wave power in the occipital area.[28]

Furthermore, research has indicated that fatigue manifests differently between men and women.[29,30] To account for potential gender-based differences in fatigue response, this study also included a comparative analysis of fatigue indicators between male and female workers.

Methods

Subjects

The primary responsibility of the forklift operators was to transport materials according to production orders, a task consistent with their routine job duties. Their working environment extended from the workshop to the warehouse.

This study employed a cross-sectional observational design to assess fatigue among forklift operators working extended shifts. A purposive sampling method was used to recruit participants who met specific inclusion criteria. A total of ten forklift operators (five male and five female) were selected from a large tire manufacturing enterprise located in Northeastern China. All participants were full-time employees working 12-h rotating shifts and had a minimum of five years of experience in their current roles. The mean age of the participants was 38 years (standard deviation [SD] = 6; range: 30–50 years), with an average job tenure of 11 years.The study was conducted in May 2024.

Participants were included in the study if they were in good physical health and had no history of neurological, musculoskeletal, or sleep-related disorders. Individuals who reported regular smoking or alcohol consumption were excluded to avoid confounding variables related to fatigue. Prior to participation, all individuals provided informed consent, and the study protocol was approved by the institutional ethics committee.

The forklift operators' primary responsibilities included transporting materials according to production orders, which involved navigating both the manufacturing workshop and warehouse environments. These work tasks were consistent with their daily job activities, ensuring ecological validity in the study setting.

No control group was included in this observational study, as the primary aim was to document fatigue patterns under natural working conditions rather than to evaluate the effects of an intervention. However, within-subject comparisons were conducted across different times of day (e.g., during day shifts vs. night shifts) and between gender groups to identify patterns and differences in fatigue responses.

Tools

Electromyography (EMG) data were collected from the right and left lumbar erector spinae muscles using the BIOPAC MP150 system (BIOPAC Systems Inc.). The skin over the muscle belly was prepared following the method described by Cholewicki et al.[31] Subsequently, pairs of electrodes were placed longitudinally along the midsection of the muscles, maintaining a center-to-center distance of 20 mm.

Electroencephalography (EEG) signals were recorded using the Emotiv Epoc + system (Emotiv Systems Inc.), as illustrated in Figure 1. The Emotiv Epoc + is a portable EEG device capable of monitoring cortical electrical activity without requiring invasive procedures.

Figure 1.
Emotiv Epoc + system.

Subjective fatigue was assessed using Borg's Rating of Perceived Exertion (RPE) scale,[32] a widely used and time-efficient method. Its simplicity ensures that participants can complete the assessment quickly, minimizing any potential influence on their physical or mental state.

Procedure

During the experiment, participants completed a full shift rotation, which included a 12-h day shift (7:00–19:00) followed by a 12-h night shift (19:00–7:00), with a 24-h rest period in between. Throughout their shifts, fatigue-related data—including subjective fatigue ratings, as well as EMG and EEG recordings—were systematically collected. Fatigue fluctuations across all working hours were comprehensively monitored and analyzed.

Prior to the study, all participants underwent an interview, and written informed consent was obtained. To ensure consistency in baseline conditions, they were instructed to maintain their regular work and sleep schedules, refrain from strenuous exercise, and ensure they were in good physical condition before the test.

Fatigue data, including subjective ratings and physiological measurements (EMG and EEG), were recorded every two hours throughout the work shifts. Fatigue trends over the entire shift duration were visualized and analyzed. A designated room within the forklift workshop was converted into a temporary laboratory for data collection and monitoring.

Data analysis

EMG data were analyzed using Acknowledge 4.0 software, while EEG data were processed with Emotiv Xavier Test Bench 3.1.19. Additional calculations and statistical analyses were conducted using MATLAB R2011b (The MathWorks Inc., Natick, MA, USA). Group differences were assessed using paired or independent-samples t-tests, depending on the data structure. A p-value of less than 0.05 was considered statistically significant.

Results

Subjective feelings of fatigue

Measurements were conducted at intervals of 1.5–2 h of effective working time, excluding designated lunch and rest breaks. The time points were labeled T1 through T7, with T1 representing the start of the work shift, T5 corresponding to 8 h of work, and T7 marking 12 h of work. Fatigue scores for both day and night shift drivers are presented in Table 1, and Figure 2 illustrates the corresponding trends in fatigue scores.

Figure 2.

Change in subjective fatigue.

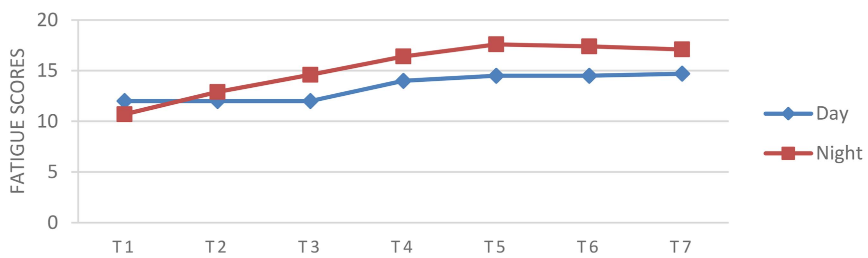

Table 1.

Subjective fatigue scores of drivers.

	Day		Night	
	Mean	**SD**	**Mean**	**SD**
T1	12	1.91	10.7	2.68
T2	12	2.23	12.9	1.96
T3	12	2.48	14.6	3.48
T4	14	1.56	16.4	2.66
T5	14.5	2.67	17.6	2.38
T6	14.5	2.94	17.4	1.47
T7	14.7	1.88	17.1	2.95

As shown in Table 1, subjective fatigue in the day shift remained stable until T3 (12:00). In the afternoon, drivers began to experience increased fatigue, with fatigue scores peaking at T5, after 8 h of work. The fatigue score then rose slightly again at T7, after 12 h of work.

In contrast, during the night shift, the subjective fatigue score steadily increased until T5, before slightly declining. Initially, drivers on the night shift reported better fatigue levels than those on the day shift. However, as the work progressed, night shift drivers experienced greater fatigue at the same time points compared to their day shift counterparts.

Physical fatigue in day shift drivers remained unchanged until T3. In the afternoon, fatigue levels increased. On the night shift, fatigue scores continued to rise until T6, before gradually declining thereafter.

Male vs female

Differences in subjective fatigue between men and women are illustrated in Figures 3, with the corresponding data provided in Table 2. Overall, the patterns of fatigue change were similar for both men and women; however, women's subjective fatigue scores were slightly higher than those of men.

Figure 3.

Comparison of subjective scores between men and women.

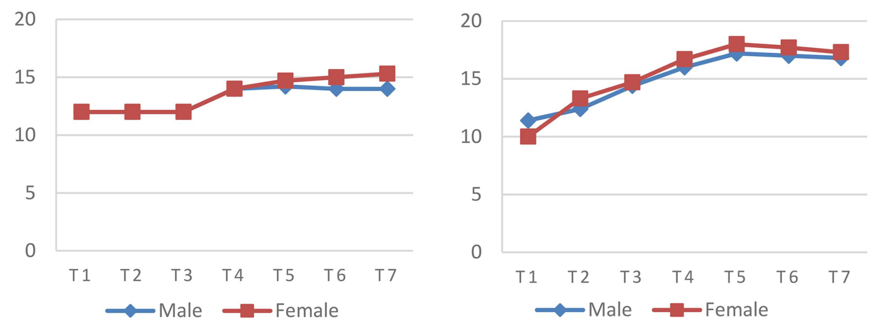

Table 2.

Subjective fatigue scores of male and female drivers.

	Male				Female			
	Day		Night		Day		Night	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
T1	12	1.67	11.4	2.33	12	1.33	10	1.91
T2	12	2.47	12.4	1.67	12	2.54	13.3	2.67
T3	12	2.58	14.4	2.42	12	1.65	14.7	2.33
T4	14	3.03	16	2.67	14	2.21	16.7	2.58
T5	14.2	1.67	17.2	3.15	14.7	2.37	18	3.67
T6	14	2.84	17	2.35	15	3.13	17.7	3.46
T7	14	3.16	16.8	2.67	15.3	2.51	17.3	2.86

Mental fatigue

Based on the relationship between the relative power of EEG signals and mental fatigue, the band waves from the AF3 channel and O1 channel were selected as indicators of mental fatigue. The average relative powers are presented in Table 3, with corresponding change curves shown in Figure 4.

Figure 4.

Changing trend of relative powers of δ, θ, α waves. (a) Changing Trend of Relative Powers of δ Waves, (b) Changing Trend of Relative Powers of θ Waves and (c) Changing Trend of Relative Powers of α Waves.

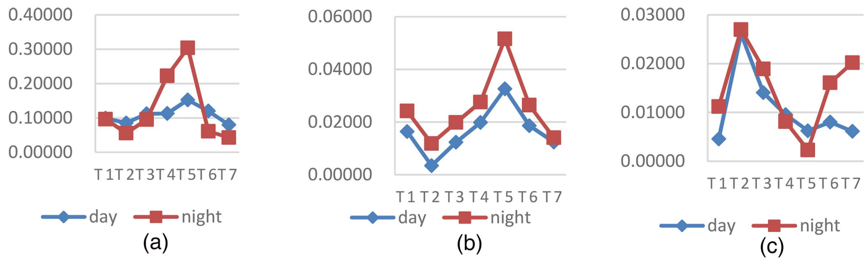

Table 3.

Relative powers of θ, α, and δ.

	δ				θ				α			
	Day		**Night**		**Day**		**Night**		**Day**		**Night**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
T1	0.0992	0.0462	0.0964	0.0205	0.0164	0.0029	0.0242	0.0089	0.0046	0.0011	0.0112	0.0045
T2	0.0855	0.0215	0.0557	0.0157	0.0034	0.0005	0.0118	0.0054	0.0261	0.0092	0.0269	0.0084
T3	0.1122	0.0497	0.0952	0.0284	0.0123	0.0033	0.0198	0.0038	0.0141	0.0051	0.0189	0.0068
T4	0.1129	0.0386	0.2226	0.0891	0.0198	0.0042	0.0276	0.0077	0.0096	0.0024	0.0081	0.0039
T5	0.1526	0.0605	0.3039	0.1323	0.0326	0.0125	0.0516	0.0231	0.0066	0.0018	0.0023	0.0009
T6	0.1202	0.0315	0.0612	0.0149	0.0186	0.0041	0.0264	0.0097	0.0082	0.0014	0.0161	0.0065
T7	0.0801	0.0214	0.0429	0.0138	0.0124	0.0026	0.0141	0.0045	0.0061	0.0019	0.0202	0.0086

As shown in Figure 4(a), the relative powers of δ waves during the drivers' working hours can be divided into three distinct stages. The first stage (T1–T2) showed a slight decrease in δ wave power. The second stage (T2–T5) exhibited an upward trend, suggesting that sustained concentration on work may have led to the accumulation of mental fatigue after 8 h. During this period, drivers transitioned from alertness to fatigue, with the highest fatigue levels occurring at T5. The third stage (T5–T7) showed a gradual decline in mental fatigue.

Comparing the EEG powers between day and night shift workers, it was observed that drivers felt more fatigued during the night shift, particularly after T3 in the second stage.

The relative powers of θ waves from the frontal and temporal areas increased with the progression of fatigue. Figure 4(b) shows that the trend in θ wave power closely mirrored that of δ waves. This finding aligns with the three stages of mental fatigue described above. The power of θ waves peaked at T5, indicating the point at which drivers felt most fatigued after 8 h of work.

The power of α waves from the occipital area decreased as mental fatigue increased, potentially signaling the onset of drowsiness. The power of α waves gradually diminished as the drivers transitioned from alertness to drowsiness. As shown in Figure 4(c), the changes in α wave power followed a similar three-stage pattern to that of δ and θ waves, with T2 and T5 serving as inflection points. In the first stage, α wave power increased; in the second stage, it rapidly declined until T5; and in the third stage, the power increased sharply at night, with only a slight increase during the day. These results suggest that after working for 8 h, drivers experienced both fatigue and pronounced drowsiness.

Male vs female

EEG signals are commonly used to assess differences in mental fatigue between men and women due to their sensitivity to individual characteristics. In this study, the powers of δ, θ , and α waves for both men and women are presented separately in Table 4, with the corresponding trends shown in Figure 5.

Figure 5.

Comparison of powers of δ, θ, α waves between men and women. (a) Comparison of Powers of δ Wave between Men and Women (Day Shift), (b) Comparison of Powers of δ Waves between Men and Women (Night Shift), (c) Comparison of Powers of θ Waves between Men and Women (Day Shift), (d) Comparison of Powers θ Waves between Men and Women (Night Shift), (e) Comparison of Powers of α Waves between Men and Women (Day Shift) and (f) Comparison of Powers of α Waves between Men and Women (Night Shift).

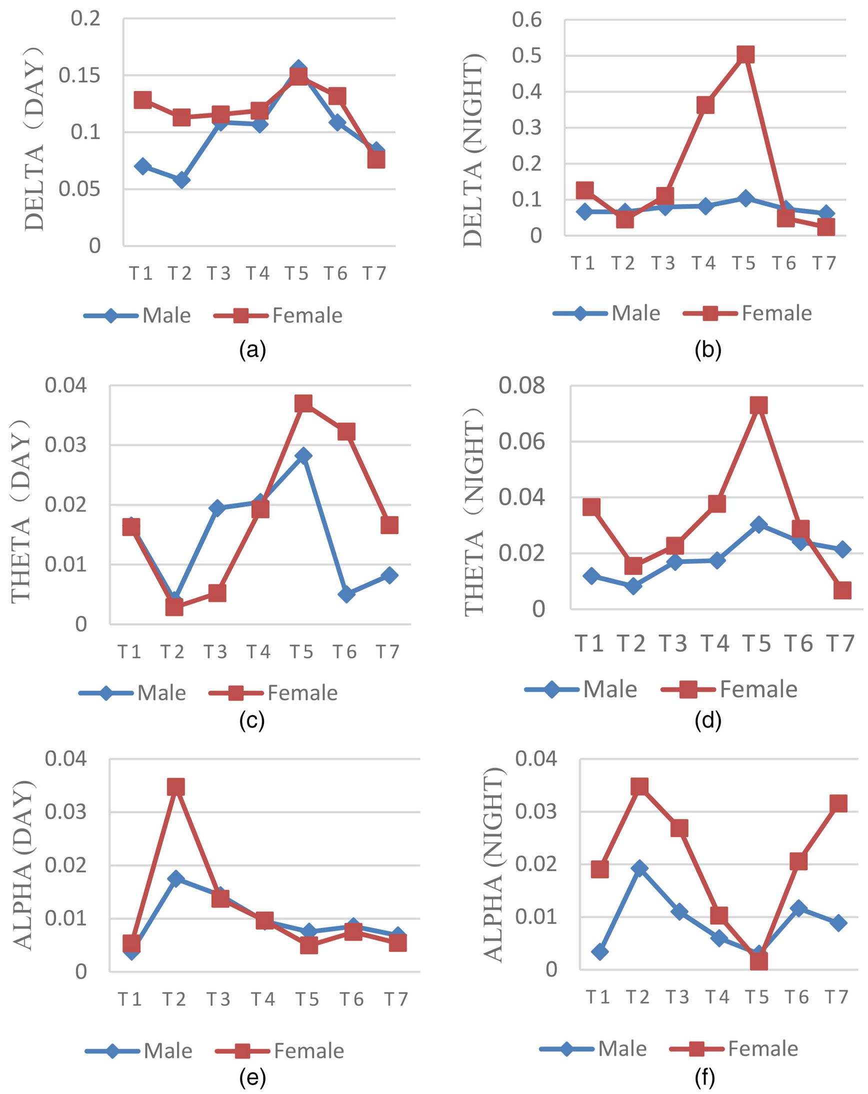

Table 4.

Powers of δ, θ, and α waves in male and female drivers.

		δ				θ				α			
		Male		**Female**		**Male**		**Female**		**Male**		**Female**	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
	T1	0.0701	0.0254	0.1283	0.0544	0.0165	0.0061	0.0163	0.0076	0.0038	0.0011	0.0053	0.0018
	T2	0.0581	0.0156	0.1130	0.0369	0.0040	0.0016	0.0028	0.0009	0.0175	0.0089	0.0347	0.0157
	T3	0.1087	0.0388	0.1157	0.0287	0.0194	0.0087	0.0052	0.0042	0.0144	0.0054	0.0137	0.0069

Day		δ				θ				α			
		Male		**Female**		**Male**		**Female**		**Male**		**Female**	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
	T4	0.1070	0.0425	0.1190	0.0384	0.0205	0.0064	0.0192	0.0082	0.0095	0.0028	0.0096	0.0027
	T5	0.1563	0.0846	0.1489	0.0594	0.0282	0.0083	0.0369	0.0164	0.0075	0.0033	0.0050	0.0013
	T6	0.1086	0.0468	0.1318	0.0514	0.0050	0.0014	0.0322	0.0159	0.0086	0.0021	0.0075	0.0025
	T7	0.0842	0.0351	0.0759	0.0159	0.0082	0.0038	0.0166	0.0088	0.0068	0.0019	0.0054	0.0016
	T1	0.0667	0.0249	0.1261	0.0544	0.0119	0.0055	0.0365	0.0166	0.0034	0.0013	0.0190	0.0081
	T2	0.0664	0.0305	0.0451	0.0159	0.0082	0.0023	0.0154	0.0077	0.0192	0.0094	0.0347	0.0125
	T3	0.0800	0.0311	0.1104	0.0439	0.0170	0.0089	0.0227	0.0167	0.0110	0.0058	0.0269	0.0155
Night	T4	0.0822	0.0397	0.3630	0.1529	0.0175	0.0077	0.0377	0.0198	0.0060	0.0019	0.0103	0.0066
	T5	0.1042	0.0453	0.5036	0.2967	0.0303	0.0148	0.0729	0.0325	0.0030	0.0015	0.0016	0.0009
	T6	0.0743	0.0328	0.0482	0.0255	0.0241	0.0126	0.0287	0.0142	0.0116	0.0048	0.0206	0.0108
	T7	0.0619	0.0217	0.0241	0.0133	0.0214	0.0114	0.0067	0.0022	0.0089	0.0029	0.0315	0.0127

As shown in Figure 5(a), the changes in fatigue for both male and female drivers generally followed the same pattern, which can be divided into three stages. The first stage (T1–T2) marked a gradual increase in alertness. In the second stage (T2–T5), mental fatigue began to increase, reaching its peak at T5. The third stage (T5–T7) showed a gradual easing of mental fatigue. Notably, female drivers experienced more severe fatigue than male drivers during the first stage of the day shift.

Figure 5(b) illustrates slight differences in the changes in θ waves compared to those in δ waves during the first stage. However, the results still show that female drivers experienced greater fatigue than male drivers.

As shown in Figure 5(c), the power of α waves in female drivers exhibited a more pronounced decrease, indicating that female drivers generally felt more drowsy than their male counterparts.

Figures 5(d) and 5(e) show that the powers of δ and θ waves underwent more significant changes in night shift drivers. One female driver experienced frustration with work-related issues during the measurement period, and these negative emotions contributed to an increase in the powers of δ and θ waves,[26,31] resulting in an abnormal point in the curve at that specific measurement time.

Finally, as shown in Figure 5(f), the power of α waves in female drivers decreased more significantly, indicating that female drivers were generally more drowsy than male drivers during the night shift, consistent with the findings during the day shift.

Physical fatigue

The mean power frequencies (MPFs) of the EMG data are presented in Table 5, with the corresponding trends illustrated in Figure 6.

Figure 6.

Comparison of MPFs between day and night shifts.

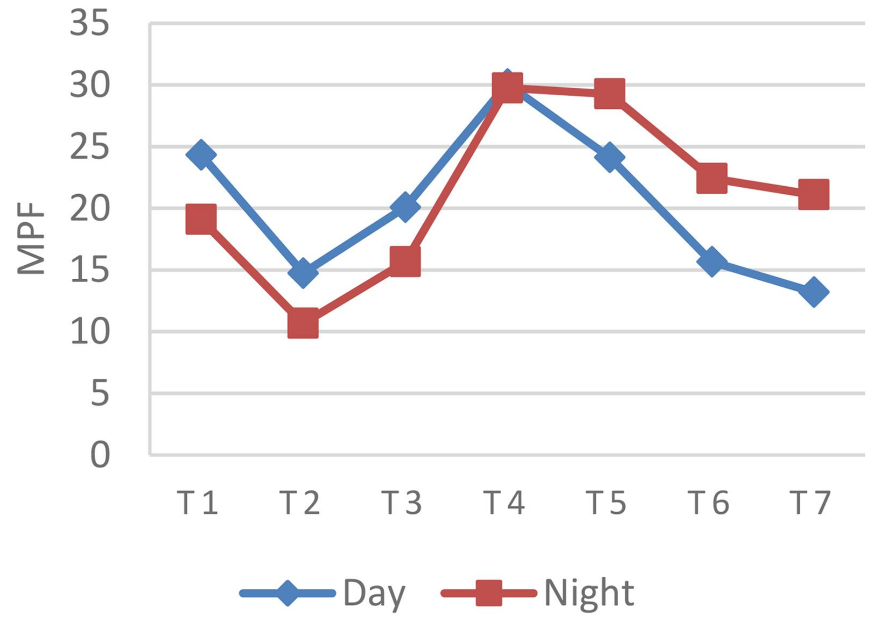

Table 5.
MPFs of the EMG data during day and night shifts.

	Day		Night	
	Mean	**SD**	**Mean**	**SD**
T1	24.33	9.24	19.10	5.46
T2	14.75	3.65	10.66	2.58
T3	20.10	5.98	15.65	6.44
T4	30.08	7.55	29.76	11.23
T5	24.14	9.46	29.27	8.57
T6	15.65	3.69	22.42	9.63
T7	13.20	5.22	21.10	10.14

The changes in MPFs can be divided into three stages. The first stage (T1–T2) is characterized by a significant decrease in MPFs. The second stage (T2–T5) shows a gradual increase in MPFs, with a slowing growth rate. The third stage (T5–T7) marks another decline in MPFs. Overall, MPFs are lower at the end of the work shift compared to the beginning.

When comparing the MPFs between day and night shifts, the trends are largely similar. However, MPFs were slightly lower in night shift drivers than in day shift drivers during the early part of the work period (T1 to T3). From T3 to T5, the MPFs in night shift drivers increased rapidly, surpassing those of day shift drivers, and continued to rise until the end of the shift.

For day shift drivers, MPFs began to decline at T5, reflecting increasing fatigue that became harder to alleviate after 8 h of work. In contrast, the MPFs in night shift drivers began to decrease at T4, and fatigue in night shift drivers started to increase after 6 h of work.

Male vs female

The MPFs for different sexes are presented separately in Table 6, with the corresponding trends shown in Figures 7.

Figure 7.
Comparison of MPFs between male and female drivers.

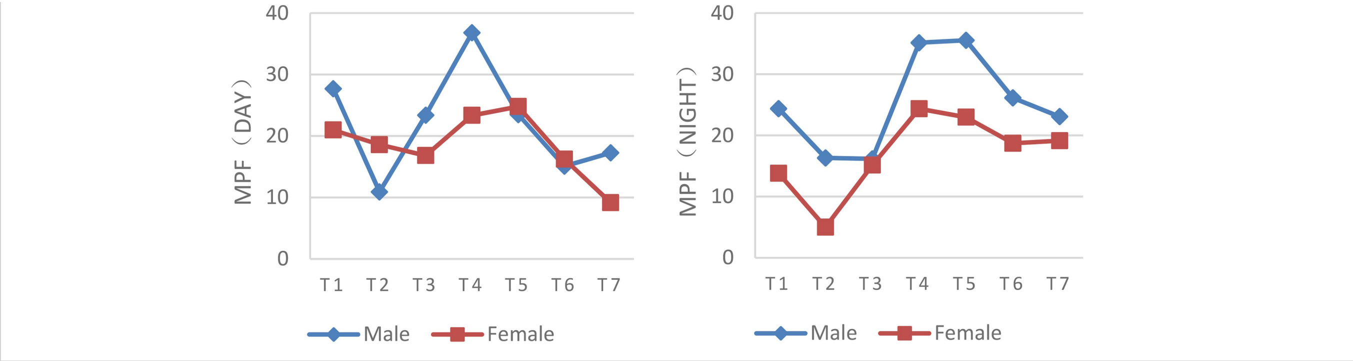

Table 6. Comparison of MPFs between male and female drivers.								
	Day				**Night**			
	Male		**Female**		**Male**		**Female**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
T1	27.70	11.22	20.97	9.46	24.39	8.46	13.81	4.57
T2	10.90	4.32	18.59	4.57	16.32	4.87	5.01	1.54
T3	23.38	10.57	16.81	6.43	16.17	6.43	15.14	6.66
T4	36.80	12.32	23.36	9.89	35.15	12.58	24.36	9.45
T5	23.49	9.76	24.79	8.65	35.55	11.04	22.98	7.45
T6	15.08	5.58	16.23	2.64	26.14	9.76	18.70	5.42
T7	17.26	6.21	9.15	2.97	23.07	10.25	19.13	7.98

As shown in the figures, the changes in MPFs for both men and women generally follow the same pattern, with a “decline-rise-decline” trajectory. However, the inflection points occur at different times. For day shift drivers, the MPF of male drivers decreased at T4, while the MPF of female drivers decreased at T5, indicating that male drivers experience fatigue accumulation earlier. In night shift drivers, the MPF of male drivers decreased at T5, whereas that of female drivers decreased at T4, suggesting that female drivers begin to accumulate fatigue earlier during the night shift.

Discussion

The results indicate that changes in different indicators follow certain patterns. Most drivers reported feeling highly fatigued and drowsy after completing 8 h of work, suggesting that they likely need a break at this point. Night shift forklift drivers were more prone to fatigue, which aligns with the body's natural biorhythms and is consistent with the findings of Akerstedt et al.[33] The measurement results also reveal that drivers experience both physical and mental fatigue by the end of their shifts and are unable to recover quickly from this state. Fatigue appears to begin accumulating at this time, suggesting that extended workdays may lead to significant problems.

Subjective fatigue

The results from the subjective fatigue questionnaires indicate that the highest fatigue scores occurred at T5. Between 8 and 12 h of work, drivers reported increasing fatigue, which could negatively affect their performance and health.

Night shift drivers generally started their shifts in better condition compared to day shift drivers. The investigation revealed that many drivers live far from the factory and have long commutes. Day shift drivers often need to wake up early, and upon arrival at the workplace, most feel drowsy. In contrast, night shift drivers typically take an afternoon nap before work, which helps them feel more refreshed at the start of their shifts. However, despite this initial advantage, night shift drivers still experienced more fatigue after midnight, in line with their biorhythms.[33]

Subjective fatigue assessments revealed that soreness was primarily concentrated in the neck, back, and waist muscles. Some drivers also reported discomfort in their knees, wrists, and shoulders, likely caused by poor working posture.[34] These areas of the body are at risk for developing occupational musculoskeletal disorders. Additionally, as shifts progressed, drivers began to exhibit symptoms of ocular and mental fatigue, such as dry eyes, drowsiness, and slower reaction times, particularly between T4 and T5.

Mental fatigue

As shown in Figure 4, the powers of the δ and θ waves peak at T5 for both day and night shifts. The increase in power is 2.5 to 3 times greater in night shift drivers compared to day shift drivers. The δ wave power rises rapidly at T4, while the power of the α wave reaches its lowest point at T5. Thus, T5, which occurs after 8 h of work, is the most critical time point for the onset of fatigue in drivers. Furthermore, mental fatigue appears to change more significantly at night, which aligns with drivers' reports of "more drowsiness and fatigue during the night shift." The EEG results indicate that night shift drivers begin with a better initial state compared to day shift drivers, consistent with subjective assessments. Over the course of their shifts, night shift drivers gradually adapt to the working conditions, become more efficient, and rarely make errors. However, they report feeling extremely drowsy by T3, while day shift drivers experience less drowsiness, likely due to differences in their biorhythms. The study also found that even if night shift drivers get sufficient rest before their shifts, they still experience drowsiness and fatigue.

Accident records from the workshop office show that most forklift truck accidents occurred between 2:30 and 4:00, coinciding with the time when significant changes in the EEG data were observed. The drivers' drowsiness and fatigue are likely the primary contributors to these accidents. The study also found that the power of α waves decreased as mental fatigue appeared to ease at the end of both day and night shifts. This relief may stem from the drivers' excitement at completing their tasks and the anticipation of finishing their work. However, this emotional boost did not reduce mental fatigue in a meaningful way; it only provided temporary relief. At the end of their shifts, night shift drivers experienced more severe mental fatigue than day shift drivers, likely because they required more sleep to recover. Additionally, female drivers were found to be more fatigued than their male counterparts, both during day and night shifts.

Physical fatigue

The change in MPF (mean power frequency) reflects the conduction capacity of muscle fibers and serves as an indicator of muscle fatigue. At the start of the shift, MPF decreases from a high value at T1, suggesting that the drivers' muscles are in a "pseudo-fatigue" state. The investigation revealed that the parking lot is located far from the workshop, requiring the drivers to walk to their workplace. This long walk may increase muscle load before the shift, which could lead to an elevated discharge frequency of motor units, possibly explaining the high MPF at T1.

During the shift, the drivers remain seated in the cab for its entirety. The MPF of EMG decreases rapidly after two hours of driving, likely due to the low muscle strength and fewer motor units engaged by sitting. Additionally, the energy consumption from prolonged work without food intake could reduce the discharge capacity of motor units and the conduction capacity of muscle fibers, further contributing to the decrease in MPF.

As the shift progresses, the drivers' muscle fatigue gradually increases, and motor units continue to discharge, causing MPF to rise. However, once motor units can no longer maintain the required force level, muscle fatigue sets in. At this point, MPF increases more slowly or experiences small fluctuations. The relaxation of muscle fibers signifies muscle fatigue and a reduction in muscle force. With the task continuing, the drivers cannot rapidly recover from muscle fatigue. Muscle strength and conduction velocity of muscle fibers decrease, causing MPF to decline. The drivers' overall fatigue seems to increase, with the period between T4-T5 being particularly important for muscle fatigue recovery.

Further analysis shows that the MPF of night shift drivers increases rapidly during T3-T4 (0:00–2:30). This could be due to the drivers frequently adjusting their body posture to stay awake, which likely increases the discharge frequency of motor units. Interestingly, this phenomenon did not appear in day shift drivers. Night shift drivers experienced fatigue earlier and for a longer duration compared to day shift drivers. In terms of gender, the MPF for male drivers was higher than that for female drivers, which may be attributed to differences in muscle strength between men and women.[35]

The effect of night work

Night work significantly impacted the psychology and work capacity of the drivers. In this study, EEG analysis revealed that night shift drivers experienced more mental fatigue than their day shift counterparts. This conclusion was also supported by EMG data and questionnaire responses. Fatigue was found to prolong response times to composite signal stimuli and reduce driver alertness. During their shifts, the drivers were tasked with transporting parts to designated locations and adjusting their routes as needed according to orders. The reduced vigilance associated with fatigue could negatively impact the completion of driving tasks.

Additionally, extended periods of night shift work, coupled with sleep deprivation, could lead to further psychological issues. If this state persists, it may become increasingly difficult for drivers to maintain vigilance during night shifts. Even the following day shift could be affected by the prior night's fatigue. Although some research suggests that individuals prefer 12-h work shifts, our study on fatigue indicators indicates that 8-h shifts are more beneficial for health than 12-h shifts. If a shift starts too early, drivers are likely to experience poor physical and mental states at the outset, but later work hours may help alleviate physical and mental fatigue. These findings align closely with the research of Tucker et al.[3]

The study also found that men are generally better able to tolerate night shift work than women. Women often get less sleep than men due to family responsibilities, and they tend to be more affected by environmental factors while sleeping, leading to higher levels of fatigue. This is consistent with previous research.[36] Based on the findings of this study, female drivers experienced more significant fatigue than male drivers during the same working hours.

Furthermore, some studies suggest that shift work has different effects on individuals based on age. For instance, after several days of continuous night work, individuals over the age of 34 experience a 20% reduction in the duration of physical work, while those under 34 show no significant change.[37] In our study, older drivers had more difficulty maintaining normal work performance during the night shift, experiencing higher levels of fatigue and other negative effects.[6] These results are consistent with the conclusions drawn in our study

Conclusion

In this study, both subjective and objective fatigue indicators were collected from forklift drivers working in a 12-h shift system through field measurements, and the fatigue changes in the drivers were analyzed. The results revealed that most drivers experienced fatigue after working for 8 h. After completing 8 h, drivers continued working in a fatigued state until the end of their 12-h shifts, which could negatively impact their performance and health, and increase the likelihood of accidents. Therefore, 8-h shifts are more suitable for this type of work than 12-h shifts.

Additionally, night shift drivers reported higher levels of fatigue compared to day shift drivers. The main periods of drowsiness and fatigue occurred in the afternoon (12:00–16:00) and midnight (0:00–4:00), with the most intense fatigue and drowsiness observed between 14:30–16:00 and 2:30–4:00. Fatigue changes were generally similar across both genders, with no significant gender differences during the day. However, at night, women were more likely to experience greater fatigue and drowsiness than men.

These findings highlight the critical need for industrial shift managers to reconsider shift scheduling and implement fatigue mitigation strategies, especially by limiting shift lengths and providing targeted interventions during identified high-risk periods, to enhance worker safety and productivity.

Limitations

This study has several limitations that should be acknowledged. First, the sample size was relatively small, comprising only ten forklift operators from a single tire manufacturing enterprise. While the findings provide valuable insights, the limited participant pool may affect the generalizability of the results. Future studies should aim to include a larger and more diverse sample across multiple industrial settings to enhance external validity.

Second, although both subjective and objective indicators of fatigue were used, the statistical power of some analyses may have been insufficient to detect subtle differences, particularly in gender-based comparisons. Incorporating a broader range of biometric data, such as heart rate variability (HRV), skin temperature, and eye tracking, may provide a more comprehensive understanding of fatigue mechanisms.

Third, this study primarily focused on temporal fatigue patterns during 12-h shifts but did not investigate long-term cumulative fatigue or potential recovery patterns during off-shift periods. Future research should consider longitudinal designs to evaluate chronic fatigue trends and the effectiveness of rest or intervention strategies.

Lastly, environmental and task-related factors—such as ambient noise, lighting conditions, or workload intensity—were not systematically controlled or quantified in this study. Future work should integrate contextual and ergonomic variables to better isolate their impact on fatigue development.

Despite these limitations, the study offers a meaningful foundation for fatigue monitoring and management in extended shift systems, and it highlights the need for personalized and evidence-based approaches in industrial fatigue risk mitigation.

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Ethical approval

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Informed consent

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