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Impact of Occupational Fatigue on Human Performance among Oil and Gas Workers in Indonesia

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Abstract

Occupational fatigue is a serious problem since it may cause several issues, including deteriorating human performance. Some major accidents in the oil and gas industries were associated with the lack of human performance due to occupational fatigue. This study aimed to analyze the impact of occupational fatigue on human performance among oil and gas workers in Indonesia. This study used a cross-sectional design using a self-administered validated questionnaire to gather information on demographic (gender and age), work characteristics (work rotation, work duration, shift work model, day/night shift, job position), sleep debt, sleep quality, occupational (acute and chronic) fatigue, and at-risk behavior as the indicator of human performance. In this study, a total of 1,650 workers from different fields (production, drilling, well service, construction, and administration/office) participated. This study showed that occupational fatigue (both chronic and acute) has potentially decreased level of human performance. This implied that managing occupational fatigue may prevent deteriorating human performance.

Keywords: at-risk behavior, business continuity, fatigue, human performance, oil and gas workers

Introduction

Fatigue is one of the contributors to human errors and results in slower reactions. It reduces the ability to process information, memory lapses, absent-mindedness, decreased awareness, lack of attention, underestimation of risk, and reduced coordination.[1,2] Fatigue can lead to errors and accidents, moreover in workplaces. The Health and Safety Executive of the United Kingdom even stated that fatigue contributes to 20% of accidents on major roads and causes financial costs.[2] Oil and gas industries are well known to be linked to very-high-risk operations. A small mistake (at-risk performance) may lead to a catastrophic incident resulting in multiple fatalities, environmental damage, loss of assets, and business disruption.

The British Petroleum Texas City Refinery accident on March 23, 2005, caused fifteen fatalities, 180 injuries, and financial losses of up to more than US$ 1,5.[3] From the results of The U.S. Chemical Safety and Hazard Investigation Board (CSB) investigation, it was also found that the workers experienced sleep deprivation, some of them forced to work overtime due to a reduction in workers.[4] The British Petroleum had to pay a total compensation cost of US$65B after the incident.[5] The investigation revealed that some crewmen were working three weeks offshore and were thus perhaps suffering from fatigue. There was a similar incident at the Deepwater Horizon oil rig in the Gulf of Mexico on April 20, 2010. The drilling rig was preparing to temporarily abandon the Macondo Well when it, unfortunately, experienced a kick and ended with a disastrous oil spill in the Gulf of Mexico. The oil rig's crew was also exposed to commercial pressure to speed up the temporary abandonment procedure, which was already six weeks behind schedule.[6]

The British Petroleum Texas City and Deepwater Horizon incidents show that defective human performance can lead to major incidents or business disruption. In many industrial incidents, fatigue was observed to be the critical factor that influenced human performance.[7] It was also explained that when workers experience excessive fatigue, they will be unable to make the right decisions or find it difficult to do so. Especially when there is an emergency situation or when excessively fatigued workers come to face a life-threatening condition, the probability of them making a wrong decision increases

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up to 99%.[8] Mostly, a wrong decision caused by fatigue can lead to impaired reasoning, decreased decision-making ability, reduced vigilance and focus/attention, reduced mental functioning. This decision is usually low reaction time, temporary loss of situational awareness, bypassing procedures, or shortcuts.[9]

Occupational-fatigue risk factors as consisting of three main groups: individual factors, work factors, and non-work-related factors.[10] The individual factors include age, health status, and adaptability. Work factors include roster pattern, work time, poor work scheduling, shift time, type of work done, continuous demanding work, and position level/decision latitude. Non-work-related factors include recovery time between shifts, long periods of awake time, inadequate rest breaks, a non-conducive environment, lack of sleep and rest, poor quality of sleep, other employment, and excessive travel time.[10]

Acute fatigue is fatigue after a period of physical and mental stress, including strenuous muscle effort, immobility, heavy mental workload, intense emotional distress, monotony, and lack of sleep.[11] If acute fatigue is experienced continuously over a long period and there is no adequate recovery, it will develop into chronic fatigue. Chronic fatigue brings with it a combination of physiological and psychological problems.[11] Fatigue that workers experience has the potential to cause negligence and poor judgment.[9]

When workers experience or are exposed to fatigue, their performance will decrease. This decrease has the potential to cause human error. Gerald Matthews, *et al.*,[12] showed that each individual has different susceptibility (Individual Differences IDs) to the fatigue they experience. The human performance decrease is mainly determined by the level of vulnerability (fatigue vulnerability) and resilience (fatigue resistance) of each worker IDs.[12]

Therefore, managers need to know the relationship between worker fatigue and human performance, so they will be able to anticipate potential incidents by managing the factors contributing to worker fatigue in the organization by developing a fatigue risk management system (FRMS).[13] This study aimed to analyze the association between work fatigue and human performance among Indonesian oil and gas workers. The results of this study can be considered to prevent and control worker fatigue in the workplace and maintain and improve human performance for business continuity management.

Method

This cross-sectional study used a self-administered validated questionnaire to measure occupational fatigue using a standard method, "Occupational Fatigue Exhaustion Recovery (OFER)," as the independent variable and nine at-risk behaviors to predict the change of human performance as the dependent variable. In order to have represented the sample, this study used random sampling method. The sample calculation refers to Roscoe (1975) quoted by Sakaran U,[14] the minimum sample required is 10 times the number of variables. In this study the number of variables was 25 variables. Thus, the minimum sample required was 10 x 25 = 250 sample. The sample inclusion criteria in this study were all employees of oil and gas at Perusahaan Migas X. Meanwhile, the exclusion criteria in this study were employees who were sick, on leave, and workers who were not willing to fill out questionnaires. This study was deployed to all entities in the organization, such as the Production & Maintenance Department, onshore & offshore fields workers, drilling rigs & well servicing, construction, and administration/office. There were 1,573 data out of 1,650 total respondents included in this study analysis, and 77 were excluded (50 data were used for questionnaire validity test, and the other 27 data were incomplete and thus considered invalid).

The OFER standard questionnaire developed by Windwood, *et al.*,[15] consisted of 15 questions, including three sub-scales; acute fatigue five questions, chronic fatigue five questions, and inter-shift recovery five questions. All subscales were scored using 7-point Likert Scale and scored 0-100.[15] Overall, the results of the acute and chronic fatigue calculation were grouped into four quartiles of 0-100 (e.g., scores 0–25 was categorized as a mild acute or chronic fatigue level; 26-50, moderate acute or chronic fatigue level; 51-75, high acute or chronic fatigue level; and 76-100, very high acute or chronic fatigue level).

At-risk performance was measured using a self-administered questionnaire which adopted from the U.S. Department of Energy (DOE),[9] and had been tested for the reliability and validity. The results of the validity test showed all the questions in the questionnaire were valid that showed by the significant value (2-tailed) was 0.000 (p value<0.05). The reliability test, used the Cronbach Alpha test, showed an alpha value of 0.883 where the value into the category of high reliability. The at-risk performance questionnaire consist nine at-risk behaviors when the respondents worked in a fatigued state in the last 12 months before the survey (Table 1). These nine at-risk behaviors are shown below.

At-risk 1 – Working while tired/sleepy
At-risk 2 – Short memory loss
At-risk 3 – Mis-prediction/anticipation
At-risk 4 – Wrong/poor decision
At-risk 5 – Slow body movement/reflex
At-risk 6 – Taking a shortcut/skipping or bypassing a task in the task sequence
At-risk 7 – Lack of focus/attention

At-risk 8 – Working in a hurry
At-risk 9 – Lack of verification (over-assumption)

The total at-risk behavior score is cumulative of nine individual answers: never = 0, once = 1, and more than one = 2. The total score for each respondent will vary from 0 to 18. The gathered data were analyzed using Stata for Windows version 12.1 for the univariate and multivariate analysis.[15] Level of acute and chronic fatigue, a score of acute and chronic fatigue, and human performance respondents were variables explained by univariate analysis. Single linear regression linear analysis was used to determine the relationship between acute fatigue score and chronic fatigue score as independent variables and human performance score as the dependent variable. The significance of multivariate analysis was alpha 5%. If p-value<0.05, it means that acute fatigue and chronic fatigue significantly could predict human performance.

At-Risk Behavior (When Working in a Fatigued State in the Last 12 Months before This Survey)	Never	Once	More than Once
Have you ever experienced working with a limp, powerless, or in a tired body condition?	O	O	O
Have you ever experienced short-term memory loss (forgetting or not realizing what you just did)?	O	O	O
Have you ever mispredicted something?	O	O	O
Have you ever been unable to make the right decision at work or had difficulty making one?	O	O	O
Have you ever felt slow in responding to unsafe conditions?	O	O	O
Have you ever bypassed tasks/job sequences or decided to perform only those steps you considered important (skipping seemingly unimportant steps or deviating from the proper sequence/order of tasks)?	O	O	O
Have you ever experienced being misfocused, wanting to do A but ending up doing B instead (e.g., wanting to turn left but instead turning right)?	O	O	O
Have you ever left a task unfinished or left the workplace early?	O	O	O
Have you ever done something relying only on your assumption/prediction (e.g., coming up with a report without checking from the field)?	O	O	O

Table 1. At-Risk Behavior Questionnaire

Table 2. Distribution of Respondents with Acute and Chronic Fatigue Levels

Level of Fatigue	Chronic Fatigue		Acute Fatigue	
	n	%	n	%
Mild	734	46.66	316	20.09
Moderate	521	33.12	825	52.45
High	252	16.02	350	22.25
Very high	66	4.20	82	5.21
Total	1,573	100.00	1,573	100.00

Results

The distribution of respondents age between 20 – 57 years old which age mean in 37 years old. Mostly respondents work in onshore field (46.4%) and the second one was swampy field (43.2%). Mostly respondents (75.5%) have 12 working hours. A total of 53.6% of respondents worked with a shift work system. Respondent positions vary, consisting of manager, superintendent/assistant manager, foremen/supervisor, operator/technical/crew of land/sea/air transportation, and assistant operator/helper. The most position of the respondents was operator/technical/crew of land/sea/air transportation (52.4%).

Table 2 shows the distribution of the respondents with acute and chronic fatigue levels based on their score assessments. On average, almost all workers were at a moderate level of fatigue (score 26-50). Table 3 shows that the average acute fatigue score of the respondents was 42.3 (95% confidence interval (CI) = 41.3–43.2), with a standard deviation of 19. Meanwhile, the average chronic fatigue score of the respondents was 31.9 (95% CI = 30.8–33), with a standard deviation of 22.62.

The study participants' human performance was assessed using nine questions regarding the at-risk behaviors experienced by the worker respondents in the last

Table 3. Distribution of Acute and Chronic Fatigue Scores

Variable	Mean	SD	Minimum-Maximum	95% CI
Acute fatigue	42.3	19	0–100	41.3–43.2
Chronic fatigue	31.9	22.62	0–100	30.8–33.0

Notes: CI = Confidence Interval, SD = Standard Deviation

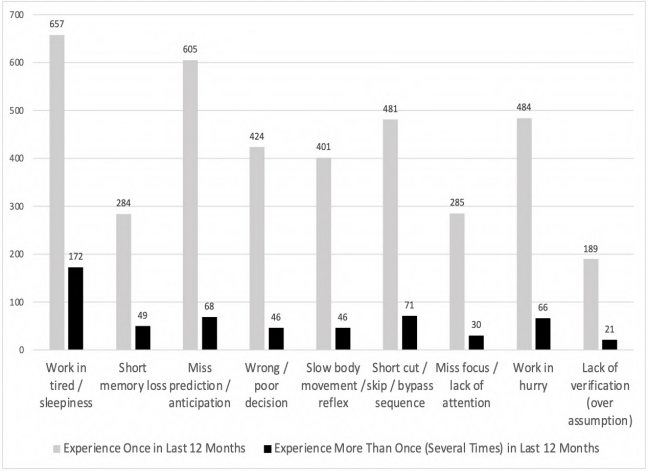


Figure 1. At-Risk Behaviors of the 1,573 Respondents

Table 4. Association between Acute Fatigue and Human Performance

Independent Variable	R^2	p-value	B (CI)	95% CI (B)
Constant			104.353	102.361–106.345
Acute fatigue	0.261	<0.001	-0.511	(-0.560)–(-0.474)

Notes: CI = Confidence Interval, Dependent variable = Overall performance

Table 5. Association between Chronic Fatigue and Human Performance

Independent Variable	R^2	p-value	B (CI)	95% CI (B)
Constant			98.183	96.840–99.525
Chronic fatigue	0.261	<0.001	-0.491	(-0.525)–(-0.457)

Notes: CI = Confidence Interval, Dependent variable = Overall performance

12 months before the survey. Of nine at-risk behaviours reported during the last 12 months, work in tired/sleepiness, miss prediction/anticipation, work in hurry, and short cut/skip/bypass were the most at-risk behaviours reported. In addition, all at-risk behaviours were experiences more than once (several times) a year (Figure 1).

Tables 4 and 5 show the results of the single linear regression analysis of how the worker respondents' human performance was affected by their acute and chronic fatigue as independent variables. The associated correlation based on Table 4 can be interpreted using the formula: HP = 104.353 – 0.511 AF, where HP is Human Performance and AF is Acute Fatigue. The associated correlation based on Table 5 can be interpreted using the formula: HP = 98.183 – 0.491 CF, where HP is Human Performance and CF is Chronic Fatigue.

Discussion

The results of the study showed that most of the workers experience moderate acute fatigue. However, there were several workers experiencing high acute fatigue and even very high acute fatigue. This result must be a concern because a barrier failure can cause an accident due to high or very high fatigue. When workers experience acute fatigue continuously over a long time with no adequate recovery, it will accumulate, resulting in chronic fatigue.[11,16] In this study, most of the workers in Perusahaan Migas X experienced mild chronic fatigue. Mild chronic fatigue can develop into moderate, high, and very high chronic fatigue levels. Chronic fatigue can cause health problems for workers, especially in the nervous system and immune system.[17] In addition, it is paramount to note that there are workers who experience high levels of chronic fatigue and even very high levels of chronic fatigue. Chronic fatigue at high and very high levels has the potential to cause an accident in the workplace.

The findings of this study also showed that acute and chronic fatigue significantly impacted the human performance of workers. Acute and chronic fatigue negatively correlated to human performance, which means the more workers experience acute and chronic fatigue, the greater the decrease in their work performance. The human performance score decreased by 0.511 to increase acute fatigue value (Table 4). In other words, for every increase in chronic fatigue, human performance will decrease by 0.491 (Table 5). This result was in line with the finding of the study by the US DOE that a higher level of fatigue is likely to degrade work performance (increase in the probability of human errors, lapses, slips, mistakes, errors, and violations; negligence (human error); and inadequate judgment).[9] In addition, other previous studies showed that fatigue was one of the contributors to bad human performance, known as a human error which consists of lapses, slips, mistakes, and violations in the petrochemical, oil, and gas industry.[18] Furthermore, Yeow, *et al.*,[19] found that 48.8% of human errors committed by the subjects in her study were caused by fatigue, stress, work repetition, and the work environment.

In this study, human performance was indicated by nine at-risk behaviors. They were working while tired/sleepy, temporary memory loss, misprediction/anticipation, wrong/poor decision. They also work slow body movement/slow reaction time, take a shortcut/skipping or bypassing a task in the task sequence, lack of focus/attention, work in a hurry, and lack of verification (over assumption). This study also showed a similar result with Enoka and Duchateau,[20] that fatigue led the workers to experience impaired reasoning and decision making and decreased alertness/attention. Fatigue also slows down mental function and reaction time and leads to loss of situational awareness (forgetting for a moment) and shortcuts. Fatigue is considered an unsafe condition in the workplace as it is likely to increase the risk of accidents.[1,19]

The most at-risk behavior experienced by workers in Perusahaan Migas X is working while tired/sleepy, either experienced once or several times in the last twelve months. While working in tiring conditions, workers have the potential for negligence, poor judgment, and decreased preparedness that potentially caused accidents.[9,21] Poor judgment happens as a consequence of a decrease in mental function. Furthermore, taking a shortcut/skipping or bypassing task sequence was the second most at-risk behavior in this survey. They were taking a shortcut/skipping or bypassing a task in the task sequence. A procedural violation is a deviation from the correct working method and introduces risk to practice.[21] The background of shortcuts is a motivational problem of the workers. Workers take shortcuts when

they consider some procedure steps trivial and do not fit their individual.[22] Shortcuts increase the potential of an accident in the workplace because there were maybe the critical steps in the task sequence that workers bypassed.

In general, this study explained that most respondents reported having at-risk behaviors in various forms, implying negative human performance. Occupational fatigue may play a role, as shown that increasing occupational acute or chronic fatigue scores significantly increased at-risk behavior scores, which means more negative human performance. Occupational fatigue significantly impacted human performance by observing at-risk behavior among oil and gas workers. However, considering this study was conducted in the COVID-19 pandemic condition where several risk factors of fatigue could be different from normal. The authors suggest that the following study should be conducted in a normal situation.

Conclusion

During the last 12 months, the most-reported at-risk behaviors were working in tired/sleepiness, mis-prediction/anticipation, work in a hurry, and shortcut/skip/bypass. In addition, this study also found that occupational fatigue could cause a negatively impacts on human performance as it increases at-risk behavior among workers could lead to an incident, considering fatigue was one of many factors that could impacting to human performance. Therefore, understanding this condition is paramount to all managers to manage fatigue risk in the workplace in the Fatigue Risk Management System (FRMS) frame.

Abbreviations

CSB: Chemical Safety and Hazard Investigation Board; FRMS: Fatigue Risk Management System; OFER: Occupational Fatigue Exhaustion Recovery; DOE: Department of Energy; CI: Confidence Interval; AF: Acute Fatigue; CF: Chronic fatigue; HP: Human performance; SD: Standard deviation.

Ethics Approval and Consent to Participate

The Ethics Review Board of Universitas Indonesia examined and approved this study with the number Ket-658/UN2.F10.011/PPM.00.02/2020.

Competing Interest

The author declares that there is no significant competing financial, professional, or personal interest that might have affected the performance or presentation of the work described in this manuscript.

Availability of Data and Materials

The raw data and output SPSS obtained from the study are available and kept by the corresponding author.

Authors' Contribution

AD and BW conceptualized the theories related to fatigue, human performance, and major oil and gas incidents. AD and BW also prepared the administered survey questionnaire and analyzed the results using statistic computation software. Both authors drafted this full manuscript.

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The authors declare that this paper has no sponsor.

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