



Ergonomic Tetrapod Reduces the MSDs Risk and Productivity of Steel-Bar Assembly for Reinforcement Concrete Beams



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Abstract

The digitalization of construction has been carried out to meet the demands of the industrial era 4.0. However, there is still a lot of construction work that is performed manually, such as the steel-bar assembly for reinforced concrete beams. Based on the 2019 ILO report, it can be seen that fatal work-related illnesses reached 86%, much higher than work accidents, which was 14%. Of the various fatal illnesses due to work, MSDs require the highest health compensation costs, which reach 40%. The previous study showed that the steel-bar assembly was done in an awkward working posture (squatting, bending, twisting repeatedly) with a high risk of MSDs (Rula score: 7) and needs improvement immediately. This research was conducted through an experiment with a pre-posttest control group design. The specific target of this research is to reduce the MSDs risk and increase productivity by supporting the workers with the ergonomic tetrapod as the working table. The subjects were two groups of students at the Civil Engineering Department Politeknik Negeri Bali, with 14 students in each group. Group 1 (P1) as the control group performs the tasks with the original working condition and group 2 (P2) as the treatment group performs the tasks with the new working condition, supported by the tetrapod as a working table.

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1 Introduction

In the last few decades and until now, the construction industry contributes the most to the number of fatal work accidents, not only in developing countries but also in developed countries such as Europe. Eurostat reports that the construction industry contributes the highest fatal accidents, accounting for more than 20%, followed by transportation and manufacturing. This report is in line with National Statistics Singapore, the construction sector remained as the top contributor with 13 fatal injuries during the covid-19 pandemic. [Raymond et al. \(2017\)](#), reported that construction work accidents were partly caused by a lack of training and experience on OHS. In Nairobi-County Kenya, 74% of workers injured or killed in accidents are under the age of 40, occurring during the busiest hours (10-11 am, and 3-4 pm). Falls from heights and being hit by falling objects contribute to approximately 64% of all construction site accidents. Referring to BPJS Employment data, the number of work accidents in the construction sector in Indonesia has always been in the range of 32%, followed by the manufacturing industry at around 31% ([Raymond et al., 2017](#)). [Jones \(2019\)](#), reported that based on the results of surveys and censuses conducted by the United States Bureau of Statistics, it can be seen that until 2018 fatal accidents in the construction industry tend to continue to increase. Besides fatal accidents, what often goes unnoticed is fatal illness due to work. The ILO reports that work-related fatalities and diseases are far greater than fatal occupational accidents. Fatal work-related illnesses account for about 86% while fatal work accidents are only around 14%. The type of occupational disease with the largest cost compensation is muscle complaints or injuries (Musculoskeletal Disorders – MSDs). Health and safety summary statistics in Great Britain 2021 stated that Industries with higher than average rates of musculoskeletal disorders 2018/19 – 2020/21 is construction, nearly achieved 2,000 cases per 100,000. The previous study showed that the steelwork was done in an awkward working posture (squatting, bending, twisting repeatedly) with a high risk of MSDs (Rula score: 7) and needs curative action immediately ([Sudijeng et al., 2018](#)). Based on the results of this study, and as a follow-up research, ergonomics innovation has been conducted to improve working conditions that lead to the decrease of MSDs risk and improve the productivity of the workers in steel-work for reinforced concrete beams.

Literature Study

Ergonomic Hazard in Reinforcement Concrete Work

Reinforcement concrete work dominates the structural work in various types of construction projects, including road and bridge, civil work, and building construction. It started from foundations, sloop, coulomb, beams, slab stairs and rooftop. It is mostly done outdoors, involves manpower with various backgrounds, working on the height and is exposed to direct weather which is often less predictable. It contains three main sub-work, including framework, steelwork, and pouring concrete. Therefore, the reinforcement concrete work is very hazardous. It is reported that workers perform their task with awkward working posture, kneeling and squatting were common in all operations, especially tiling and underground utility relocation work, and material handling (lifting and carrying loads) frequently. [Buchholz et al](#) reported that construction workers mostly performed their tasks in awkward posture during working time and carried out lifting and carrying work in the moderate to heavy category ([Tak et al., 2011](#)). [Parida and Ray](#) classified three main ergonomic hazards: (1) human/labor-related factors; (2) tasks-related factors; and (3) equipment/tools-related factors based on various age groups and occupations of the construction workers ([Parida & Ray, 2015](#)). Specifically, [Fordea and Buchholza](#) reported that ironworkers spent anywhere from 13% to 48% of their work time in non-neutral trunk postures; worked with one or both arms at or above shoulder level 6–21% of the time; and stood on uneven/unstable work surfaces 3–53% of the time. The type of activity performed was consistently found to be a major predictor of the frequency of work time spent in awkward postures for the trunk, legs, and arms ([Forde & Buchholz, 2004](#)). Those research showed that the construction industry has a high risk of ergonomic hazards that can lead to various health complaints, one of which is musculoskeletal disorders (MSDs) ([Albers et al., 2005](#); [Ferguson et al., 2012](#); [Kasiani & Yusuf, 2019](#)).

Musculoskeletal Disorders (MSDs)

World Health Organization (WHO) reported that approximately 1.71 billion people have musculoskeletal conditions worldwide, with low back pain being the single leading cause of disability in 160 countries. In the past, research on MSDs mostly focus on the associated the symptom with ageing, but recently, especially in the industrial era 4.0, it is

known that many young people are already suffering from MSDs. Apart from age, there are many other factors that cause MSDs: age, educational background, working experience, sitting posture and duration, anthropometry, and work posture (Ramdan et al., 2018). Neeraja et al reported that factors associated with developing MSDs among construction workers were related to manual handling, work repetitiveness, psychosocial demands, job dissatisfaction and gender. Those factors as triggers for the emergence of MSDs complaints of Neck, shoulder or upper back with regard to equipment, machinery, tools, and furniture (Neeraja & SWAROCHISH, 2014). The low back was the site most commonly reported for job-related musculoskeletal symptoms (54.4%) in construction, which was also the most common reason for seeking care from a physician (16.8%) and missing work (7.3%). A number of years working in the construction industry was significantly associated with knee and wrist/hand MSD symptoms and was suggestive of an association with low back. Working in the same position for long periods was the job factor identified as most problematic, with 49.7 percent of all construction apprentices rating it as a moderate/major problem contributing to musculoskeletal symptoms (Merlino et al., 2003). Symptoms of MSDs are mostly experienced by workers who perform their duties manually or semi-manually. The industrial era 4.0 demands digitalization in various fields of work, including the construction sector. Digitalization of construction has been widely carried out and it is recognized that it contributes positively to the work implementation process and can reduce the risk of MSDs. However, for the construction industry, there are still many parts of the work that cannot be done with digital systems, and the risk of MSDs remains high. Numerous opportunities exist for the development and implementation of ergonomic interventions to protect the health, safety, and productivity of construction workers.

MSDs and Productivity

Many workers experience MSDs, not only in developing countries but also in developed countries such as the USA and Europe. At any one time, just under one-third of adult Americans are living with joint pain, swelling or limitation of movement. Some MSDs, such as ankylosing spondylitis, tend to develop when individuals are younger and are at the beginning or formative stages of their working lives. MSDs can also be directly caused by work, and there is near consensus that MSDs are causally related to occupational ergonomic stressors such as repetitive motions, forceful exertions, non-natural postures, vibrations and so on. In line with the US report, it shows that most of the construction workers were young males with long working hours a day. Force movement, repetition, awkward bending and fixed body postures were the major factors leading to the development of MSDs and contributed to frequent absenteeism and poor performance of workers. Research in Malaysia found that Most of the workers were exposed to Medium (56.90%), High (29.31%), and Very High (13.79%) levels of Ergonomic Risk (Mukhtar et al., 2017). Back pain, waist pain and shoulder pain were the major self-reported MSD complaints (Mustapha et al., 2022). There are significant associations ($P = 0.023$) between working duration with MSDs symptom among construction workers with respect to the worker's lower limb (Deros et al., 2014). The ILO reports that work-related fatalities and diseases are far greater than fatal occupational accidents. Fatal work-related illnesses account for about 86% while fatal work accidents are only around 14% (Figure 1). MSDs are the most occupational disease with the highest health compensation cost achieving about 40% (Figure 2).

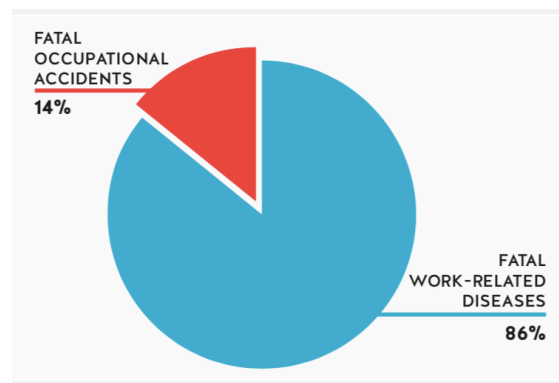


Figure 1. Occupational Fatal Accidents and Diseases

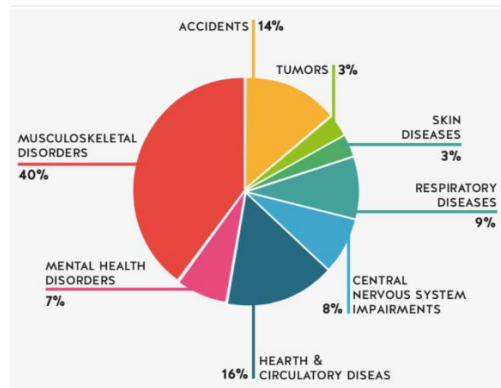


Figure 2. Global Compensation Costs of Occupational and Work-Related Accidents and Diseases

MSDs can increase health impairment, contributes to the reduction of vigilance, reduce accuracy, frequent absenteeism, and decreases the productivity of construction workers which leads to poor worker performance. Therefore, it is very important to carry out ergonomic innovations to create a harmonious relationship between workers, work tools, and the work environment.

MSDs and Ergonomic Man-machine Interface

The definition of ergonomics (or human factors) adopted by the IEA in 2000 is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance. The domain of ergonomics included Physical ergonomics, cognitive ergonomics and Organizational ergonomics (Siddika et al., 2019; Suarbawa et al., 2016). Refers to this definition, ergonomics is multi-discipline and can be applied in any kind of work activity in which considered human well-being as the first priority (Figure 3).

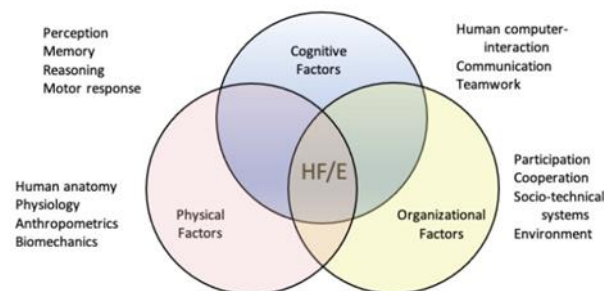


Figure 3. Domain of Ergonomics

Ergonomics Man Machine interface is more focused on Physical factors. However, it cannot be separated from cognitive and organizational factors. Degani and Heymann summarize in four main elements of all human-machine interfaces, which include machine behavior, operational objectives or task specifications, user behavior, and the interface between user and machine. These four elements must be in harmony to ensure the ergonomic man-machine interface (Degani & Heymann, 2002). The high risk of man-machine interface in construction work-system is material handling that unavoidable because of the nature of tasks. Many studies have succeeded in proving that the harmonization of the man-machine interface conditions workers to carry out their task in natural work postures so that over exertion muscle can be avoided and the risk of MSDs can be reduced. Sudiajeng et all reported that the ergonomic redesign of work station in the woodworking workshop decreased the working heart rate (16.7 %), the total score of MSDs (17.3 %), and the total score of psychological fatigue (21.5 %) (Sudiajeng et al., 2012). Ergonomics intervention reduces MSDs among semiconductor assembly workers. Some significant decrements of discomfort were observed in neck, shoulder, upper arm, elbows, lower arm, lower back and whole-body discomfort ($p < 0.05$) (Aghilinejad et al., 2016). Rapid office strain assessment (ROSA) found a significant difference in the

final mean score for ROSA in the two groups of recipients of education and ergonomic interventions ($P < 0.05$). The data also revealed a significant difference in MSDs, including neck, shoulders, and hand/wrist, among ergonomics and education groups (Safarian et al., 2019). Some of the results of these studies indicate that ergonomics intervention through harmonization of the relationship between the Man-Machine Interface is able to reduce MSDs that lead to increased productivity.

2 Materials and Methods

Research Design

This research was carried out with an experimental design with the control group design method. The subject were 2 groups each consisting of 14 students of Civil Engineering Department who joint the reinforcement concrete workshop as the subject of D4 Program. Group 1 (P1) consist of 14 students as a control group performed the task with the original work condition, while group 2 (P2) consist of 14 students as the treatment group performed the task by using an ergonomic tetrapod as the working table of the steel bar assembly for the concrete beam or column (Figure 4). The study was conducted for 6 (six) months, starting early April to the end of September 2020, at the Concrete Workshop Civil Engineering Department Politeknik Negeri Bali (Bali Stet Polytechnic)

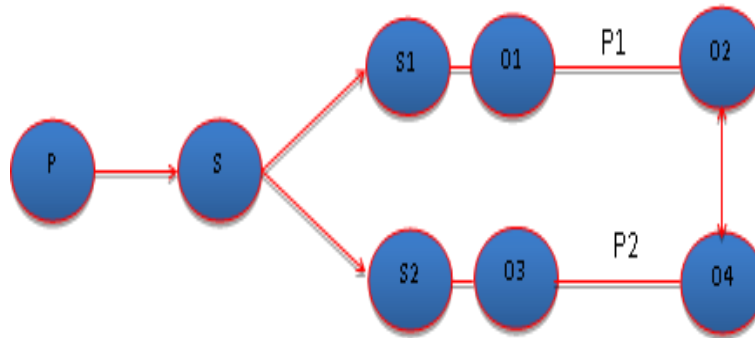


Figure 4. Research design

Notes:

- P : The target population is Civil Engineering students participating in the concrete work practice course for the 2020-2021 academic year;
- S : Selected subjects, 1 class of reinforced concrete practical participants in semester 4 of the 2020-2021 academic year (28 students);
- S1 : Control group subjects (14 students), performed reinforced concrete work practices with the original working conditions before the ergonomics intervention;
- S2 : Subjects in the treatment group (14 students) performed reinforced concrete work practices with new working conditions after ergonomic intervention
- P1 : Original working conditions before ergonomic intervention;
- P2 : New working conditions after ergonomics intervention;
- O1 : P1 data measurement before start working which includes:
 - 1) Body weigh (kg)
 - 2) Physical workload (pulse/minute);
 - 3) MSDs complaint score;
 - 4) Physical fatigue score.
- O2 : P1 data measurement after finish working which includes:
 - 1) Body weigh (kg)
 - 2) Physical workload (pulse/minute);
 - 3) MSDs complaint score;
 - 4) Physical fatigue score.

O3 : P2 data measurement before start working which includes:

- 1) Body weigh (kg)
- 2) Physical workload (pulse/minute);
- 3) MSDs complaint score;
- 4) Physical fatigue score.

O4 : P2 data measurement after finish working which includes:

- 1) Body weigh (kg)
- 2) Physical workload (pulse/minute);
- 3) MSDs complaint score;
- 4) Physical fatigue score.

P1 and P2 data measurements were carried out for 3 consecutive days.

Data Collecting

Anthropometric data collection was carried out for all selected subjects by measuring each body part for standing work posture as illustrated in Figure 5.

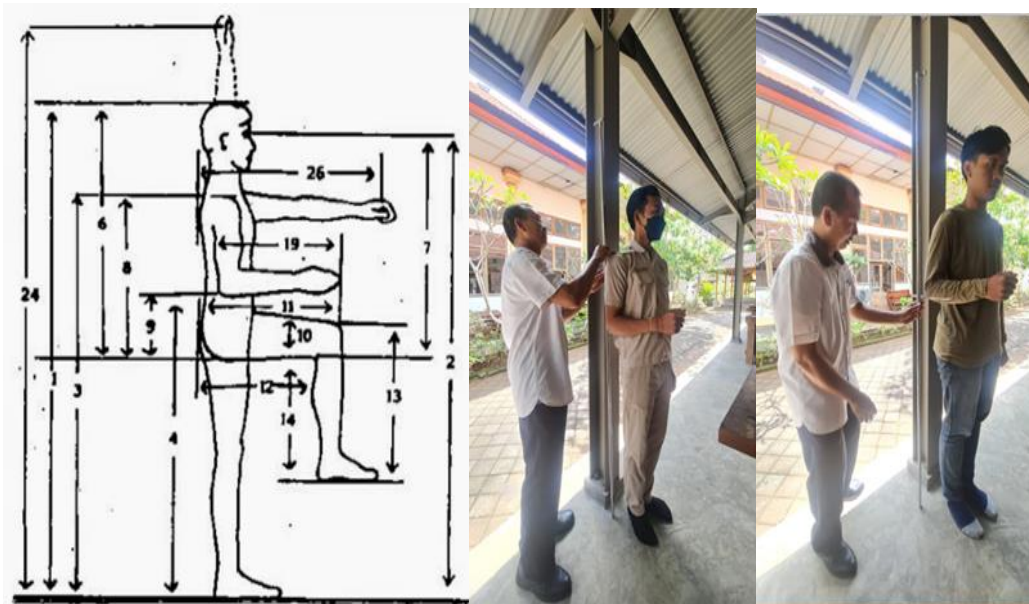


Figure 5. Anthropometric data collection

Based on the results of these measurements, the size of the tetrapod was designed as a working table for conventionally steel-bar assembly for reinforced concrete beams. Ergonomic Tetrapod was designed portable and easy to carry in, flexible, adjustable, and comfortable. The workers/user can set the height of the tetrapod that fit and comfort for natural standing working posture by setting and lock the chain as figure 6.

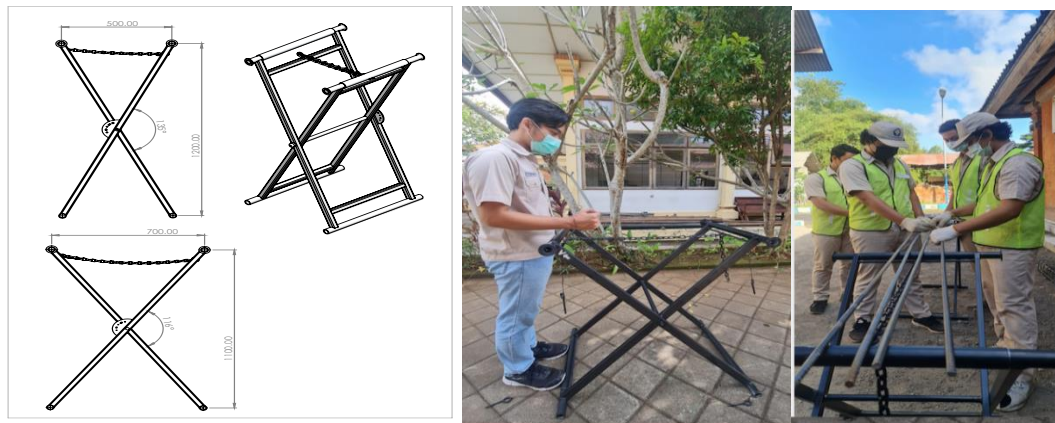


Figure 6. Setting the tetrapod height for the comfort zone

Data on the physical condition of workers is measured through indicators of work pulse, weight loss, subjective complaints of fatigue level, and MSDs. Data collecting for MSDs risk was carried out by capturing the working posture during performed the working task for both the control group (P1) and treatment group (P2), then the data will be used as the input for MSDs category analysis.

Data Analysis

The most influential anthropometric data as a basis for ergonomic tetrapod design are standing elbow height and hand reach length. The data is then used to determine the maximum height of the tetrapod (95th percentile) and the width of the tetrapod (5th percentile). Analysis of work posture was carried out by using the RULA method which was then used to determine MSDs risk level categories. The effect of the usage of tetrapod on production cost was only based on the reduced cost for the daily payment of the workers.

3 Results and Discussions

Worker's Physical Assessment

The result of the worker's physical assessment is described in Table 1.

Table 1
Worker's physical condition

No	Variable	P1	P2	Notes
1	Body weight before working (kg)	69.73	69.25	- P1 Body weight lost: 0.64% - P2 Body weight lost: 0.19% - Body weight lost P2 was 0.45% lower than P1
2	Body weight after working (kg)	69.28	69.12	- Both body weight lost in P1 and P2 were not exceed 1.5% of total body weight in a work day (within recommended limits)
3	Physical workload before working (pulse/minutes)	77.96	82.49	- The increasing Physical workload in P1: 5.81% - The increasing Physical workload in P2: 9.96% - The increasing Physical workload in P2 was 4.15% higher than P1
4	Physical workload after working (pulse/minutes)	82.49	90.71	- Both P1 and P2 in the moderate category of physical workload
5	MSDs score before	29.15	33.42	- The increasing score in P1: 35.44%

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	working			- The increasing score in P2: 5.57%
6	MSDs score after working	39.48	31.56	- The MSDs score in P2 was 29.87% less than P1
7	Physical fatigue score before working	32.19	34.25	- The increasing score in P1: 25.29%
8	Physical fatigue score after working	40.33	37.95	- The increasing score in P2: 10,80%
				- The physical fatigue score in P2 was 14.49% less than P1

From Table 1, it can be seen that both body weight lost and physical workload were at the same categories, but both MSDs score and physical fatigue in P2 were much less than P1. The MSDs score in P2 was 29.87% less than P1, while the physical fatigue score in P2 was 14.49% less than P1. This means that MSDs is correlated with physical fatigue. This is in accordance with the results of research by Reza et al which shows that there is a strong significance between MSDs symptoms and muscle fatigue (TAIB & Sirat, 2021). MSDs was correlated to total fatigue. The severity of discomfort/pain in neck, lower back, buttocks, and thighs was correlated to total fatigue and productivity (Daneshmandi et al., 2017). Thus, it is proven that the use of the tetrapod as a working table in the steel-bar assembly of reinforced concrete beams/columns can reduce MSDs and physical fatigue.

MSDs Risk Category on Original Working Posture

MSDs risk category was assessed by using Rapid Upper Limb Assessment (RULA) Analysis as described in Figure 7 and Figure 8.

Posture analysis







		
Upper arm and shoulders positions Flexi 20 – 45°, score: 2 Shoulders/Upper Arms Raise Frequently: Score +1	Lower arm positions Flexi 60° <flexi>100°, score: 2	wrist positions Flexi /Extension: 0-15°, score: 2 Twisted Wrist, score: 1
		
Neck positions Flexi: 0 - 15°, score: 1 No twist in neck	Body positions Flexi 20 - 60°, Score: 3 No twist on the body	feet and sole positions Not content with neutral: score 2
Loading: Loading and delivery of power: repetitive between 2-10 kg = score: 2		

Figure 7. Posture analysis for original working posture (before ergonomic intervention)

RULA Assessment Worksheet

Plotting the result of body posture analysis is described in Figure 8.

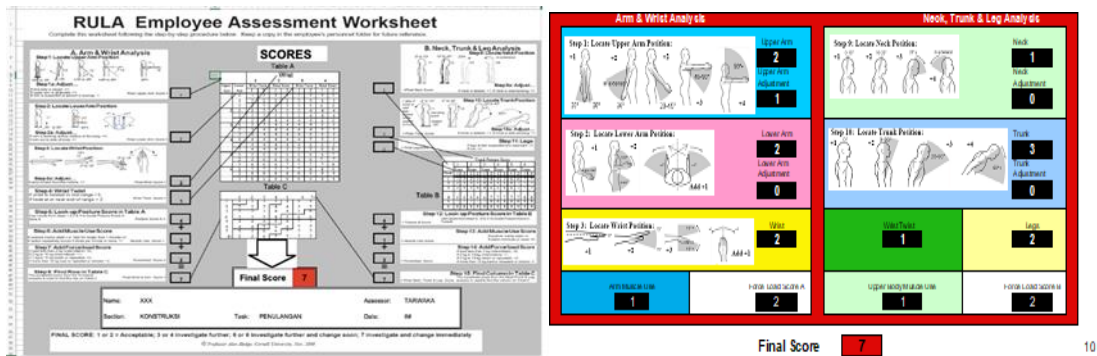





Figure 8. RULA assessment worksheet

Based on the result of body posture analysis, then all scores are plotted in the RULA assessment worksheet. The result showed that the MSDs risk score for the original working posture before ergonomic intervention is 7 (Figure 8) with the very high category. This means that the work needs repair/modification urgently.

MSDs Risk Category on the New Working Posture

MSDs risk category Analysis for the new working posture as described in Figure 9 and Figure 10

Posture analysis

 <p>Upper arm and shoulders positions Flexi 0 – 20°, score: 1 Shoulders/Upper Arms were not lifted: Score: 1</p>	 <p>Lower arm positions Flexi 60° -100°, score: 1</p>	 <p>wrist positions Flexi/Extension neutral, score: 1 Has the possibility for twisting, score: 1</p>
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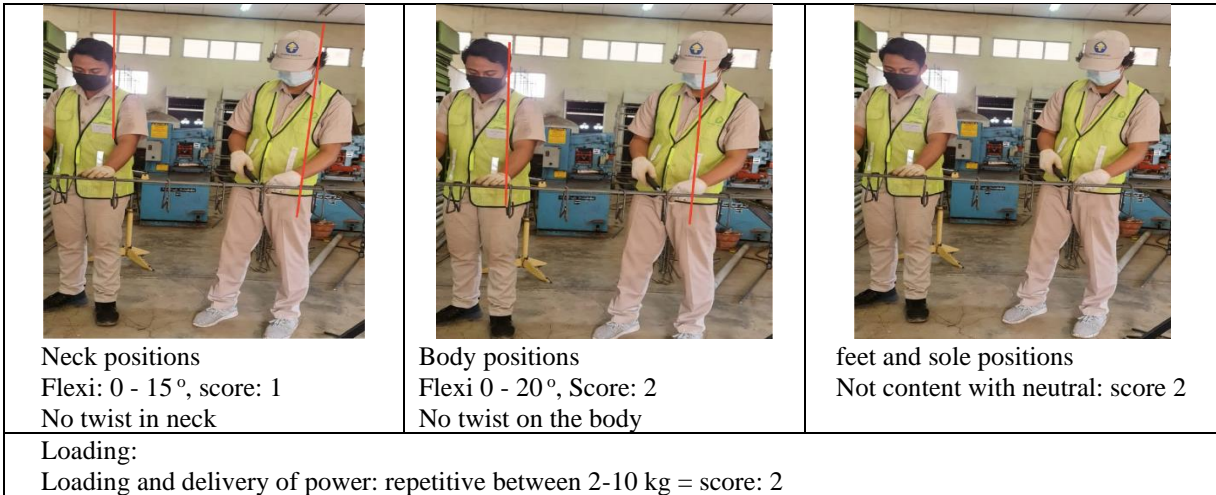


Figure 9. Posture analysis for original working posture (before ergonomic intervention)

RULA Assessment Worksheet

Plotting the result of body posture analysis is described in Figure 8.

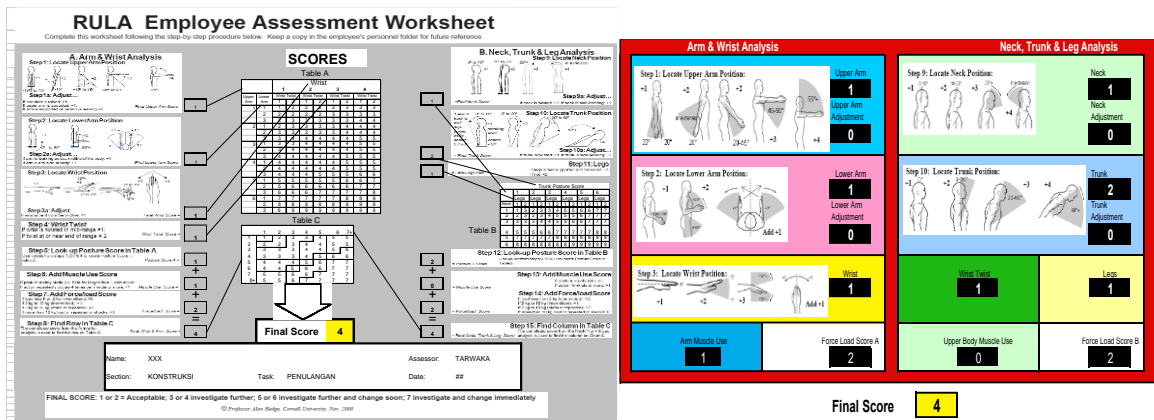


Figure 10. RULA assessment worksheet

Based on the result of the body posture analysis, then all score are plotted in the RULA assessment worksheet (Figure 10). The result showed that the MSDs risk score for the new working posture after the ergonomic intervention is 4 (four), which means that the MSDs risk category is moderate. Figure 7 and Figure 9 shows clearly that the use of the tetrapod as a working table of steel-bar assembly for reinforcement concrete beams is able to change the working posture from a sitting or squatting on the floor (Figure 7) to a dynamic standing work posture and reduced the MSDs risk category from very high to moderate. Figure 9, it shows that the interaction between the workers and the working tools was harmonious (Zare et al., 2015; Wells et al., 1994; Cimmino & Grassi, 2008). However, it seems that it is needed to socialize the ergonomic working posture, especially for neck position more intensively, so the MSDs risk category can be reduced more from the very high category to the low category. The results of this study are in accordance with the results of research from Mulyati which states that there is a correlation of work posture with musculoskeletal disorders complaints significantly with p-value of 0,003 (<0.05). Laundry workers with not ergonomic posture experienced MSDs (Mulyati, 2019). In line with Mulyati's report, Ayu and Ratriwardhani also reported that there was a significant relationship between the work position and MSDs complaints in cracker industry workers with p-value of 0.033 (< 0.05) (Ayu & Ratriwardhani, 2021). From the results of these studies, it is very important to provide a workstation that guarantees harmonization between workers and work tools so that without realizing it, workers automatically perform the task with a natural or ergonomic work

posture, the risk of MSDs can be suppressed, workers perform the task comfortably, productively and cost production can be reduced.

Ergonomics intervention and productivity

Many studies have succeeded in proving that the application of ergonomics in the production process has succeeded in increasing productivity. In this research, the increase of productivity can be seen to the decreasing number of workers from 6 (six) workers in original working condition (P1) into 2 (two) workers after ergonomics intervention by using tetrapod as a working table for steel-bar assembly of reinforced concrete beams, which means that it reduced the daily labor wages and increase the productivity. This result is in accordance with the research result by Yusuf (2014). It is reported that the ergonomic intervention increased the productivity of jewel workers in Bali for about 478,9% and the benefit for about IDR 3.911.560. Moreover, Hemphälä and Eklund also reported that a visual ergonomics intervention in mail sorting facilities gave a positive impact. The postmen/women felt better in general, experienced less work-induced stress, and considered that the total general lighting had improved. The most pronounced decreases in eyestrain, MSD, and mail sorting time were seen among the younger participants of the group (Hemphälä & Eklund, 2012; Walsh et al., 2014).

4 Conclusion

In general, ergonomic interventions aim to improve workstations so that workers can perform the task safely, comfortably, efficiently and productively. The occurrence of MSDs, and early fatigue can be avoided, the level of alertness, thoroughness, and work endurance is maintained and finally lead to an increase of productivity. Whatever the ergonomics intervention, including the technical, management, or workers' behavior, should place the workers as the first priority of consideration. Based on the analysis, result, and discussion, it can be concluded that the usage of tetrapod as a working table which was designed based on the anthropometry data of the workers has been proven to be able to change the working posture of sitting and squatting on the floor into a dynamic standing work posture. It gave a positive impact in reducing the MSDs and improving the MSDs category from very high risk to moderate, avoid early fatigue, and increasing productivity. However, this research was done in the workshop with students that less practical experience. It is needed the following research with true experimental design in the real project.

Conflict of interest statement

The authors declared that they have no competing interests.

Statement of authorship

The authors have a responsibility for the conception and design of the study. The authors have approved the final article.

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