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by Muhamad Iwan Ramdan

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Iwan Muhamad Ramdan[1]*, Krishna Purnawan Candra[2], Ulfah Rana Mahdiyyah[1]

[1]*Department of Public Health, Mulawarman University, Samarinda, Indonesia;* [2]*Department Agricultural Product Technology, Faculty of Agriculture, Mulawarman University, Samarinda, Indonesia*

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***Correspondence:** Iwan Muhamad Ramdan, Department of Public Health, Mulawarman University, Samarinda, Indonesia. E-mail: iwanmuhamadramdan@gmail.com
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Abstract

BACKGROUND: Work-related fatigue (WRF) plays a significant role in performance, work safety, and work productivity in all industries. Oil and gas are an industry with a high level of occupational safety and health risks. Research of WRF is needed to detect critical risk factors early to prevent the adverse effect of WRF.

AIM: This study aims to analyze the prevalence of WRF in oil refinery workers at one of the oil refineries companies in Indonesia and analyze the factors that influence it.

DESIGN AND METHODS: A cross-sectional study was conducted on 224 of 511 oil refinery workers. Questionnaire and WRF scales were used to assess demographic characteristics and WRF prevalence, respectively. A medical examination was applied to determine the health status of workers based on blood pressure, body temperature, and respiratory rate. The sound level meter and heat stress meter were used to measure noise and work climate. Cramer's V correlation was applied to identify correlations between WRF and other parameters.

RESULTS: WRF was found among workers in all sections of the oil refinery plant, categorized as low, medium, high, and very high. The WRF prevalence issues only appear in the hydrocracking plant section. The WRF at the section was significantly related to working period ($p = 0.037$, $r = 0.795$), respiratory rate ($p = 0.026$, $r = 0.852$), and blood pressure (diastolic, $p = 0.047$, $r = 0.274$). Besides, the WRF prevalences are related significantly to noise exposure ($p = 0.000$, $r = 0.248$) and heat stress exposure ($p = 0.030$, $r = 0.656$).

CONCLUSION: Working period, respiratory rate, and blood pressure are the intrinsic characteristics that should be paid attention to, especially at the hydrocracking plant, to overcome the WRF of oil refinery workers. At the same time, noise and heat exposure is the extrinsic factor needed to be standardized by increasing the work safety standard for the workers.

Introduction

Oil and gas is an industry with a high level of occupational safety and health risks. Some potential hazards that can be found in this sector include transportation activities, being struck by an object, falling from heights, exposure to chemical materials, and working in confined space, slips, trips, explosions, and fires [1]. At the stage of oil refining, workers have different risks of health and safety problems depending on the location of work. Workers in oil fields, drilling rigs, and other oil production workplaces are exposed to various chemical hazards, fire and explosion, physical strain, exposure to high noise, exposure to oil on the skin, and increased work stress due to work often isolated locations [2]. Other research reported that oil refining industry workers are exposed to various health hazards, e.g. physical (noise), chemical (O_2, CO, NH_3, C_2H_4, and H_2S), mechanical/ergonomic (obsolete machines and equipment), and biological (organic dust/carbon black) [3].

Work accidents in the oil and gas sector in the last decade are also severe. The risk of death due to work accidents of oil and gas workers is 8.5 times higher than that of other sector workers. Most of the causes of accidents experienced are related to work fatigue due to longer work hours (more than 20 h per day) [4], research in this sector is needed to detect critical risk factors early to prevent accidents [5].

Work fatigue plays a significant role in all industries regarding performance, work safety, and work productivity [6]. The impact of work fatigue on industrial workers has caused considerable losses, estimated work fatigue has spent more than $ 18 billion per year due to loss or decline in work productivity. Work fatigue in the oil and gas industry has a devastating effect. It can trigger disasters, such as the BP Texas City Incident in 2005, which resulted in the death of 15 workers, 180 injuries, and losses of at least $ 1.5 billion and the Piper oil rig disaster. Alpha resulted in the death of 167 workers. It is estimated that 80% of industrial work accidents are caused by a human error related to work fatigue [7]. Other studies prove work fatigue is significantly associated with work overload, work situation awareness, and work performance [8], [9]. Other adverse effects of work fatigue for workers include impaired cognitive

functioning and health problems such as depression and cardiovascular diseases [10].

The causes of work fatigue in each industry are different. Three factors cause work fatigues, namely physical (forceful exertion, awkward posture, static load, and repetition movement), mental (irregular work hours, job demands, job stress, co-worker relationships, and autonomy deviation), and environmental load (temperature, noise, light level, vibration, and humidity) [11], [12]. Other studies have concluded that the leading causes of work fatigue are sleep quality [1], [3], changes in circadian rhythm [13], work shifts [14], lack of sleep, work stress and poor medical history [15], work-family conflicts [16], and labor emotional disharmony [17]. Based on various research publications, research on work fatigue in oil and gas workers (especially oil refinery workers) still requires a more specific and complete investigation.

This study aimed to analyze the prevalence of work fatigue of oil refinery workers and the related factors, i.e., demographic characteristics, work environment, and workers' health status.

Design and Methods

A cross-sectional study was conducted between September until November 2019 on all plants in the oil refinery plant of an oil company in Indonesia. Respondents in this study were sampled from the oil refinery workers population of 511. Slovin's formula was applied to collect respondents by random sampling of a total of 224 respondents, i.e., 65 workers from hydro-skimming plant, 122 workers from the hydrocracking plant, 59 workers distilling and wax plant, 101 workers from utilities, 106 workers from oil movement, and 58 workers from the laboratory.

Demographic characteristics (age, education, marital status, and working period) were measured using a questionnaire. Work fatigue is measured by the Japanese Industrial Fatigue Research Committee [18]. This questionnaire consists of 30 question items. In general, this questionnaire consisted of 3 parts, the first ten questions revealed "weakening of activities", the second ten questions revealed "weakening motivation", and the third ten questions reveal "physical weakening". The questionnaire used five Likert scales with the answer options consisting of: (1) Never, (2) sometimes, (3) being felt regularly, (4) often experienced, and (5) always experienced. Total scores are obtained by summing all scores per item, then categorized into four work fatigue categories: (1) Scores 30–52 is "low"; (2) scores 53–75 is "medium"; (3) scores 76–98 is "high"; and (4) scores 99–120 is "very high".

Noise exposure is measured using a sound level meter (Monotaro, Japan), work climate is measured using a heat stress monitor (Questemp-34 heat stress meter, USA). The determination of the threshold limit value (TLV) of noise and work climate is based on Indonesia's Minister of Manpower Regulation number 05 of 2018, where the TLV of noise for 8 h of work is 85 dB, and the TLV of working climate with the Wet Bulb Globe Temperature parameter is 28°C. The health status of workers in this study was obtained through a medical examination using three indicators (blood pressure, body temperature, and respiratory rate). Workers' blood pressure classification is based on JNC 7 classification of blood pressure for adults [19], as follows:

Blood pressure classification	Systole (mm Hg)	Diastole (mm Hg)
Normal	<120	<80
Prehypertension	120–139	80–89
Stage 1	140–159	90–99
Stage 2	≥160	≥100

The worker's respiratory rate classification used in this study was adopted from London's Royal College of Physicians [20]. Based on this classification, the normal reference range for people age 18 to 65 is 16–20 breaths per minute, bradypnea is <60 breaths per minute, and tachypnea >100 breaths per minute. In addition, Cramer's V test was applied to see the correlation between work fatigue and independent variables (demographic characteristics, exposure to noise and work climate, and the health status of workers). Data analysis was done using the Statistical Package for the Social Sciences (SPSS ver. 21, Chicago, IL, USA).

Results

The distribution of age, sex, education background, marital status, body temperature, respiratory rate, systole, and diastole of oil refinery workers is shown in Table 1.

The age of workers is varying in each oil refinery plant section. The age of the workers was mainly 37–42 years old, which was distributed at hydrocracking, hydro skimming, and the utility plant, as well as at the oil movement for 30.19, 28.57, 36.36, and 29.79%, respectively. At the distilling and wax plant and laboratory, workers' age was mainly 31–36 years old, distributed at 30.77% and 38.46%, respectively. Most workers had more than 10 years of experience in all plant sections (57.69–88.68%). The workers' educational background and marital status in all refinery plant sections were graduate (29.55–53.85%) and married (71.4–92.3%), respectively.

The oil refinery workers' body temperature mainly was in hypothermia and normal categories. The normal body temperature was primarily found in hydrocracking plant (52.8%), in distilling and wax plant (57.7%), and laboratory (50.0%). In comparison, the

Table 1a: Demography and health characteristics of oil refinery workers and the environmental condition at the oil refinery plants (a) Demographic characteristics and health condition

Variables	HC (n = 53)		HS (n = 28)		UTL (n = 44)		DWP (n = 26)		OM (n = 47)		Lab (n = 26)	
	freq	%	freq	%	freq	%	freq	%	freq	%	freq	%
Age (years)												
25–30	11	20.75	5	17.86	9	20.45	5	19.23	12	25.53	3	11.54
31–36	13	24.53	6	21.43	10	22.73	8	30.77	9	19.15	10	38.46
37–42	16	30.19	8	28.57	16	36.36	7	26.92	14	29.79	6	23.08
43–48	8	15.09	6	21.43	5	11.36	4	15,38	9	19.15	2	7.69
49–54	5	9.43	3	10.71	4	9.09	2	7.69	3	6.38	5	19.23
Working period (years)												
<5	2	3.77	2	7.14	3	6.82	0	0.00	2	4.26	1	3.85
5–10	4	7.55	8	28.57	13	29.55	8	30.77	13	27.66	10	38.46
>10	47	88.68	19	67.86	28	63.64	18	69.23	32	68.09	15	57.69
Education background												
Graduated from 12^{h} Class	8	15.09	4	14.29	8	18.18	4	15.38	7	14.89	3	11.54
Diploma III	10	18.87	7	25.00	9	20.45	5	19.23	9	19.15	5	19.23
Diploma IV	6	11.32	2	7.14	6	13.64	1	3.85	6	12.77	1	3.85
Graduate	18	33.96	10	35.71	13	29.55	13	50.00	15	31.91	14	53.85
Postgraduate	11	20.75	5	17.86	3	6.82	3	11.54	10	21.28	3	11.54
Marital status												
Unmarried	5	9.4	5	17.9	2	4.5	2	7.7	4	8.5	4	14.3
Married	45	84.9	22	78.6	39	88.6	24	92.3	41	87.2	20	71.4
Ever been married	3	5.7	1	3.6	3	6.8	0	0	2	4.3	2	7.1
Body temperature												
Hypothermia	22	41.5	24	85.7	29	65.9	11	42.3	27	57.4	10	35.7
Normal	28	52.8	4	14.3	14	31.8	15	57.7	20	42.6	14	50.0
Hyperthermia	3	5.7	0	0	1	2.3	0	0	0	0	2	7.1
Respiratory rate												
Bradypnea	8	15.1	0	0	2	4.5	1	3.8	0	0	1	3.6
Normal	41	77.4	25	89.3	33	75.0	22	84.6	29	61.7	16	57.1
Tachypnea	4	7.5	3	10.7	9	20.5	3	11.5	18	38.3	9	32.1
Systole												
Normal	13	24.5	6	21.4	15	34.1	7	26.9	11	23.4	7	25.0
Prehypertension	30	56.6	13	46.4	19	43.2	13	50.0	26	55.3	13	46.4
Stage 1	10	18.9	9	32.1	10	22.7	6	23.1	10	21.3	6	21.4
Stage 2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Diastole												
Normal	13	24.5	6	21.4	15	34.1	7	26.9	11	23.4	7	25.0
Prehypertension	30	56.6	13	46.4	19	43.2	13	50.0	26	55.3	13	46.4
Stage 1	10	18.9	9	32.1	10	22.7	6	23.1	10	21.3	6	21.4
Stage 2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0

hypothermic body temperature was primarily found at the hydro-skimming plant (85.7%), at the utility plant (65.9%), and the oil movement plant (57.4%).

The oil refinery workers' respiratory rate mainly was normal in the range of 57.1–89.3%. The highest respiratory rate is found in the hydro-skimming plant, and the lowest is found in the laboratory. The systole and diastole data show that the oil workers' blood pressure was categorized in prehypertension with the systole and diastole range of 43.2–56.6%.

Table 1b: Demography and health characteristics of oil refinery workers and the environmental condition at the oil refinery plants (b) The environmental condition of the oil refinery plant

Variables	HC	HS	UTL	DWP	OM	Lab
Noise exposure	>TLV	>TLV	>TLV	<TLV	<TLV	<TLV
Heat exposure	>TLV	>TLV	>TLV	>TLV	>TLV	<TLV

Note: The freq (frequency) and percentage within each oil refinery plant column are calculated based on the number of respondents in each refinery plant. HC: Hydrocracking, HS: Hydro skimming, UTL: Utilities, DWP: Distilling and wax plant, OM: Oil movement, Lab: Laboratory, TLV: Threshold limit value, for noise and heat stress exposure are 85dB and 28°C (wet bulb temperature), respectively.

Three oil refinery plant sections, namely hydrocracking, hydro-skimming, and utility plant, have noise above TLV. In comparison, five from six oil refinery plant sections have heat stress above TLV, i.e., hydrocracking hydro-skimming, utilities, distilling and wax, and oil movement plant.

Table 2 shows the distribution of work-related fatigue (WRF) levels experienced by the oil refinery workers. Work at an oil refinery is at high risk. Most oil refinery workers generally experienced WRF at a medium level, i.e., 49.2%, followed by high and very high levels of 27.9% and 14.3%, respectively. The distribution of WRF prevalence among the oil refinery workers is varying depending on the plant section types. The WRF level is distributed in all categories (low to very high). All respondents who work at the hydrocracking plant section (100%) experienced WRF at a high level. The respondents who work at utilities, distilling and wax, oil movement plant section, and laboratory experienced the WRF mostly at a medium level (61.3–96.1%).

Table 2: Distribution of WRF s prevalence among the oil refinery workers at different plant areas

Oil refinery plant	n	n	Low		Medium		High		Very high	
			freq	%	freq	%	freq	%	freq	%
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Hydrocracking	122	53	0	0.00	0	0.00	53	100.0	0	0.0
Hydro-skimming	65	28	4	14.2	2	7.1	7	10.25	15	53.5
Utilities	101	44	13	29.5	27	61.3	4	9.09	0	0.0
Distilling and Wax	59	26	1	0.38	25	96.1	0	0.0	0	0.0
Oil Movement	106	47	1	2.1	43	91.4	3	6.38	0	0.0
Laboratory	58	26	2	7.6	23	88.4	1	3.8	0	0.0
Total	511	244	21	8.6	120	49.2	68	27.9	15	14.3

Note: Data within columns 5, 7, 9, and 11 are calculated based on data within column 3. All the 224 respondents are a man. WRF: Work-related fatigue.

The correlation of demographic characteristics of the oil refinery workers and WRF is presented in Table 3. Among the six oil refinery plant sections, only the hydrocracking plant section shows a significant correlation between WRF and some demographic characteristics of the oil refinery workers. Working period ($p = 0.037$, $r = 0.795$), respiratory rate ($p = 0.026$, $r = 0.852$), and blood pressure (diastolic, $p = 0.047$, $r = 0.274$) are the three demographic characteristics

Table 3: Intrinsic characteristics of oil refinery workers (n = 244) and the association with symptoms and WRF s prevalence in every work area

Demographic characteristics of workers at each oil refinery plant section	WRFs		Weakening type					
			Activities		Motivation		Physical	
	r	p	r	p	r	p	r	p
Hydrocracking								
Age	0.112	0.424	0.190	0.173	0.072	0.610	0.048	0.731
Working period	0.795	0.037	0.626	0.069	0.876	0.022	0.860	0.025
Body temperature	–0.124	0.377	0.089	0.526	–0.121	0.388	–0.127	0.364
Respiratory rate	0.852	0.026	–0.294	0.033	0.648	0.000	0.808	0.000
Systole	–0.240	0.053	–0.294	0.033	0.648	0.000	0.808	0.000
Diastole	–0.274	0.047	–0.294	0.033	0.648	0.000	0.808	0.000
Hydro-skimming								
Age	–0.053	0.788	0.057	0.772	0.015	0.940	–0.237	0.224
Working period	–0.304	0.116	–0.263	0.175	–0.314	0.103	–0.252	0.196
Body temperature	–0.299	0.240	–0.037	0.853	–0.282	0.146	–0.321	0.095
Respiratory rate	0.252	0.196	0.307	0.111	0.203	0.301	0.176	0.371
Systole	0.274	0.159	0.217	0.267	0.247	0.205	0.290	0.134
Diastole	0.254	0.191	0.168	0.393	0.220	0.260	0.318	0.099
Utilities								
Age	–0.238	0.120	–0.255	0.142	–0.220	0.152	–0.128	0.407
Working period	–0.132	0.399	–0.229	0.135	–0.143	0.354	0.037	0.812
Body temperature	0.038	0.805	0.019	0.903	0.028	0.855	0.041	0.792
Respiratory rate	–0.077	0.621	–0.238	0.120	0.088	0.571	0.000	1.000
Systole	–0.173	0.260	–0.191	0.213	0.034	0.828	–0.199	0.195
Diastole	–0.069	0.656	–0.043	0.738	–0.070	0.650	–0.053	0.731
Distilling and wax								
Age	0.136	0.506	–0.007	0.974	0.110	0.594	0.163	0.425
Working period	–0.164	0.432	0.039	0.848	–0.166	0.417	–0.195	0.340
Body temperature	–0.251	0.215	–0.085	0.680	–0.356	0.460	–0.046	0.824
Respiratory rate	–0.022	0.917	–0.065	0.752	0.132	0.522	–0.107	0.603
Systole	0.054	0.793	0.234	0.250	0.030	0.855	–0.166	0.418
Diastole	0.140	0.496	0.245	0.229	0.072	0.726	–0.052	0.800
Oil movement								
Age	0.032	0.832	0.199	0.427	–0.142	0.341	0.032	0.832
Working period	–0003	0.984	–0.006	0.966	0.027	0.855	–0.018	0.906
Body temperature	0.054	0.721	0.100	0.504	–0.042	0.780	0.028	0.852
Respiratory rate	–0.193	0.194	–0.223	0.132	–0.229	0.122	0.007	0.965
Systole	0.006	0.966	0.076	0.611	–0.185	0.214	0.055	0.714
Diastole	0.090	0.547	0.105	0.483	–0.033	0.825	0.091	0.545
Laboratory								
Age	–0.094	0.649	0.004	0.985	–0.091	0.660	–0.121	0.555
Working period	–0.120	0.560	–0.355	0.075	0.250	0.218	–0.143	0.485
Body temperature	0.135	0.512	0.224	0.272	–0.103	0.617	0.167	0.416
Respiratory rate	0.230	0.258	0.229	0.260	0.224	0.270	0.008	0.967
Systole	0.001	0.997	–0.073	0.723	0.104	0.612	–0.030	0.883
Diastole	0.019	0.927	–0.001	0.995	0.092	0.654	–0.060	0.769

Note: Data were analyzed by Cramer's V (φc), (**): Education background versus Work-related fatigue $P = 0.175$, $r = 0.866$; *** Marital status versus Work-related fatigue $P = 0.135$, $r = 0.663$, WRF: Work-related fatigue.

that should have more attention in elucidating the WRF issues among oil refinery workers.

At the hydrocracking plant, the demographic characteristics (working period, respiratory rate, and blood pressure), correlated significantly to WRF, also significantly relate to motivation and physical weakening by having the correlation factor p-value between 0.000 and 0.025 (Table 3).

The noise (p = 0.000, r = 0.248) and heat stress exposure (p = 0.030, r = 0.656) was correlated significantly to the WFR among the oil refinery workers (Table 4). Therefore, fixing these issues is needed to overcome the WRF among the oil refinery workers caused by the noise and heat exposure at oil refinery plants, which shows a higher value than TLV (Table 1b). Furthermore, the noise and heat stress exposure was also correlated significantly with the weakening of activities, motivation, and physic of the oil refinery workers by having the correlation power p-value between 0.000 and 0.049, except the heat exposure with physical weakening (p = 0.059) (Table 4).

Table 4: Correlation of work environment with WRF of oil refinery workers

Variables	WRFs		Weakening type					
			Activities		Motivation		Physical	
	r	p	r	p	r	p	r	p
Noise exposure	0.248	0.000	0.478	0.000	0.873	0.000	0.901	0.000
Heat stress exposure	0.656	0.030	0.466	0.049	0.672	0.028	0.306	0.059

Note: Data were analyzed by Cramer's V (φc), WRF: Work-related fatigue.

Figure 1 shows the symptoms profile of the activities, motivation, and physical weakening among the oil refinery workers at each plant type. The figure explores the symptoms profile of each weakening, i.e., activities, motivation, and physic. At the hydrocracking plant, oil refinery workers who experienced weakening symptoms in motivation and physic were detected as "always" and "regularly" at a level of about 30–70%. In contrast, the activities weakening was not an issue.

At the five other oil refinery plant sections, the demographic and health characteristics were insignificantly related to weakening activities, motivation, and physic (Table 3). However, Figure 1 shows that all weakening is becoming a severe issue. The workers who experienced WRF showing all the three weakening symptoms at "always" and "regularly" levels of 20–60% and 20–80%, respectively.

Figure 1 also shows issues with the activities and physical weakening at the utility plant section. The number of workers who experienced WRF shows the two weakening symptoms at a "regularly" level of about 20–30% for activities weakening and 30–50% for physical weakening.

At distilling and wax, and oil movement plant sections, as well as laboratory, the issue of WRF was only with the physical weakening. Nevertheless, the number of workers experienced thirsty at an "always" level of about 55–70% (Figure 1).

Discussion

WRF prevalence

We found that all workers experienced job burnout with various categories and occurs in motivation weakening and physics dimensions. This condition requires immediate treatment so that the adverse effects of work fatigue experienced such as work accidents [5] and decreased work productivity [21] do not occur.

Factors affected WRF prevalence

Demographic factors and WRF

The demographic factors of workers significantly related to work fatigue in this study are only the working period (length of work). In contrast, the age of the workers, level of education, and marital status were

Figure 1: Distribution of weakening symptoms of oil refinery workers at different plant areas having work-related fatigues prevalence. This figure is related to Table 3

not found to be related to work fatigue. The relationship of work period related to work fatigue is understandable because the increase in work–life illustrates an increase in an age where there is a decrease in body capacity (physical and cognitive) in accepting workload [22]. As workers' age increases, there will be a decrease in physiological abilities of various body organs, decreased metabolic function, and reduced adaptability to physical and psychological stress [23], [24]. On the other hand, the addition of a working period will improve

job skills. Workers with high job skills will be a more efficient use of energy in completing the work demands that may slow the experience of fatigue.

The results of this study complement the results of previous studies, which reported that marital status, education level, years of service, and mental health status of workers are significantly related to chronic fatigue syndrome [25]. The opposite report showed no correlation between demographic characteristics (age, body mass index, marital status, education level, and shift work) and work-related factors in oil and gas industry workers in Iran [26] and Malaysia [27]. Work fatigue for female workers at Holland with a high education level had 44% higher odds of reporting high WRF when compared with women with a low or intermediate level of education [9]. Perceived health status, age, and gender are related to work fatigue, but education level is not correlated [28]. Unmarried status was more associated with fatigue than was married status and being overworked [29].

Health status and WRF

In this study, the health status of workers was assessed based on three vital sign indicators (blood pressure, body temperature, and respiratory rate). The results of blood pressure measurements found that most workers (50.9%) were in prehypertension status, the results of body temperature measurements of most workers (53.6%) were within normal limits (36°C–37°C), and respiratory rate measurement results from the majority (74.1%) were normal. Statistical test results showed that only respiratory rate was significantly related to work fatigue ($p = 0.018$).

A vital sign is the simplest, cheapest, and most widely performed important information to describe a person's health status. Although this method has long been used and now has become an area of active research, early detection of changes in vital signs can prevent worse health conditions [30]. This study proves the relationship between the health status of workers with work fatigue. These results make sense because blood pressure measures the strength of the heart in pumping blood throughout the body through arteries. At the same time, breathing is breathing oxygen from the air and releasing carbon dioxide and water vapor. Therefore, changes in blood pressure and respiratory rate from normal limits will affect the blood supply to cells/tissues, which will involve work fatigue.

These results are in line with studies of work fatigue in other occupations that conclude a relationship between the health status of workers with WRF, among others, perceived physical health and perceived mental health, and psychological distress was associated with work fatigue among employees in Taiwan [31], medical personnel in Taiwan with poor and very poor self-reported health were more likely to report WRF [32].

Noise and heat stress exposure and WRF

The results found that most of the workers (55.8%) were exposed to noise above TLV (85 dB), i.e., workers in the HCC, HSC, and UTL sections. Furthermore, almost all workers (88.4%) were exposed to a work climate above TLV (WBG Parameters 28°C), i.e., workers in the HSC, HCC, dis-waxed, UT, and OM sections. Only workers in the laboratory are not exposed to work temperatures above the TLV.

Statistical tests prove a significant relationship between noise exposure and work fatigue. These results are in line with the opinion of Kjellberg *et al*. [33], which stated that noise might have fatiguing effects as noise may contribute to a general over-stimulation. In addition, monotonous noise has been found to have sleep-provoking effects and noise may make the task more difficult and tiring to perform, for example, by masking important acoustic information. In addition, Münzel *et al*. [34] concluded that noise exposure could cause sleep disturbances which will ultimately cause work fatigue. Studies on the architect concluded that changes in sleep rest patterns due to noise induce frequent arousals, increase the duration of frequent awakenings, increase autonomic arousals, and increase heart rate.

Our finding can complement the research results on other types of work, such as Fredriksson *et al*. [35], which concluded that health personnel occupational noise and work stress correlated significantly with work fatigue. In addition, Saremi *et al*. [29] proved that high noise exposure significantly increased the level of work fatigue. Noise exposure is an essential factor causing work fatigue in chemical plant workers in France. Hebrani *et al*. [36] concluded that noise exposure was significantly related to work fatigue in Indonesia's oil and gas industry workers.

This study implies that various control efforts must be made to reduce noise exposure in the workplace to reduce work fatigue in oil refinery workers. Following the hierarchy of hazard control in the workplace from NIOSH [37], noise control at work can be carried out using elimination, substitution, engineering control, administrative control, and personal protective equipment.

Statistical tests prove that exposure to high working temperatures is significantly related to work fatigue. These results follow a new model introduced by Ismaila *et al*. [38] who explain the interaction model of the effects of hyperthermia on various body systems that lead to fatigue. In the cardiovascular system, hyperthermia decreases cardiac output, which causes the supply of blood flow to the muscles to fall and affects blood flow to the brain, thereby disrupting the balance of brain heat. Hyperthermia in the central nervous system could cause neurobiological changes. They affect motor activity and psychological conditions and lead to decreased motivation, mood, pain

tolerance, and expectation of task demand. Finally, in the respiratory system, heat pressure will be increased ventilation, lowered $PaCO^2$, increased pH, and causing breathlessness.

This study can complement previous studies on various types of work, which concluded that exposure to high environmental temperatures is significantly related to work fatigue. Chen *et al*. [39] reported that steel plant workers in Taiwan exposed to a hot environment are inclined to subjective fatigue. Their fatigue symptoms increase with the heat exposure levels. Makowiec-Dąbrowska *et al*. [40] concluded that heat exposure was significantly related to work fatigue in professional drivers in Poland.

This result implies that work fatigue for oil refinery workers can be reduced through efforts to control heat exposure. According to the recommendations of NIOSH [41], controlling heat exposure at workplace can be done through control of heat stress (engineering control and safe work practices), train workers before hot outdoor work begins, acclimatization, hydration, and rest breaks.

Conclusion

All oil refinery workers experienced work fatigue, and it is categorized as low, medium, high, and very high for 8.6, 49.2, 27.9, and 14.3%, respectively. Hydrocracking is the only plant section having the issue with WRF. The WRF prevalences at the section are related significantly to the working period, respiratory rate, and blood pressure. In addition, the working period is related significantly to motivation and physical weakening. At the same time, the respiratory rate and blood pressure correlated significantly with all weakening types, i.e., activities, motivation, and physical. Besides, noise exposure and heat stress are also related significantly to WRF prevalences. The noise exposure is significantly associated with all weakening types, while the heat stress is associated only with activities and motivation weakening. Therefore, the companies should improve the health status of workers and reduce the workload for aging workers. Preventing noise exposure and heat stress is also recommended to minimize WRF prevalence.

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