Work System Design Analysis and Improvement Using the Participatory Ergonomics Approach to Reduce Musculoskeletal Disorder Complaints and Risk Exposure at a Workshop Unit

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Abstract

Material handling activities in workshop units can potentially create musculoskeletal disorder complaints and injuries to workers. To reduce this potential for injury, it is necessary to analyze and improve the work system design. This study uses a participatory ergonomics approach to analyze the work system design in a workshop unit at company "X." Participatory ergonomics emphasizes the involvement of workers and ergonomics experts in discussing the improvements needed for work system design within a Focus Group Discussion. An ergonomics evaluation was carried out as a means of observation and analysis using the Nordic Musculoskeletal Questionnaire, a Quick Exposure Check, and the NIOSH Lifting Equation. Focus Group Discussions were conducted by the ergonomics team and led to the following improvements: (1) socialization of correct manual handling, (2) installation of work safety posters, (3) selection of hearing protection equipment, (4) selection of hand protection equipment, (5) stretching and reduction of workloads and repetition in material lifting, (6) changes in workplace layout, and (7) design of step ladder aids. The improvements to the work system design were evaluated by dividing workers into a control and an experimental group. Data analysis results showed a decrease in the level of musculoskeletal complaints by 55.9%, a decrease in the average index of risk exposure level by 25.2%, and no potential risk of injury to the lifting activity.

Keywords: Work System Design, Participatory Ergonomics, Workshop, Musculoskeletal Disorders.

1. INTRODUCTION

As a company operating in the oil and gas industry, company "X" has a maintenance workshop that supports production equipment. Many activities in this workshop relate to material handling. According to the California Department of Industrial Relations [1], handling is defined as "the workers' hands move individual containers manually by lifting, lowering, filling, emptying, or carrying them." Material handling can expose workers to physical conditions that can cause accidents, excessive energy consumption, or wasted time. Potential injuries that can occur when moving material are strains and sprains when lifting weights, as well as being bruised, scratched, or pinched by material [2]. Injuries due to repeated or persistent exposure can cause fatigue and discomfort, and damage muscles, tendons, nerves, and blood vessels. Such injuries are known as musculoskeletal disorders (MSDs) [1].

A large proportion of workplace accidents are due to work-related musculoskeletal disorder (WRMSD) complaints. According to UK Health and Safety Executive [3], 507,000 workers have suffered from WRMSDs and 8.9 million workdays were lost due to WRMSDs in 2016/2017. In the US manufacturing sector in 2016, the number of injuries and illnesses experienced by workers due to transportation and material removal was 18% of the total lost workdays while injuries due to falling, slipping, and tripping accounted for 19% of total cases or 22,040 cases [4].

WRMSDs are common health problems in the industrial world. MSDs are conditions of the nerves, tendons, muscles, and supporting structures of the musculoskeletal system that can cause fatigue, discomfort, pain, local swelling, or numbness and tingling. MSDs usually developed by cumulative damage resulting from long-term exposure to physical and psychosocial stresses at work [5]. Risk factors that can cause MSDs at work include (1) handling of heavy materials; (2) repeated actions and overload power; (3) vibration; (4) static and rigid postures arising from work stations, tools, or bad working methods; and (5) bad work organization.

Ergonomic assessment is required to reduce the potential risk of musculoskeletal injuries and increase productivity. However, with the development of human-machine interface technologies, a new ergonomics approach, called macroergonomics, is needed that covers the entire level of the work system design [6]. According to Hendrick, in Salvendy [7], macroergonomics can be defined as “a top-down, sociotechnical systems approach to work system design and the carrying through of that design to the micro-ergonomic design of jobs and related human-machine and human-software interfaces.” In macroergonomics, the factors in the work system and work organization are balanced because they influence each other.

One of the methods used in macroergonomics approach is the participatory ergonomics method [8]. Participatory ergonomics emphasizes the involvement of workers in the design and analysis of ergonomics [9]. Employees as end users are involved in the design, improvement and operation of the organization. Employees are required to be actively involved in technology improvement and implementation, and to complement ergonomic knowledge in workplace procedures [10].

To reduce MSD complaints and maintain health and safety at company "X", this research analyzed and improve the work system based on a macroergonomics and participatory ergonomics method. With this approach, it is expected that the existing work system in the workshop can be optimized in relation to the sociotechnical system, be of good influence at the work subsystem level, and increase worker productivity.

2. METHODOLOGY

2.1. Subjects & Evaluation Instruments

The subject of this research was the work system design at the workshop unit in the company “X”. Work system design includes workers and working activities at both individual and group levels. This research was conducted at the workshop unit on June and July of 2018.

The evaluation instruments that are used in this research include (1) the Nordic Musculoskeletal Questionnaire (NMQ) to compare complaints about body parts used for work [11]; (2) a Quick Exposure Check (QEC) to assess risk exposure for WRMSDs and provide a basis for ergonomic interventions [12]; (3) NIOSH Lifting Equation to determine risk of musculoskeletal injury due to lifting of materials [13].

2.2. Research Procedure

The research procedures are formulated as follows:

1. Preparation Stage

At this preparation stage, data sheets and questionnaires of Nordic Musculoskeletal, Quick Exposure Check, and NIOSH Lifting Equation were prepared.

2. Initial Data Observation and Collection Stage

At this stage, direct observation was carried out to find out the location and condition of the workshop and work activities performed by workers daily. Interviews with workers were conducted to determine the extent of workers' knowledge on the risk of musculoskeletal injury. Distribution of data sheets and pretest questionnaires were also conducted to obtain the initial data of the control group.

3. Work System Design Analysis Stage
In accordance with the participatory ergonomics approach, ergonomics team was formed to analyze work system design in the workshop unit. This ergonomics team consists of workers or representatives, supervisors, ergonomist, OHS experts and researcher himself. After the team was formed, they conducted Focus Group Discussion (FGD) by discussing matters related to the existing problems. The researcher explained the results of the initial observation and data collection stage, then requested responses from the ergonomics team for problem analysis.

Each involved party will provide ideas and creativities to solve problems in the FGD. Improvement ideas were collected to generate and develop a shared final concept. Furthermore, the joint concept was implemented and evaluated.

4. Work System Design Improvement Stage
The design improvement stage was a follow-up of the work system analysis with the participatory ergonomics approach. The joint concept, the results of the Focus Group Discussion, was drafted by accommodating suggestions for improvement from various related parties. Literature studies were also conducted to get solutions to existing problems.

5. Evaluation Stage
After the work system design improvement was agreed and designed, the next step was evaluation stage. At this stage, the trial of a new work system design was carried out and implemented to the workshop unit organization. Furthermore, data sheets and posttest questionnaires were spread to get data of experimental group. Finally, statistical data analysis was conducted to show whether there are changes to the tested variables, namely musculoskeletal complaints and the level of exposure to injury risk.

2.3. Statistical Analysis
This study used a true experimental design method with Pretest-Posttest Control Group Design. In this experimental design, there were two groups selected, then they were given a pretest to find out the initial conditions and posttest to find out the differences after the experimental treatment [14]. The data that have been collected from the control group and the experimental group then analyzed by the statistical test with the help of SPSS software. Statistical tests used to test two pairs of groups with a certain level of significance [15]. This analysis was determined by the Wilcoxon signed rank test due to non-parametric characteristic of two related groups which were being compared. The measured aspects were aspects of musculoskeletal complaints and exposure to risk of injury.

3. RESULTS AND DISCUSSION
3.1. Participatory Ergonomics Process
Participatory ergonomics approach is a part of macroergonomics that prioritizes active participation by all related parties. In this study, related parties joined in the ergonomics team. Active participation was manifested in the form of Focus Group Discussions (FGDs) where all parties described the problems and together looked for ideas and concepts for problem solving. FGDs are conducted 3 times with the objectives of each FGD were:

a. First stage FGD: Identified and explained existing problems and accommodated improvement solutions from each members of the ergonomics team.
b. Second stage FGD: Each member of the ergonomics team proposed a concept and discussed alternative designs and proposed improvements.

c. Third stage FGD: Evaluated the improvement of the work system design that had been tested and provided additional improvement solutions.

In this study, Participatory Ergonomics Framework was adopted and implemented in order to participatory ergonomics approach can work in accordance with the desired objectives [8]. In the analysis of the design of this work system, decision making is carried out in individual and group consultations. Participants or members of the ergonomics team are operators, supervisor, OHS officer and doctor (as ergonomist). The existing task stages include problem identification, solution generation, solution evaluation and solution implementation.

In this participatory ergonomics, the ergonomist was acted by OHS officer and doctor as team member as well as consultants for the FGD group. This approach used full member involvement, with a focus for designing work and organizations. The outcome of a joint decision will influence the level of the department or work group, with the level of need to be carried out by all existing workers, and the level of ongoing permanence.

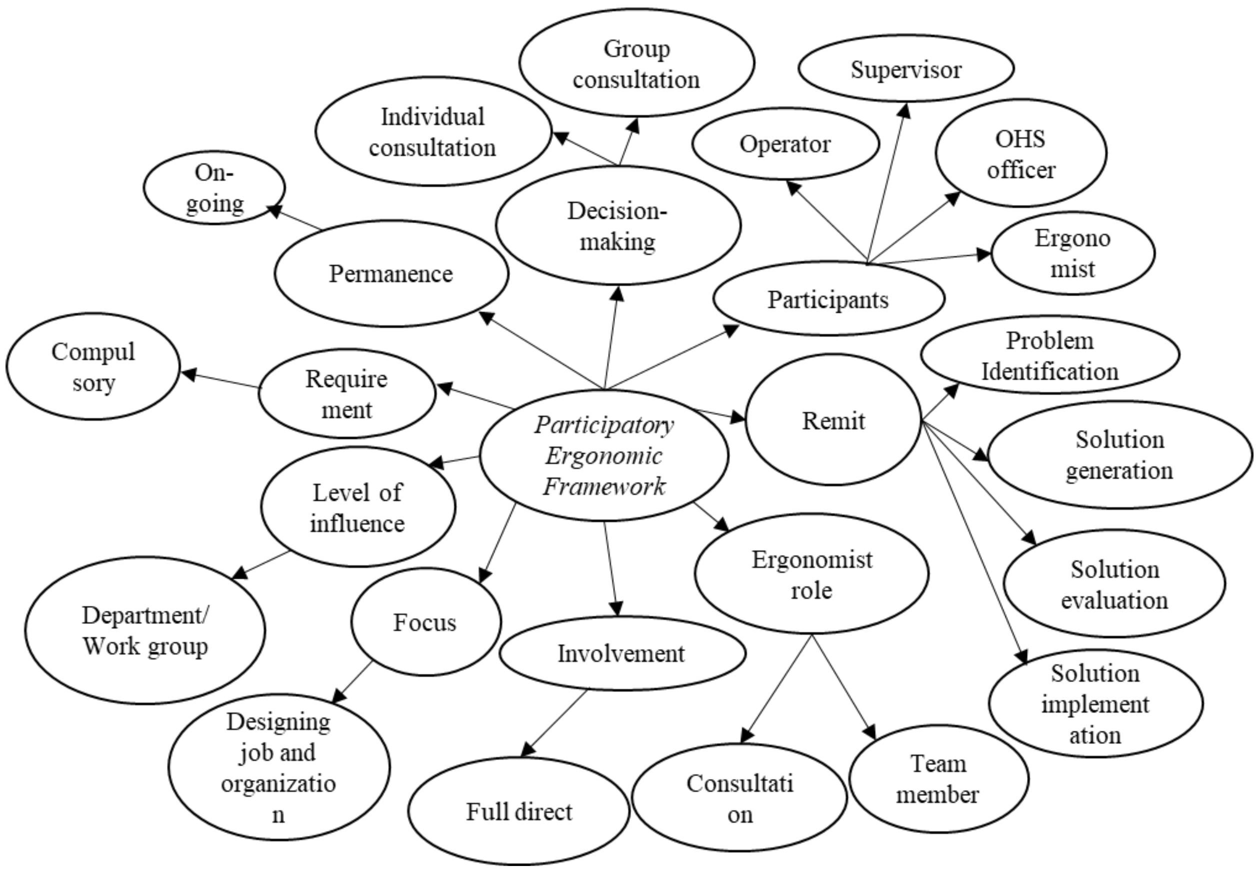

FIGURE 1: Research's participatory ergonomics framework (Adopted from Hignett, Wilson, & Morris [8]).

To reduce musculoskeletal disorders complaints and risk exposure, the FGD provided solution, namely: (1) Socialization of correct manual handling; (2) Installation of work safety posters; (3) Selection of hearing protection equipment; (4) Selection of hand protection equipment; (5) Stretching and reduction of workload & repetition in material lifting; (6) Changes in workplace layout; and (7) Design of step ladder aids. Detail is available in this following table.

Discussion Point	FGD I (Problems Identification)	FGD I (Improvement Solution)	FGD II (Improvement Design & Concept)	FGD III (Improvement Design & Concept)
Socialization of correct manual handling	The results of the NMQ and QEC assessment showed MSD complaints and high risk exposure level in the back, shoulders and arms.	Socialization of manual handling and ergonomic body position while working.	Training materials: ergonomic work positions, occupational diseases, and how to reduce the potential risk of MSD.	Training material added: fatigue management and best practice.
Installation of work safety posters		Installation of work safety posters which contains correct working postures.	Occupational safety posters about personal protective equipment and material handling.	-
Selection of hearing protection equipment	During observation, noise at workshop was beyond Threshold Limit Value (TLV).	Choosing the right hearing protection devices according to the job.	The company has provided ear plugs and ear muffs. Workers should wear according to Noise Reduction Ratio (NRR) and nature of jobs.	Ear plug (NRR = 33) and ear muff (NRR = 27). Hearing protection equipment must be installed correctly and hygienically to be effective.
Selection of hand protectors	The use of hand glove was not in accordance with their work.	Socialization of the correct selection of work gloves.	The company has provided cotton hand glove and impact handglove. Need additional vibration handgloves.	Workers should use cotton handglove for light work and impact handglove for high impact work. Vibration work using anti-vibration gloves.
Material lifting	NIOSH Lifting Equation indicated potential risk of injury in workshop activities.	Designing a tool (step ladder). Workers need to have stretching before work.	Load was reduced and brought closer to the body. Reduced work repetitions. Used step ladder tools.	Stretching before work. The company will hold a fitness program to encourage workers to maintain health & fitness.
Changes in workplace layout	-	-	Facilitated worker mobility, tool retrieval, and add special rest & work areas.	-
Designing step ladder aids	-	-	Design of anthropometric-based step ladder aids.	Lightweight materials was used for design and ensured easy to operate.

TABLE 1: Ergonomics Team FGDs Result & Solution.

FIGURE 2: Comparison of incorrect manual handling (left) and correct manual handling (right)

3.2. Result of Work System Design Improvement

The results of the work system design analysis in the workshop unit have been discussed with participatory ergonomics in FGDs. From FDGs result, there were several improvement plans that had been implemented in the work system design. Comparison before and after the improvement of the work system design are shown in the table below.

Before Improvement	After Improvement
Lack of workers' understanding on manual handling and accompanying risks	Manual handling socialization and installation of safety posters gave workers' understanding of correct way of manual handling to reduce potential risk of injury.
There were several machines with noise levels above Threshold Limit Value	Selection and usage of suitable ear protectors can reduce noise levels below the TLV.
Use of hand protection devices were not in accordance with their functions	Workers had understood the selection of hand protection devices that appropriate for their work to reduce MSD complaints on the hands.
In lifting activities, the load is exceed of RWL and repetitive activities	Reduced the load weight and work repetition. There is stretching or stretching activity to prepare the muscles before working.
Workplace layout was less effective	Changes in workplace layouts facilitated workers mobility so that more effective time.
None of work tools	Step ladder design and fabrication to assist lifting activities.

TABLE 2: Comparison of work system design conditions before-after improvement.

3.3. Evaluation

In the initial data collection, it was found that there were MSD complaints and risk exposure experienced by workers at the workshop unit. The analysis using the Nordic Musculoskeletal questionnaire, Quick Exposure Check, and the NIOSH Lifting Equation calculation had shown there were musculoskeletal complaints with minor to mild levels, and high-risk exposure to the back, shoulders and arms. Whereas according to the calculation of NIOSH Lifting Equation, there were 2 activities that having Lifting Index value above 1.0 which indicates the potential risk of injury.

After improvements were made, the final data collection reported a decreasing in the level of complaints and risk exposure. The results of the analysis with the Nordic Musculoskeletal questionnaire showed a decrease in the average value of the level of complaint of pretest and posttest, initially 1.36 to 0.60 or a decrease of 55.9% (shown in Fig. 3). While the results of the analysis using the Quick Exposure Check indicate that there is a decrease in the average index of risk exposure level between pretest and posttest, initially 40.77% to 30.5% or a decrease of 25.2% (shown in Fig. 4).

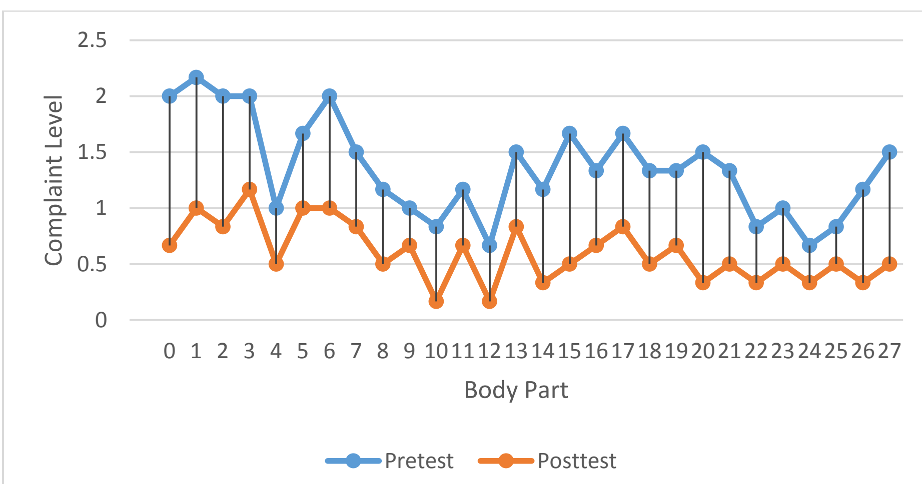

FIGURE 3: Pretest-Posttest data comparison of MSD complaints by NMQ.

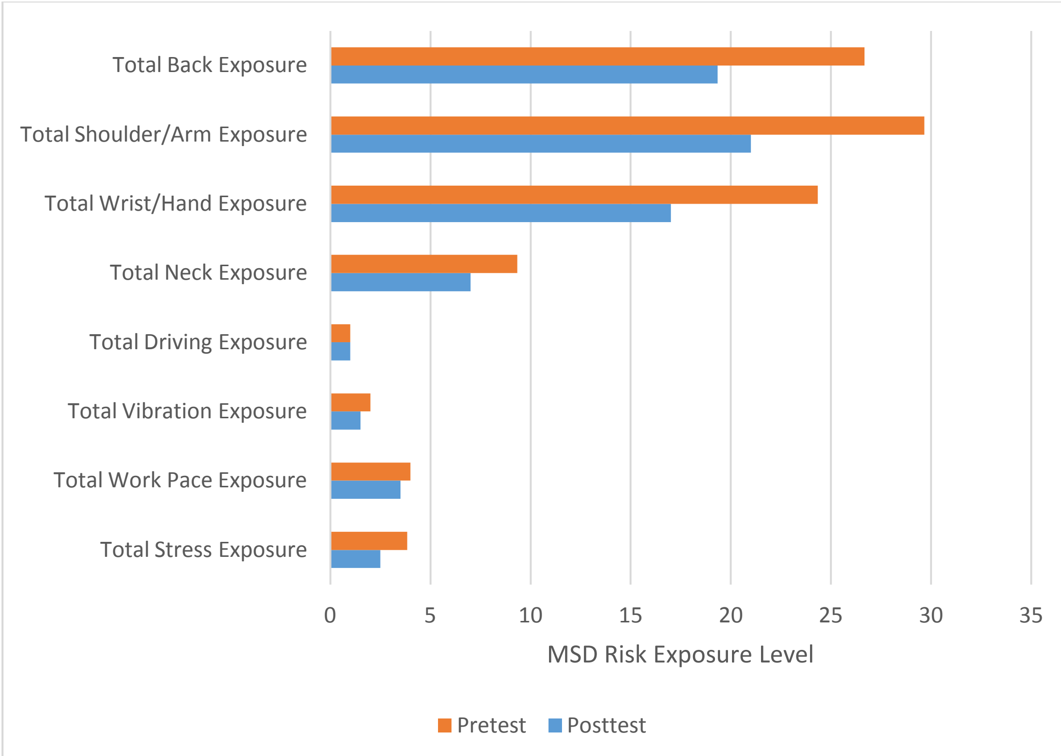

FIGURE 4: Pretest-Posttest data comparison of risk exposure level by QEC.

The results of the posttest calculation for the tool bag lifting activity, RWL values were 7.246 kg and the Lifting Index was 0.966 (no potential injury). For the results of the posttest calculation for the activity of lifting the valve, the RWL value is 15.303 kg and the Lifting Index is 0.784 (no potentially injury). Comparison of the Lifting Index values between the control group (pretest) and experimental group (posttest) shows a decrease in the Lifting Index value after the improvement of the work system design. The results of the NIOSH Lifting Equation calculation show a decrease in Lifting Index below 1.0 which indicates that there is no risk of injury (shown in Table. 3).

Data	Hand tools Lifting Activity		Tool bags Lifting Activity		Valve Lifting Activity	
	RWL (kg)	LI	RWL (kg)	LI	RWL (kg)	LI
Pretest	11,497	0,9567	7,246	2,07	9,564	1,255
Posttest	none		7,246	0,966	15,303	0,784

TABLE 3: Pretest-Posttest data comparison of lifting activity risk by NIOSH Lifting Equation.

According to the previous results, the reducing of MSD complaints and risk exposure level by using participatory ergonomics is in accordance with other researches. Tappin, Vitalis, & Bentley were applying participatory ergonomics in New Zealand meat processing industries. According to their results, participative approach is the need for industry credibility and generate MSD intervention [16]. In other research, Pehkonen et al., [17] was evaluating participatory ergonomic intervention in municipal kitchens in Finland. A feasible intervention model was evaluated and verified to increased knowledge and awareness of workers, decreased physical load and improved musculoskeletal health [17]. Reducing workload and increasing productivity due to participatory intervention was also proven in Brazilian furniture company. Integration of macroergonomics and production management principles is relation each other that can increase productivity level and system sustainability [18].

4. CONCLUSION

Based on the results of analysis of work system design in this study, it can be concluded as follows:

1. Design of the work system at workshop unit had fulfilled some aspects of occupational health and safety. However, there was room to improve the work system design to be better and more effective.
2. The results of the improvement of the work system design with participatory ergonomics approach were: (1) Socialization of the correct manual handling; (2) Installation of work safety posters; (3) Selection of hearing protection equipment; (4) Selection of hand protection equipment; (5) Stretching and reduction of workload & repetition in material lifting; (6) Changes in workplace layout; and (7) Design of step ladder aids.
3. Improvement of work system design at works unit can reduce musculoskeletal complaints by 55.9%, the average risk exposure index is 25.2% and there is no potential risk of injury to the lifting activity.

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