THE USE OF MACRO-ERGONOMIC WORK SYSTEM DESIGNS TO REDUCE MUSCULOSKELETAL DISORDERS AND INJURY RISK IN TRAINING

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ABSTRACT

Training based on competency is a government effort to improve employee candidates' job competence. The Technical Implementation Unit of the Technopark Ganesha Sukowati Sragen is a training centre in the Sragen Regency. Ergonomic issues have still not received attention in some training programmes. The work system design is constructed to support the achievement of the agency's vision and mission, using the macro-ergonomic analysis and design approach (MEAD). Research results show that the key variance is the installation of embroidery hoops, which is difficult and time-consuming. Integration of the work system with ergonomic designs is necessary to create a pleasant training environment and to improve job competence. The new designs include adjustable seats, embroidery hoops tables with a foot rest, improved lighting, facemasks, earplugs, and a drinking water facility. The workshop layout is designed to follow the work process. The trainees also participated in stretching exercises before training began. A t-test was conducted with the same research design and the same subject, and the results showed a reduction of up to 60.39 per cent in musculoskeletal disorders and a reduction of up to 22.2 per cent in the risk of injury

OPSOMMING

Opleiding met bevoegdheid as basis is 'n regeringspoging om die werknemer kandidate se werksvertoning te verbeter. Die Tegniese Implementeringseenheid van die Technopark Ganesha Sukowati Sragen is 'n opleidingsentrum in die Sragen regentskap in Indonesië. Ergonomiese kwessies het nog nie aandag in sommige opleidingsprogramme gekry nie. Die werkstelsel is ontwerp om die sukses van die agentskap se visie en missie te ondersteun deur gebruik te maak van die makro-ergonomiese analise- en ontwerpbenadering. Navorsingresultate toon dat die sleutel variansie die installasie van borduurhoepels is, omdat dit moeilik en tydrowend is. Integrasie van die werksisteem met ergonomiese ontwerpe is nodig om 'n aangename opleidingsomgewing te skep en sodoende werkbevoegdheid te skep. Die nuwe ontwerp sluit verstelbare sitplekke, tafels met 'n voetrus, verbeterde beligting, gesigmaskers, oorpluisies en drinkwater in. Die werkswinkel uitleg is ontwerp om die werkproses te volg. Die vakleerlinge het ook in strekoefeninge deelgeneem voor opleiding 'n aanvang geneem het. 'n T-toets is uitgevoer met dieselfde navorsingsontwerp en dieselfde proefpersoon. Die resultate toon 'n vermindering van tot 60.39 persent in spier-skelet afwykings en 'n vermindering van tot 22.2 persent in die risiko dat 'n besering gaan plaasvind.

1 INTRODUCTION

According to the 2003 Republic of Indonesia Act No. 13 concerning labour, and Presidential Regulation No. 31 of 2006 regarding Indonesia's national qualifications levels and national job training system, the function and purpose of work training is to equip, improve, and develop job competence in order to improve capabilities, productivity, and well-being [1][2][3].

There are currently 329 government employment training institutes (ETIs) in Indonesia, divided into 307 technical implementation units (TIUs) and 22 central technical implementation units (CTIUs) [4]. Musculoskeletal disorders (MSD) experienced by trainees in the ETIs were found to be caused by uncomfortable working conditions while practising the operation of machinery and equipment. This finding is supported by several studies of ergonomically-designed workstations that can reduce MSD and improve productivity [5][6]. Gallagher and Heuberger [7] add that there is an interdependence between high-force demands and the repetition of MSD risk factors. Other studies have also found that poor working postures can have a negative impact on job performance [8], and the development of quick exposure check (QEC) research has found that there is a work-posture stress risk that needs immediate attention to decrease the risk of work-related musculoskeletal disorders (WMSD) [9][10]. Finally, the prevalence of pain symptoms in various body parts has been found to be related to age, work experience, work shift, and body mass index (BMI) [11].

The Regional Technical Implementation Unit (RTIU) has a duty to provide a variety of vocational trainings. Previous research has shown a need to improve the work system. Initial observations of computerised embroidery machine operator training found that, of the MSD symptoms experienced by workers, 57 per cent suffered from back pain, 62 per cent from hip pain, 37 per cent from right knee pain, and 25 per cent suffered from lower neck pain. All conditions were related to non-ergonomic operation of the human-machine system. This study concentrated on improving the work systems at RTIU Technopark Ganesha Sukowati Sragen. The research location was chosen for its computerised embroidery machine operator training programme. The result of a new, ergonomic work system can serve as a tutorial and a model for the entire computerised embroidery operator machine training work system in Indonesia.

This research study used the macro-ergonomic analysis design (MEAD) methodology, which focuses on systematically mapping out organisational problems and solutions by involving all elements of the work system. The related macro-ergonomic research proposes to improve work satisfaction and decrease MSD symptoms [12][13]. Another research study concludes that the use of macro-ergonomic design is an important factor in influencing behaviour and good and efficient performance, while providing an effective learning environment [14][15]. The macro-ergonomic approach has advantages that can generate greater performance than can be achieved through only ergonomic interventions [16].

MEAD is a system that can provide solutions for complex problems. This claim is supported by Suzianti, Humaira and Anjani [17], who state that the MEAD approach can even solve garbage problems in Jakarta. Macro-ergonomic theory and safety zones can be integrated to guide analysis and work system design, thus decreasing negative safety results and improving organisational performance [18][19]. Furthermore, Juprianto, Sutalaksana, Bahagia, abd Iridistadi. Have concluded that success at every technology transfer level in Indonesia has been influenced by a macro-ergonomic factor [20]. This conclusion is the basis for creating a work system training method, based on competency, that was developed in the work training center (WTC) using the macro-ergonomic approach. WTC stakeholder participation is vital to a successful organisational vision and mission through ergonomic training.

2 METHOD

2.1 Subjects and evaluation instruments

The research was located in the Technical Implementation Unit (TIU) of the training centre at Technopark Ganesha Sukowati Sragen. The participants were 16 operators of computerised embroidery machines who met the following criteria: (1) female; (2) aged 21.8 ± 4.8 years; (3) height 155.5 ± 5.3 cm; (4) weight 49.25 ± 7.9 kg; (5) BMI 20.4 ± 3.6 kg/m^2; (6) do not have computer embroidery skills; (7) healthy, with no disability; (8) willing to be participants in this research, as evidenced by providing informed consent. The instruments used were the following: (1) the Nordic

Body Map Questionnaire to measure musculoskeletal disorders [21]; (2) the Quick Exposure Check Questionnaire to measure injury levels [8]; (3) a Canon EOS 550D digital camera for documentation; (4) the Lux brand Physics Line meter to measure lighting; (6) a Cirrus brand sound level meter to measure noise; and (7) a Quest brand thermal environment monitor to measure microclimates.

2.2 Research procedure

2.2.1 Preparation

At this stage of the research, the Nordic Body Map questionnaires were prepared, along with the QEC risk assessment forms for work posture and the biographical data forms for collecting the name, age, gender, and level of education of each participant.

2.2.2 Identification stage using MEAD

MEAD is one of the macro-ergonomic methods used to analyse and improve work systems. The MEAD steps, according to Kleiner [22], are: (1) Define the sub-organisational system, which consists of input-output, customers, work processes, feedback on the organising vision, and mission review; then identify the formal statement of vision and mission, the major stakeholders in the organisational system, and the wishes of the workers and owners. (2) Define types of work systems and establish key performances to be achieved and the desired level of performance. (3) Define work processes and workforce analytics, first by identifying the work units already in the organisation, then identifying the existing work processes of these units and the workforce analytics in order to measure improvement potentials and identify coordination problems. (4) Define the variance of actual and expected factors that cause, or may cause, a gap between worker wishes and owner identification. (5) Make a matrix of variance, using deviation results from the analysis at Step 4, to identify how deviations might influence each other. (6) Identify the roles of personnel who take responsibility for the unit where the deviation happened. (7) Allocate functions and merge design, and make some improvement in the work process and assign responsible persons. (8) Conduct perception and responsibility analysis of identified skills and knowledge needed from the responsible personnel, including tasks and what was done. If there are any gaps between roles needed and personnel perception, then the gaps can be reduced. (9) Redesign support and incorporated subsystems to improve subsystem support. For example, if there are problems in communication or feedback, then it would be necessary to redesign the communication system within the organisation's system. (10) Finally, improve implementation, iteration, and performance.

2.3 Statistical analysis

The control and experiment group normality test was done using the Kolmogorov-Smirnov (K-S) test, yielding a significance level of ($\alpha = 0.05$). A paired-sample t-test (same treatment for the same subject) was also performed to measure decreased musculoskeletal disorders and reduced incidences of injury in the control group and the experimental group. It yielded a significance level of ($\alpha = 0.05$).

Hypothesis (formulation of H_0 and H_1)

H_0 : $\mu1 = \mu2$ (The mean of musculoskeletal disorders and risk injury value of the control group is equivalent to the mean of musculoskeletal disorders and risk injury value of the experiment group).
H_1 : $\mu1 > \mu2$ (The mean of musculoskeletal disorders and risk injury value of the control group is larger than the mean of musculoskeletal disorders and risk injury value of the experiment group).

3 RESULTS AND DISCUSSION

This section describes the implementation of the 10 MEAD steps in the new competency-based work system training design.

3.1 Define the organisation's subsystem and type of workforce system, and establish a desired level of performance (Step 1 of MEAD)

A competency-based training programme in the Technical Implementation Unit of the training centre at Technopark Ganesha Sukowati Sragen was held for community job-seekers. A total of 16 candidates were accepted for a 30-day programme. The training programme contains the competency units that must be taken. The organisational vision is to realise the value of human resources and new technology innovations. The organisational mission is (1) to implement competency-based training; (2) to implement competency testing; (3) to conduct research and development (R&D) testing that results in innovative collaboration with universities, R&D

institutions, companies, and communities; (4) to carry out operational secretarial tasks; (5) to carry out other duties assigned by the head of manpower and transmigration units in accordance with their duties and functions; and (6) to increase earnings from local goods and services. The primary stakeholders are the trainees, because the main goal is to improve work competency based on their area of employment. The objective is to establish an ergonomic training process to support the target achievement of field-based work competency.

3.2 Define types of work systems, establish desired levels of performance, and define work processes and workforce analytics (Steps 2 and 3 of MEAD)

The computerised embroidery machine operator training process requires the following eight units of competency to be completed:

1. Conducting 5S workplace organisational methodology
2. Following OHS workplace procedures
3. Performing maintenance
4. Reading and understanding punch image design
5. Setting and editing computer embroidery machine programs
6. Installing yarn and materials
7. Operating computer embroidery machine
8. Applying quality standards

Sixteen trainees followed the computerised embroidery machine training for 30 days with two instructors. Computer embroidery training processes promote production processes. The trainee should follow the training schedule from 7:30 am to 2:45 pm, with a 15-minute break at 09:45 am and a 30-minute lunch at 11:30 am.

The technical implementation unit conducts training activities to improve the quality and productivity of the workforce as determined by the regional government budget and the Indonesian budget. The budgets need to be adapted to TIU agency needs, based on the training needs analyses of market demands and the workforce. The key performance to be achieved is equal to the employees' levels of performance, measured by the percentage of reduced trainee musculoskeletal disorder during the training process, and the percentage of reduced trainee injury risk during the training process.

The ergonomic work system needs to be applied to the training process in order for the trainee to avoid injury when standing, bending, squatting, and lifting and moving materials, and when pressing embroidery hoops repeatedly and continuously. The TIU's job analysis of existing work processes in computerised embroidery machine training identified unnatural body positions and non-ergonomic ways of working for extended, continuous periods of time as the primary causes of workers' health problems. These problems include pain in hands, feet, back, or waist, depending on the job performed; decreased motivation and comfort during the training process; and movement disorders in certain body parts, including difficulty moving feet, hands, and neck.

3.3 Define actual variances and expectations, and create a variant matrix (Steps 4 and 5 of MEAD)

Table 1 shows the various data in the training process steps, trainee complaints, problems, and the effects of those problems. At this stage, the main computer embroidery competency unit is analysed.

Table 2 is the variances matrix that was created to see the relationships among the factors involved in computer embroidery operator training. 'Weight' is the level of representation of the problems experienced by the trainees. In interviews with 48 employees (16 trainees in three training periods), 13 (27 per cent) of the trainees stated that material installation was difficult and time-consuming; 10 (21 per cent) had problems reaching the work machine; eight (17 per cent) complained about poor lighting; five (10 per cent) were annoyed by the high noise level; four (eight per cent) stated that material dust interfered with their work; and eight (17 per cent) of the trainees said that the layout was irregular. From the calculations in Table 2, the greatest variance weight of 4.06 is given to difficult and time-consuming work. This is the key variance that has priority for work system improvement. Other priorities in order of weight are improved lighting, layout, need for footstools, and use of PPE.

Identified personnel roles (Step 6 of MEAD)

This section analyses the role of personnel, and aims to identify how to control the existing variances and the role of responsible personnel during training implementation in which each variation occurs. Some aspects are illustrated in Table 3.

Based on Table 3, the problem of installation was caused by inadequate preparation, so the role of the participant was to solve these problems. Technically, this problem requires supporting employment facilities to provide the embroidery hoops, desks and chairs, and footstools.

Table 1: Variant data

Training process stage	Variances	Cause	Effect	Expectations
Setting and editing computer embroidery program	a. Bad lighting b. Machine too high to reach comfortably	a. Low light intensity b. No footstools	a. Low comfort level b. Competency not achieved c. Compromised health and work safety	a. Increased comfort and work safety b. Adequate lighting c. Can reach machine comfortably
Installing yarn and material; operating computer embroidery machine	a. Material installation difficult and time-consuming b. Bad lighting c. High noise level d. Annoying material dust e. Machine too high to reach comfortably f. Irregular layout	a. No embroidery hoops clamp b. Low light intensity c. High noise intensity d. No protective personal equipment (PPE) e. No footstool f. Layout not yet arranged	a. Low comfort level b. Competency not achieved c. Compromised health and work safety	a Increased comfort and work safety b Adequate lighting and normal noise levels c Protection from dust with mask d Can reach the machine comfortably

Table 2: Variances matrix

	Variances	Weight (%)	1	2	3	4	5	6	Total
1	Material installation is difficult and time-consuming	27			■		□	□	4.06
2	Machine too high to reach comfortably	21			□	○			0.83
3	Bad lighting	17	■	□				□	2.50
4	High noise level	10		○				○	0.21
5	Annoying material dust	8	□					○	0.33
6	Irregular layout	17	□		□	○	○		1.33

Crisp Code: ○ = 1; □ = 3; ■ = 9. Adapted from Matrix House of Quality [23].

Table 3: Key variance control and personnel role analysis

No	Key variance	Involved personnel	Person in charge	Control*	Technical support
1	Difficult and time-consuming installation of materials	Trainees	Trainees	Emphasis of K3 and 5S cultural programmes	Embroidery hoops, seat, and desk
2	Working range of reach to the machine is too high	Trainees	Trainees	Emphasis of K3 and 5S cultural programmes	Foot stool
3	Poor lighting on machine	Trainees	Training Provider	Emphasis of K3 and 5S cultural programmes	Improved lighting
4	Disruptive noise near the machine	Trainees	Training Provider	Emphasis of K3 and 5S cultural programmes	Earplugs
5	Uncomfortable dust	Trainees	Training Provider	Emphasis of K3 and 5S cultural programmes	Masks
6	Irregular layout	Trainees	Training Provider	Emphasis of K3 and 5S cultural programmes	Consistent layout

* Improvements in key variances are controlled by emphasis of K3 and 5S cultural programme (sort, straighten, shine, standardise, sustain).

3.4 Allocate function and merge design (Step 7 of MEAD)

At this stage, the aim is to create a work system design and allocate responsible personnel to create an improved work system alternative. The old work system is straightforward and non-ergonomic, while the new work system considers trainee comforts to achieve the desired levels of competence.

Table 4: Differences between old work system and new work system

Factor	Before improvement	After improvement
1. Physical environment		
a. Dusty air pollution	Did not use mask	Trainees must use mask while operating the machine
b. Heat temperature	Air conditioning	Air conditioning
c. High machine noise level	Did not use earplugs	Earplugs used while operating machines
d. Inadequate lighting	Inadequate lighting	Lights with a minimum 600 lumens
2. Fatigue	Ordinary mineral water facility	Provision of a drink dispenser for easy access to hot and cold water
3. Musculoskeletal disorder	No stretching exercises	Stretching exercises
4. Risk of injury	Non-ergonomic work facility	Provision of embroidery hoops, desks and chairs, and ergonomic footstool
5. Work layout	Work layout in rotated position	Work layout side-by-side

3.5 Analyse perception and responsibility, and redesign subsystem support (Step 8 of MEAD)

At this stage, the aim is to provide an analysis of the work system training programme. The system design will provide a comfortable work space geared toward the best competency-based training. Work system design is meant to provide solutions to the key issues that computer embroidery training participants face in the difficult and time-consuming process of material installation. The role of the trainee is that of the main stakeholder involved in, and responsible for, the work system design. Focus group discussions facilitate and accommodate trainees' ideas, and participant involvement in facility design encourages shared responsibility. The method used to achieve the facility design is the focus group discussion (FGD). The FGD members consist of seven people, made up of two participants, two instructors, a researcher, a designer, and the head of WTC. Seven members are enough because the ideal member total is recommended to be between six and 12 persons [24]. The FGD met once in the first week, once in the second week, and once in the third week. The desired design was formulated from FGD input results. Evaluation of the results improved the design, reaching the final draft stage. The design improvement evaluation was as follows:

1. Stage One: Desk dimensions to be adapted with user anthropometry in standing position; seat dimension to be adapted with user anthropometry in sit-to-stand position; footrest to be adapted to user anthropometry; seat and desk should be to the left of the machine; seat, desk, and footrest materials should be acceptably hygienic material.
2. Stage Two: FGD results at this stage; have an agreement from the first stage, with some improvements made by adding embroidery hoop clamps and placing a footrest under the desk.
3. Stage Three: Improvement made on second stage by including chairs with a steel frame and a circumference pedestal equipped with anti-slip rubber on the foot soles.

The results of the FGD forum involved sit-to-stand seat facilities formulated by the trainees, embroidery hoops desks, and footrests adapted to the trainees' anthropometry as a corrective alternative. The final evaluation is done by reaching agreement in the FGD for better results. Dimensions used in the facility design, based on the trainees' anthropometry and the anthropometric data used, are:

1. Elbow stand height with an average of 97.3 ± 5.3 cm was used to design desk height (A) using 5th percentile; thus dimension A becomes 88.6 cm. The 5th percentile for desk height was used to ensure no extended reach or uncomfortable working conditions [25].
2. Arm length average of 72.1 ± 4.8 cm was used to design the desk width (B) using the 5th percentile; thus dimension B becomes 64.2 cm. The desk width using the 5th percentile fulfills the needs of those with small anthropometry [26].

3. Arm span with an average of 156.7 ± 6.0 cm was used to design the desk length (C) using the 5th percentile; thus dimension C is 146.8 cm. The desk length using the 5th percentile accommodates people with small dimensions [27].
4. Hip height with an average of 69.1 ± 4.1 cm was used to design the seat height (D) using the 5th percentile; thus dimension D is 62.2 cm. Seat height using the 5th percentile ensures reach is not out of range [25].
5. Hip width with an average of 36.7 ± 3.0 cm was used to design the seat width (E) using the 95th percentile; thus dimension E is 41.6 cm. The seat width using the 95th percentile is to accommodate larger hip widths [28].
6. Light height from desk surface (F) was designed to be 100 cm above the desk board using two lamps, each with a light power of 40 watts, capable of producing 600 lumens of light intensity [29].
7. The elbow seat height is used to design the footrest height (G). The 5th percentile height is 88.6 cm, but the desk surface height is 100cm. The footrest height (G) is 11.4 cm (100-88.6 cm).

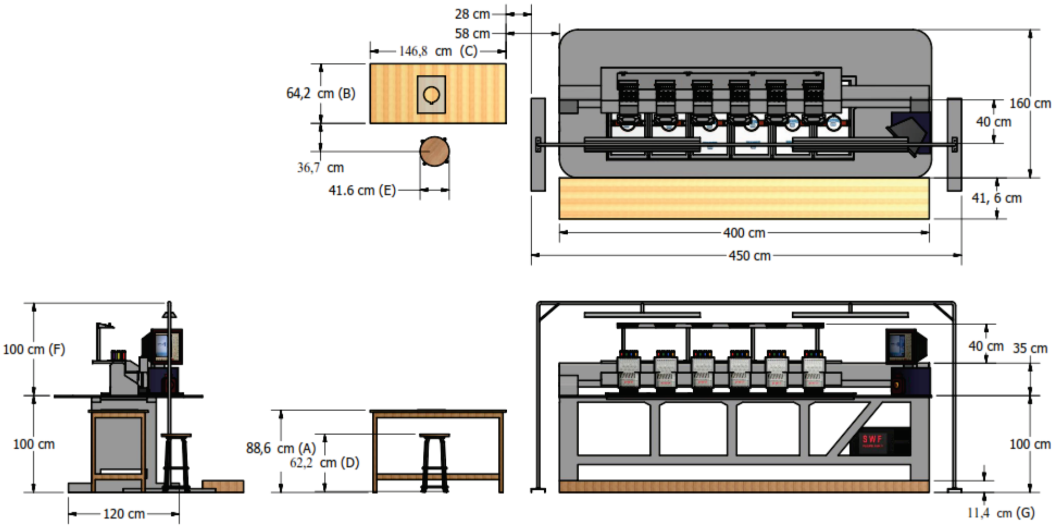

Figure 1: Work facility design

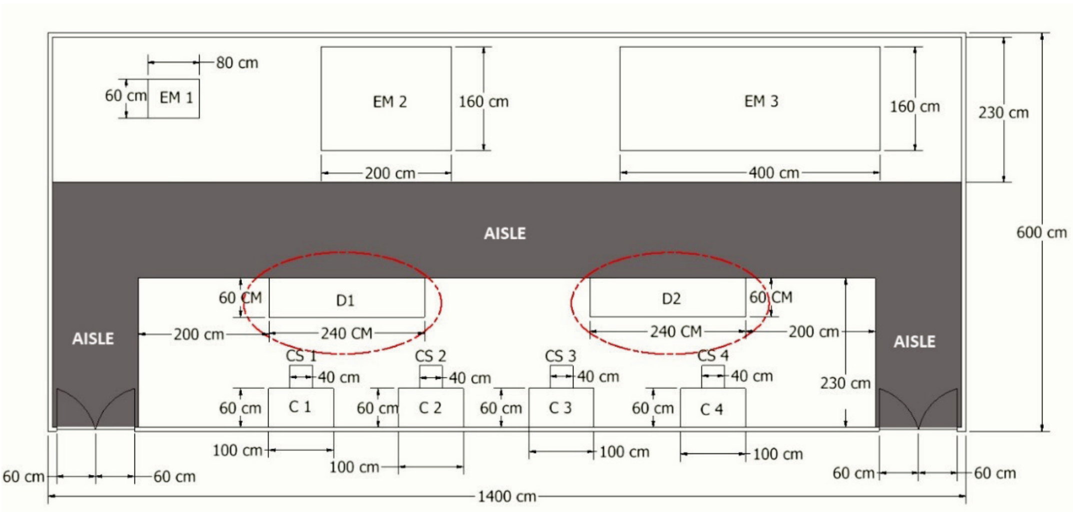

Figure 2: Previous layout of the computer embroidery training workshop

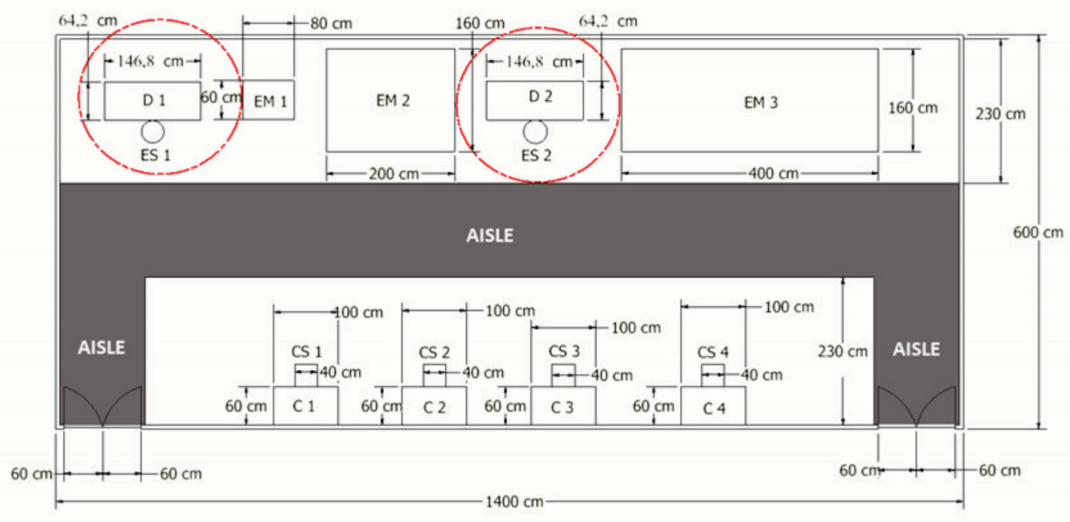

Figure 3: New computer embroidery training workshop layout

Note: EM 1, 2, 3 = embroidery machines 1, 2 and 3; C1, 2, 3, 4 = computers 1, 2, 3 and 4; D1, 2 = desks 1 and 2; CS 1,2,3,4 = computer seats 1, 2, 3 and 4.

The differences between the previous and the new layout are as follows: (a) the previous layout places the trainee behind the machine, forcing her to twist around to work the embroidery machine; (b) the new layout includes an additional seat and renewable embroidery hoops desk; and (c) the desk position is placed to the left of the embroidery machine.

3.6 Redesign support and incorporated subsystems; implementing, iterating and improving (Steps 9 and 10 of MEAD)

This stage evaluates and possibly redesigns the plan if there is any deficiency in design and implementation. The new work system design is meant to provide solutions for computer embroidery trainees. If there is no need to redo it, the FGD makes sure that the design is ready to be implemented. The FGD results at week four show that all stakeholders are in agreement with the new design. The previous and new designs are shown in Figure 4.

a b c d

Figure 4: (a) old embroidery hoops process; (b) improved embroidery hoops process; (c) old embroidery process; (d) improved embroidery process

Work system designs that are based on competency in the computer embroidery operator program to support the achievement of trainee competence require the integration of work system components. Work environment factors and the work facility must be aligned with the desired performance levels. The work facility designs applied in this case are: sit-to-stand seats, embroidery hoops desks, and footrests. An ergonomic work environment is achieved by implementing standardised lighting, using masks to protect the trainee from inhaling dust, and using earplugs while operating the machines. The layout is achieved by placing machines efficiently, and reduced musculoskeletal disorders are achieved by stretching for five minutes.

The final results of the macro-ergonomic work system are measured by a paired-sample t-test, using a treatment-by-subject design (the same treatment for the same subject). This research planned to have a control group as the subjects, but treatment was done at a different time. The control treatment was tested for as long as 10 days, with the gap between the first and the second treatment as long as 10 days; the experiment group treatment was done in 10 days.

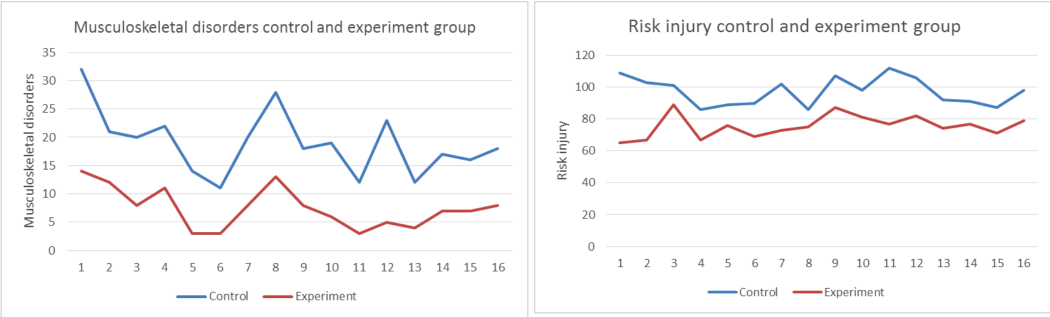

Figure 5: Chart of decreasing musculoskeletal disorders and risk of injury in control and experiment groups (see online version for colour images)

Based on the normality test, the data showed a normal distribution of $p>0.05$. Meanwhile, t-test results showed that trainee musculoskeletal disorders and the risk of injury have a probability of 0.00 ($p<0.05$), indicating that H_0 could be rejected. This means that musculoskeletal disorders and the risk of injury showed a meaningful decline for both the control group and the experiment group. The mean difference for musculoskeletal disorders between the control and experiment groups was 14.47, declining by 60.39 per cent. The mean difference for the risk of injury between the control and experiment groups was 9.052, declining by 22.2 per cent.

4 CONCLUSION

The results of this research study have shown that a competency-based training work system design using MEAD was able to identify key variances that negatively affected the process of competency acquisition in a training programme. It can be concluded that musculoskeletal disorders and the risk of injury can be decreased with the use of an ergonomic work system design that integrates sit-to-stand seats, embroidery hoops desks, and footrests into the existing structure. An improved work environment was accomplished by applying an adequate lightning standard and an effective work area layout. And providing masks and earplugs while operating machines, and stretching before training begins, improved the health and safety standards.
Work system designs using MEAD could significantly reduce musculoskeletal disorders and the risk of injury. Ergonomic work training processes are expected to be applied in all work training workshops in Indonesia. Support from stakeholders will help significantly in creating a safe and comfortable work culture that is in compliance with the organisational vision and mission.

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