POSTURE, MUSCLE ACTIVITY AND OXYGEN CONSUMPTION EVALUATIONS AMONG METAL STAMPING OPERATORS: A PILOT STUDY IN MALAYSIAN SMALL AND MEDIUM INDUSTRIES

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ABSTRACT

In the new era of world industrialization, ergonomics plays an important role to improve occupational health and productivity in most industries including small and medium industries (SMIs). However, SMIs in Malaysia do not put any priority on ergonomics awareness, for an example, by not designing the workstation ergonomically. As a consequence, operators are exposed to various ergonomic risk factors and prone to have ergonomic injuries. The objectives of this study are to evaluate working posture, muscle activity, and oxygen consumption while operators perform metal stamping process in a workstation, before and after the workstation is modified. The Rapid Entire Body Assessment (REBA), surface electromyography (SEMG), and oxygen analyser are used to evaluate working posture, muscle activity, and oxygen consumption respectively. Results of evaluations found that the modified workstation has reduced the physiological stress such as extreme posture, work/loading in the muscles as well as energy expenditure. The study concluded that an ergonomic workstation design can contribute significantly to improve physiological performance of the operators.

Keywords: *Metal Stamping Process, Muscle Activity, Oxygen Consumption, Workstation Design, Working Posture*

1.0 INTRODUCTION

In Malaysia, Small and Medium Industries (SMIs) has been recognised as one of the contributors to the growth of the nation's economy. Although the growth of Malaysian SMIs is rapid and their expansion is fast, they still face challenges that can affect their competitiveness. The companies under Malaysian SMIs have limitation in terms of ergonomics awareness, for examples, lack of materials handling equipment and improper workstation design. In addition, the efforts to enhance ergonomics awareness in Malaysian SMIs have several constrains in terms of manpower and availability of the service of ergonomits [1]. As a consequence of this, workplace conditions in the SMIs received very minimum intervention in ergonomics services. For example, the workstations for operators to perform the jobs are not designed ergonomically, thus exposing them to various difficulties such as extreme working posture, muscle fatigue, and the extra effort required to get the job done.

In industrial workplaces, designing a workstation is really important because it can contribute to feasible occupational health, job satisfaction, and work efficiency. Physiological factors such as posture, muscle activity and oxygen consumption should be critically studied when designing a workstation. Working posture can be defined as the orientation of body parts in space and in relation to each other while an operator performs a task [2].

Working posture is determined by the anthropometry of the operator, design of the workstation and the way the job is carried out. Dimensions, spatial position, orientation and design of workstation must be suited to the physical condition of the operator so that the operator can perform the task comfortably and safely in the workstation. The criteria for an ergonomic workstation design include locating materials and tools at appropriate height, thus making it easy to be reached by the operators. A proper workstation design will enable operators to practice safe working postures; otherwise it may contribute to awkward working postures [2].

In the design of a workstation, working height is very important. The height of the working surface should vary based on the operator's elbow height, and the type of work. A previous study pointed out working height, in general, should be set at 5 cm below the elbow level [3]. However, the working height can vary several centimeters, up or down, without any significant effect on performance [4]. A proper working height will allow a comfortable working posture. In contrast, inadequate posture from an improperly designed workstation can cause ergonomic injuries such as muscle strain, low back pain, and consequently decreased performance and productivity [5].

Popular methods to identify ergonomic risk factors in the workplace include observational method and direct technical measurement method. Usually, observational method is applied to obtain psychophysical feedbacks from respondents (operators) through personal interviews and questionnaire surveys.

Other tools include Rapid Upper Limbs Assessment (RULA) [6] and Rapid Entire Body Assessment (REBA) [7]. REBA is an ergonomic assessment tool that is specifically designed to assess working postures and movements corresponding to the tasks and workstations. It was developed on the basis of Rapid Upper Limbs Assessment (RULA) analysis, but it is also appropriate for evaluating tasks where the working postures are dynamic, static or where there are gross changes in posture [7]. Similar to RULA, this survey tool is useful when investigating postural stress during performance of tasks.

On the other hand, direct technical measurement method is applied to acquire information on physiological and biomechanical responses of subjects (operators). Normally, direct technical measurement method uses scientific tools which can measure specific parameters such as frequency, and voltage during the evaluations. The surface electromyography (SEMG) is one of the scientific instruments that has been applied to quantify muscle fatigue among operators while they are performing jobs [8-11].

The SEMG measures and records electromyography signals associated with the contraction of the muscles. It has been used in ergonomics for evaluation of operator performance associated with workstation design, for example, in the analysis of working posture for sedentary task [12], sewing operation [2] and manual materials handling [13].

Other equipment categorised under the direct technical measurement method is oxygen analyser. It is used to measure oxygen consumption of workers. The measurement of oxygen consumption is aimed to quantify the energy demands posed by the workstation design and task. Oxygen consumption can be defined as the volume of oxygen that is consumed by the worker during performing the task. This volume is expressed as a rate, either liter per minute (l/min) or milliliter per kilogram per minute (ml/kg/min). From the measurement of oxygen consumption, the energy expenditure of worker also can be obtained. A previous study quantified that 1 liter of oxygen consumed by the worker while performing task is equal to 21.2 kJ of energy needed by the worker [14]. Table 1 presents the amount of energy expenditure with respect to workload category.

Table 1: Classification of energy expenditure while performing task [14]

Workload Category	*Energy Expenditure*
Light task	Up to 10 kJ/min
Medium task	About 20 kJ/min
Heavy task	About 30 kJ/min

Realising the needs of ergonomic workstation design, this study was conducted to evaluate working posture, muscle activity, and oxygen consumption while operators perform metal stamping process at their workstation (existing design), and later at the modified workstation.

2.0 RESEARCH METHODS

Three metal stamping operators have participated as subjects in the study. The profile of the subjects:

- Age: mean = 20 years, SD = 2.0 years
- Gender: male
- Work experience: mean = 1 year, SD = 1.5 year
- Body mass: mean = 55.9 kg, SD = 3.3 kg
- Body height: mean = 1.7 m, SD = 0.07 m

The study was divided into two stages. During the first stage of the study, the evaluation was performed at the existing workstation (before the workstation design is modified). The second stage evaluation was carried out after the workstation was modified. Both stages analysed the same operators carrying out similar tasks. Before conducting the study, the researchers have obtained research approval regarding the methods and procedures from the Research Ethics Committee of Universiti Teknologi MARA.

2.1 Working Posture Evaluation

REBA [7] was used to analyse the working posture. The analysis can be done either using REBA Worksheet [7] or using computer programming to generate the results. Analysis using manual method (worksheet) may be time consuming and may lead to errors especially when large volumes of data have to be assessed. To overcome the shortcomings, computer programmed REBA was used to record, analyse and save all data and information regarding working posture analysis [15].

In the programmed REBA, the system has four graphical user interfaces. In the first graphical user interface, it records the profiles of operator to be assessed. This interface captures the information about personal particulars such as operator's identification card number, operator's name, position, age, weight, height, gender, marital status, service duration, working mode, alcohol consumption and smoking of cigarettes. The second graphical user interface records information regarding the workstation. This includes the task carried out in the workstation, and description of the task. In this graphical user interface also, the researcher has to tick the evaluation stage: whether the analysis is conducted before, or after ergonomic intervention is carried out in that workstation.

The third graphical user interface captures the information of operator's body parts. The information includes the movements and postures of six body parts while performing the task in the workstation. The fourth graphical user interface presents the results of analysis. The result is presented in four parts: Part A, Part B, Part C and Part D. Part A presents the personal particulars of operator. This includes name of company, operator's identification card number, operator's name, position, and workstation. Part B describes the working posture of the operator while the task is performed. It includes the posture of the body parts such as trunk, neck, legs, upper arm, lower arm, and wrists. Part C presents the working condition of the operator in the workstation such as load handled, coupling condition and the style or movement of operator while performing a task. Part D presents the result of risk levels of ergonomic injury (in terms of REBA score) corresponding to working posture adopted by the operator. The REBA Score is expressed on a scale of 1 to 15, as tabulated in Table 2.

Table 2: Risk levels of ergonomic injury corresponding to REBA score

REBA Score	Risk Levels of Ergonomic Injury
1	Safe
2 - 3	Low
4 – 7	Medium
8 – 10	High
11 – 14	Very High

2.2 Muscle Activity Evaluation

The surface electromyography (SEMG) ME3000P4 (MEGA Electronics, Finland) and MegaWin Software were used to record, store and interpret all the data regarding to muscle activity of the operators. The SEMG system is equipped with surface electrodes attached conscientiously to operator's skin to detect the electromyography signals of operators while the task is performed. Eight muscles were selected for the evaluations: deltoid-medial part (left), deltoid-medial part (right), trapezius muscle (left), trapezius muscle (right), erector spinae muscle (left), erector spinae muscle (right), gastrocnemius muscle (left) and gastrocnemius muscle (right). The location of these muscles is clearly shown in Figure 1.

To ensure that the electrodes are attached properly to the muscles and other SEMG protocols were complied, a physiotherapist was consulted before the evaluation is carried out. The evaluation was performed early in the workday (8:30 am) on the first day of the week (Monday) to ensure the muscles to be analysed are free from the influence of previous task activities. All muscles of the operator were concurrently measured for more than 30 minutes during the performance of the tasks.

Setting of SEMG system was based on Surface EMG for the Non-Invasive Assessment of Muscles (SENIAM) [16]. The settings are as follows:

- EMG electrodes: Surface electrode Ag/AgCl, 20 mm diameter
- Distance between electrodes: 25 mm
- Skin preparation: Shaved, clean, and scrubbed with alcohol
- Common Mode Rejection Rate (CMMR): 110 dB
- Filter: Band pass filter (85 Hz – 500Hz)
- Sampling rate: 1000 Hz

The measurements of muscle activity were conducted based on real time monitoring. All SEMG electrodes were connected to a data logger to record and store the electromyography signals. Then, the data logger was connected to a PC screen using wireless connection to display and monitor the electromyography signals. Before beginning the test, the personal particulars of the operator were recorded in MegaWin Software, and the operator was given sufficient time to get enough practice to familiarise with the SEMG instruments. The operator was also informed that he has to perform the task at his own pace and should immediately report any feeling of pain or discomfort so that the measurement can be terminated. After all the measurement settings are ready, the operator can now start to perform his task.

2.3 Oxygen Consumption Evaluation

In this study, the Metamex Cortex, Germany and MetaSoft® 3 Software were used to measure and analyse operators' oxygen consumption while performing their task at the workstation. During the measurement, the instrument is attached to the operator's body as shown in Figure 1 below.

Figure 1. Selected muscles were attached with Ag-AgCl electrodes: deltoid-medial part (shoulder region); trapezius muscle (neck region); erector spinae (lower back), gastrocnemius muscle (leg region). An operator is equipped with a chest-mounted light-weight oxygen analyzer on his body to measure oxygen consumption (right).

3.0 EXPERIMENTAL STUDY

3.1 Before Modification of the Workstation

Operators perform metal stamping process manually by feeding the workpiece into the stamping machine. The process consists of moving raw materials from the floor to the stamping machine. The operator lifted the materials weighing about 300g each, which are to be stamped at the rate of 5 to 8 movements per minute.

During the process, the operator stands in front of the stamping machine and feeds the raw materials into the machine die using both hands. The starting position was at upright posture (~90 degrees with respect to the body midline) whereby the body is close to the machine. As shown in Figure 2, the raw materials were placed in a bucket located on the floor on the right side of operator. The distance between operator's hand and the raw materials is approximated about 100 cm. The operator has to bend his body downwards to reach the materials as the bucket was in a low level.

At this instant, the distance of his shoulder and the floor is 100 cm as demonstrated in Figure 3. After a raw material has been grabbed, it will be transferred to the machine die for stamping process. As illustrated in Figure 4, operator feeds the raw material to machine die at a distance of 70 cm from his body. The machine which has capacity of 110 tons will shape the raw material according to the geometry or pattern of the die. The finished parts will be thrown into another bucket on the left side of operator. In this condition, the operator is in upright working posture, but he has to slightly bend his body to the left side as shown in Figure

5. The process is repetitive in nature, in that the operator has to perform the task continuously for 8 hours (with stop only for tea break and lunch). The temperature in the work environment was 27ºC to 31ºC.

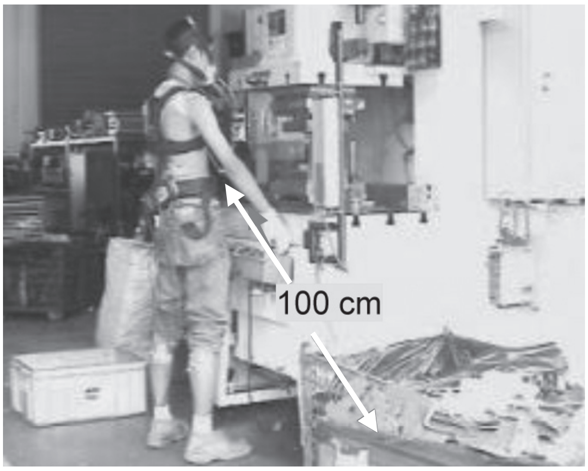

Figure 2: Operator stands in front of the machine

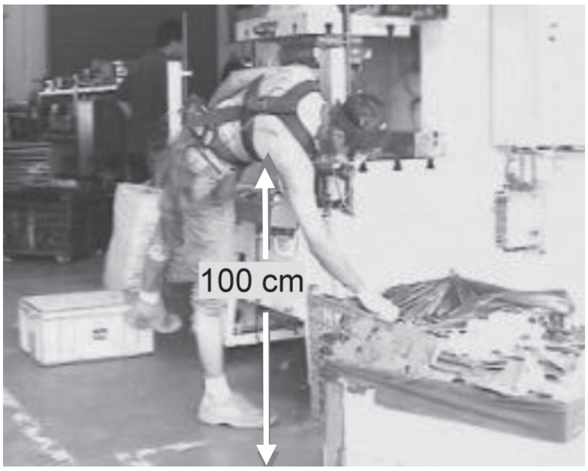

Figure 3: Operator reaches the material

Figure 4: Operator feeds the material into the machine die

Figure 5: Operator throws the finished part

3.2 After Modification of the Workstation

The workstation is later modified to improve the physiological performance of operators. A duration of four months was given to ensure the operators familiar with the new design of workstation. This intervention is essential to reduce muscle fatigue especially in the lower limbs. Two items were introduced to the workstation, namely an adjustable table to place the bucket, and a sit-stand stool.

As illustrated in Figure 6, the adjustable table was used to raise or lower the height of bucket containing the raw materials. When the bucket is at an appropriate level (elbow height), the operator is able to reach easily for the raw material from the bucket to feed them into the machine die. With the bucket at an appropriate level, bending posture has been eliminated. Meanwhile, the sit-stand stool was introduced to enable the operator to work in both sitting and standing postures. The sit-stand stool was also equipped with a foot rest to provide comfort for the operator's legs.

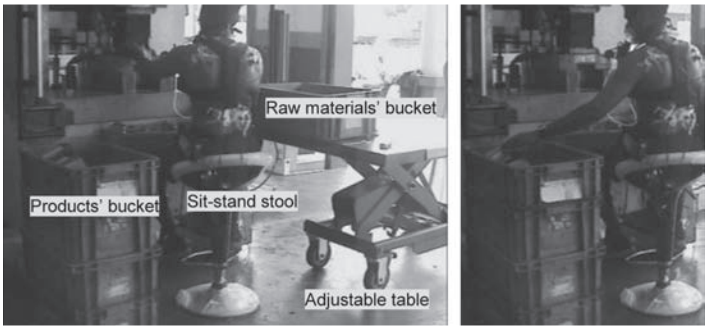

Figure 6: Operator performs metal stamping process at the modified workstation

4.0 RESULTS AND DISCUSSIONS

4.1 Results of Working Posture Evaluation (Before Modification of the Workstation)

At the existing workstation, the operators adopted four working postures while performing metal stamping process which were: standing, bending, feeding and throwing postures. The results of each working posture associated with existing workstation design are presented in Table 1. The results of standing posture show that the first and second operators obtained REBA score of 3, while the third operator acquired a REBA score of 2. According to REBA, such results indicate that the standing posture is safe to the operators as indicated by low REBA scores [7]. While in the standing posture, the operators perform the task with their trunks in upright position with their feet apart. This posture allowed the operators to perform the task in neutral working posture and standing in a stable position.

The results of bending posture found for all operators gave high REBA scores. This is due to bending of the trunk downwards and the left leg is slightly hung. This posture affects the lower back of operators because they have to perform the task in bending and standing in an unstable position. As a consequence, the operators were exposed to a high risk for ergonomic injuries associated with low back pain. REBA suggests that the working posture required further improvement [7].

The results of feeding posture show that the posture of first and third operators were safe as they obtained REBA score of 2. However, the second operator experienced medium risk for ergonomic injuries as he obtained REBA score of 4, and this requires further improvement [7]. While in feeding posture, the operators perform task in a standing posture with their trunks in upright position and their arms slightly extended.

Based on the results of throwing posture, both first and second operators were exposed to high risk for ergonomic injuries as they obtained REBA score of 8. The third operator has a slightly lower REBA score of 7, with medium risk for ergonomic injuries This posture can affect the operators because they have to slightly bend their body to left side while throwing the finished products into the bucket.

Table 3 summarises the results of working posture evaluation for each operator while they perform the task at the existing workstation. From the table, it can be concluded that both bending and throwing postures can contribute significantly to ergonomic injuries as they obtained high REBA scores. The bending and throwing postures may affect the lower back especially the erector spinae muscle.

Table 3: Results of working posture evaluation using REBA (Before modification of the workstation)

Operator	*Standing*	*Bending*	*Feeding*	*Throwing*
Operator 1	3	9	2	8
Operator 2	3	10	4	8
Operator 3	2	10	2	7

4.2 Results of Working Posture Evaluation (After Modification of the Workstation)

The second stage evaluations were conducted four months later after the workstation has been modified. At the modified workstation, the operators adopted four working postures: sitting posture, reaching posture, feeding posture and putting posture. For the sitting posture, the first and second operators obtained REBA score of 3, while the third operator obtained a score of 2. This indicates the sitting posture can be considered safe for the operators. While performing the task in sitting posture, the operators' trunks are in upright position and their legs are well supported by the foot rest of sit-stand stool as shown in Figure 7. Instead of sitting, the sit-stand stool also allowed the operators perform the task in standing posture. They can choose either to stand or to sit, whichever they feel comfortable with. As a consequence of this intervention, the operators' risk for ergonomic injuries has been reduced.

For the reaching posture, the first and third operators acquired a REBA score of 2, while the second operator acquired a score of 3. The results show that the reaching posture can also be considered safe to the operators. The reaching posture showed a positive result because the operators can easily reach the raw materials now. This is due to the adjustment made to the height of raw materials, which has been raised to an appropriate level (elbow height) using an adjustable table.

For the feeding posture, both the first and third operators acquired a REBA score of 3, while the second operator acquired a score of 4. The results indicate that the feeding posture is still safe for the operators. While adopting feeding posture, the operators' hands are parallel to the machine die so that they can feed the raw materials into the machine die easily.

For the putting posture, all operators acquired a REBA score of 2, indicating that the posture is safe for the operators. This is due to the fact that the height of the bucket was adjusted to an appropriate level and positioned as close as possible to the operators to enable them to place the finished products into the bucket easily.

Table 4 summarizes the results of working posture evaluation for each operator while they perform metal stamping process at the modified workstation design. From the tabulated results, it can be concluded that the current working postures are safe, and there is a low risk of ergonomic injuries.

Table 4: Results of working posture evaluation using REBA score (After modification of the workstation)

Operator	*Sitting*	*Reaching*	*Feeding*	*Putting*
Operator 1	3	2	3	2
Operator 2	3	3	4	2
Operator 3	2	2	3	2

4.3 Improvement of Working Posture

This section presents the effectiveness of modified workstation by comparing the results of working posture evaluation. From Figure 7 to Figure 9, it can be observed that the modified workstation can reduce the risk for ergonomic injuries as proved by decrement of REBA score. For the first operator (Figure 7), the modified workstation significantly reduced the REBA score from 9 to 2 when reaching for the raw materials. Meanwhile the REBA score for placing the finished products into finished products' bucket was reduced from 8 to 2. As illustrated in Figure 8, the modified workstation had significantly reduced the REBA score when reaching for the raw materials from 10 to 3 for the second operator. Meanwhile the REBA score for placing the finished products into finished products' bucket was reduced from 8 to 2. Figure 9 shows an improvement for the working posture of third operator was also improved through implementation of the modified workstation. The REBA score when reaching for the raw materials was reduced from 10 to 2. The REBA score when placing the finished products into bucket was also reduced from 7 to 2. The results of these evaluations clearly show that the modified workstation is capable of improving the working posture of operators.third operator was also improved through implementation of the modified workstation. The REBA score when reaching for the raw materials was reduced from 10 to 2. The REBA score when placing the finished products into bucket was also reduced from 7 to 2. The results of these evaluations clearly show that the modified workstation is capable of improving the working posture of operators.

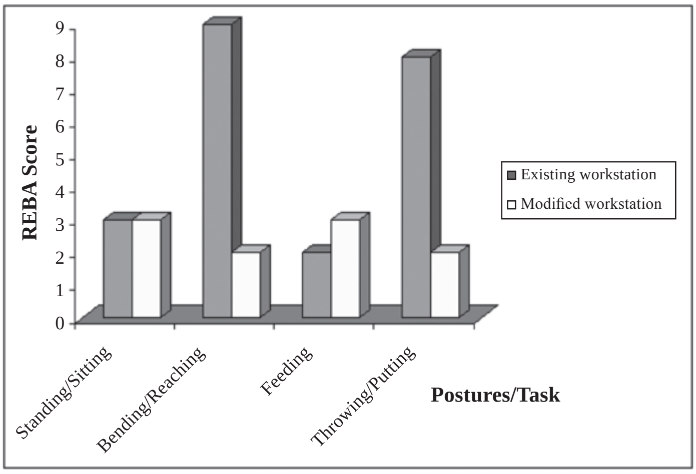

Figure 7: Comparison result of working posture evaluation for the first operator

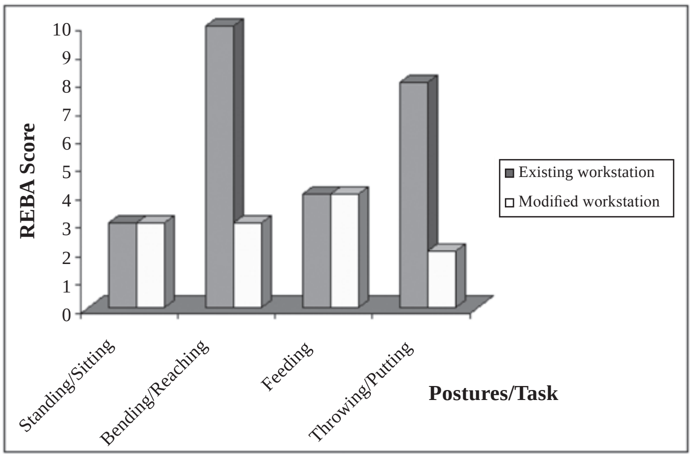

Figure 8: Comparison result of working posture evaluation for the second operator

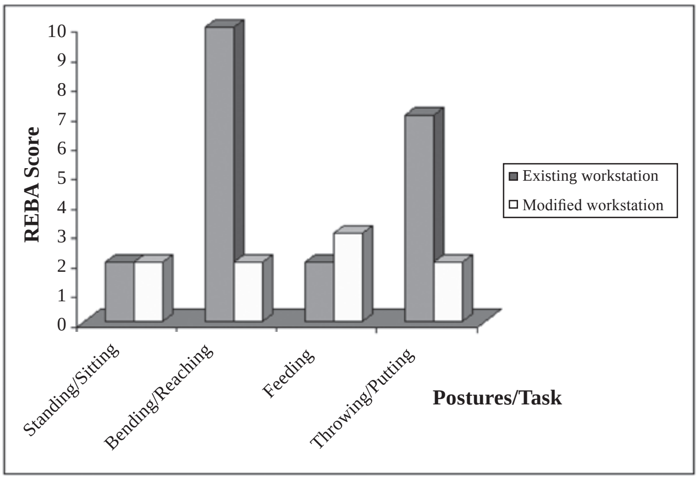

Figure 9: Comparison result of working posture evaluation for the third operator

4.4 Results of Muscle Activity Evaluation (Before Modification of the Workstation)

The following sections discuss the results of muscle activity while the operators perform the task at the existing workstation. These results described the response of operators' muscles corresponding to their working posture and task. Two types of analyses, namely raw signals analysis and work/loading analysis were performed to determine the impact of existing workstation on operators' muscles.

4.4.1 Raw Signal Analysis (before modification of the workstation)

The results of raw signal analysis represent the myoelectric signals from the operators' muscles corresponding to their task load. The myoelectric signals are measured in microvolts (µVs) and they indicate the efforts of the particular muscles to perform the tasks. If the myoelectric signals are high, it means that the muscles require high effort for the particular tasks.

Through visual interpretation, it is easy to determine the muscles that require high effort due to working posture and task. Based on raw signals obtained from the SEMG, it can be observed that the lower limb muscles, namely both left and right trapezius muscle, both left and right rector spinae muscle and both left and right gastrocnemius muscle for the first operator required higher effort than the upper limb's muscles, both left and right deltoid medial part as indicated by the high of myoelectric signals. Also, the side loading of this operator was unbalanced as shown in Table 5.

The right side loading gave on average higher myoelectric signals (486642 µVs or 58.6%) than the left side loading (273624 µVs or 41.4%). The effort required by left gastrocnemius muscle of second operator was slightly higher than the other muscles. However the side loading of this operator was better balanced as indicated by the result in Table 5, whereby the average right side loading of the myoelectric signals was 144000 µVs (48.5%) and the left side loading was152988 µVs (51.5%). Both left and right trapezius muscle and right gastrocnemius muscle of the third operator required higher effort than the other muscles. The side loading of this operator was unbalanced whereby the loading on the left side recorded higher myoelectric signals (251866 µVs or 54.4%) as compared to the right side loading (211210 µVs or 45.6%). From the results of raw signals analysis, it can be summarised that the lower limb muscles require more effort than upper limb muscles while the operators perform tasks at the existing workstation.

Meanwhile, from the comparison of side loading in Table 5, it can be summarised that the operators' muscles loading were unbalanced as indicated by average myoelectric signals and the percentage of side loading. This is due to the particular muscles being stressed significantly while the operators perform the tasks. For instance, when the operators reached for the raw materials placed in the bucket on the floor, they have to bend their body downwards.

Table 5: Results of myoelectric signals and percentage of side loading (Before modification of workstation)

Operator	*myoelectric signals (left side)*	*myoelectric signals (right side)*	*% of loading (left)*	*% of loading (right)*
1	273624 µVs	486642 µVs	41.4%	58.6%
2	152988 µVs	144000 µVs	51.5%	48.5%
3	251866 µVs	211210 µVs	54.4%	45.6%

4.4.2 Work/Loading Analysis (before modification of the workstation)

Table 6 summarises the results of amount work/loading exerted by the operators' muscles. The first operator experienced highest work/loading in the both left and right erector spinae muscle corresponding to myoelectric signals of 90676 µVs and 184665 µVs respectively. In other words, the work/loading exerted on these muscles are higher than the other muscles. The second operator obtained high work/loading in the left and right trapezius muscle with respect to myoelectric signals of 120486 µVs and 66603 µVs respectively.

Meanwhile, the third operator obtained high work/loading in the left and right erector spinae muscle corresponding to myoelectric signals of 46649 µVs and 59518 µVs respectively. It can be summarised that the effort and work/loading were concentrated in the lower limb muscles. This may be due to the bending and throwing postures while the operators reach for the raw materials in the low position and throwing the finished products into the bucket.

Table 6: Results of work/loading exerted in the muscles (Before modification of the workstation)

Operator	*DL*	*DR*	*TL*	*TR*	*EL*	*ER*	*GL*	*GL*
1	49518 µVs	44941 µVs	85453 µVs	84715 µVs	90676 µVs	184665 µVs	47977 µVs	72320 µVs
2	46388 µVs	47521 µVs	120486 µVs	66603 µVs	62529 µVs	55387 µVs	22462 µVs	41698 µVs
3	35341 µVs	29785 µVs	33452 µVs	23273 µVs	46649 µVs	59518 µVs	37546 µVs	31424 µVs

Note: DL- Left deltoid medial part, DR- Right deltoid medial part, TL- Left trapezius, TR- Right trapezius, EL- Left erector spinae, ER- right erector spinae, GL- Left gastrocnemius, GR- Right gastrocnemius.

4.5 Results of Muscle Activity Evaluation (After Modification of the Workstation)

The following sections will discuss the results of muscle activity while the operators perform the task at the modified workstation.

4.5.1 Raw Signal Analysis (After modification of the workstation)

After the workstation has been redesigned, the first operator required less effort in the lower limb muscles, namely erector spinae muscle, gastrocnemius muscle and left deltoid-medial part as indicated by low myoelectric signals. However, the myoelectric signals in the right deltoid-medial part and trapezius muscle showed that these muscles require slightly high effort when compared to other muscles.

In addition, the side loading of this operator was unbalanced whereby the loading in the left side obtained lower myoelectric signals (170054 µVs or 37.6%) when compared to the right side (282696 µVs or 62.4%). For the second operator, both left and right trapezius muscles require slightly higher effort than the other muscles. The side loading was also unbalanced; the loading in the left side acquired higher myoelectric signals (197845 µVs or 62.9%) compared to the right side loading (116462 µVs or 37.1%).

Similarly, the third operator required higher effort in the left and right trapezius muscles than the other muscles. However, the side loading of this operator had better balance; the right side loading obtained myoelectric signals of 144085 µVs (54.6%), while the left side loading acquired myoelectric signals of 119574 µVs (45.4%).

Based on the results of raw signals analysis, it can be summarised that the upper limb muscles required more effort compared to lower limb muscles when the operators perform task at the modified workstation. Furthermore, comparison of side loadings results in Table 7 revealed that the muscle loading were unbalanced.

Table 7: Results of myoelectric signals and percentage of side loading (After modification of workstation)

Operator	myoelectric signals (left side)	myoelectric signals (right side)	% of loading (left)	% of loading (right)
1	170054 µVs	282696 µVs	37.6%	62.4%
2	197845 µVs	116462 µVs	62.9%	37.1%
3	119574 µVs	144085 µVs	45.4%	54.6%

4.5.2 Work/Loading Analysis (After modification of the workstation)

Table 8 presents the average of work/loading exerted to each muscle for all operators when performing tasks at the modified workstation. The work/loading in the lower limb muscles such as erector spinae muscle and gastrocnemius muscle is considered minimum. In contrast, the work/loading in the upper limb muscles such as deltoid medial part and trapezius muscle was greater. This may be due to the operators perform the task in sitting position continuously. As a consequence, the work/loading is concentrated in the upper limb muscles. The first operator experienced high work/loading in the left and right trapezius muscles corresponding to myoelectric signals of 90676 µVs and 184665 µVs respectively. The same result was obtained by the second and third operators.

Table 8: Results of work/loading exerted in the muscles (After modification of the workstation)

Operator	DL	DR	TL	TR	EL	ER	GL	GL
1	24908 µVs	81374 µVs	107447 µVs	113612 µVs	22231 µVs	19763 µVs	4350 µVs	7530 µVs
2	54290 µVs	58717 µVs	109177 µVs	115668 µVs	14372 µVs	15255 µVs	5491 µVs	3394 µVs
3	46665 µVs	48817 µVs	126320 µVs	149759 µVs	12484 µVs	20137 µVs	4450 µVs	6983 µVs

Note: DL- Left deltoid medial part, DR- Right deltoid medial part, TL- Left trapezius, TR- Right trapezius, EL- Left erector spinae, ER- right erector spinae, GL- Left gastrocnemius, GR- Right gastrocnemius.

4.6 Improvement of Muscle Activity

Figure 10 through Figure 12 show an analysis of the results of muscle activity evaluation associated with work/loading for all operators. Figure 10 shows the results of work/loading exerted in the muscles of first operator, Figure 11 for the second operator and Figure 12 for the third. From the analysis, it can be observed that the work/loading in the lower limb muscles has decreased drastically with the implementation of modified workstation in all the three cases. However, the work/loading in the upper limb muscles (left and right trapezius muscles) showed a drastic increment. From the comparison results, the modified workstation can be considered as a potential solution to improve muscle activity of operators.

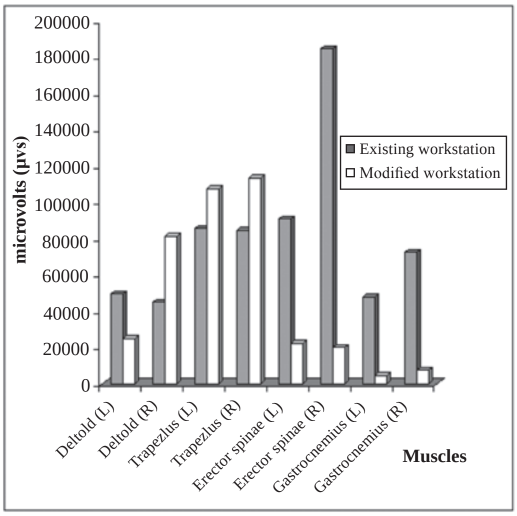

Figure 10: Comparison result of work/loading exerted in the muscles of first operator

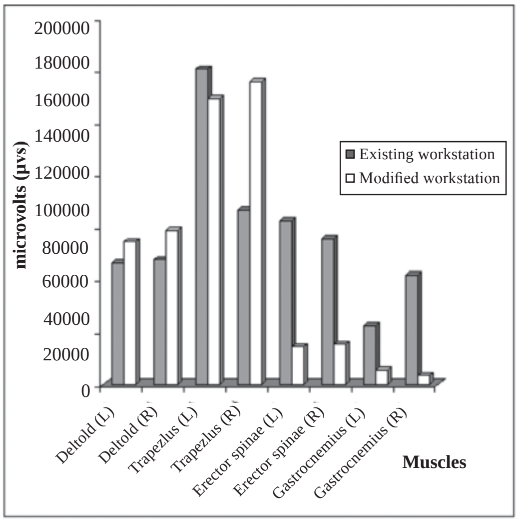

Figure 11: Comparison result of work/loading exerted in the muscles of second operator

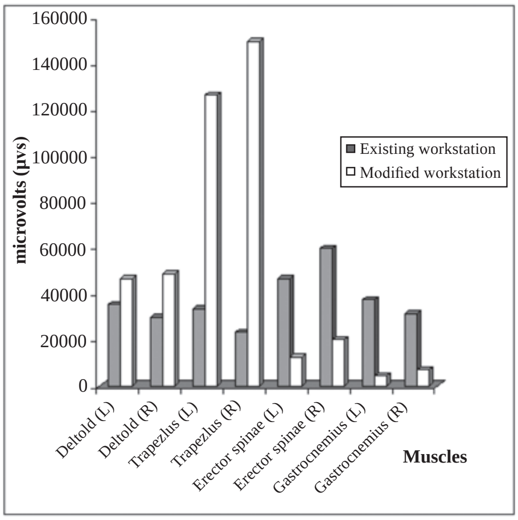

Figure 12: Comparison result of work/loading exerted in the muscles of third operator

4.7 Results of Oxygen Consumption Evaluation (Before Modification of the Workstation)

Table 9 presents the results of oxygen consumption evaluation for each operator while they perform task at the existing workstation. The first operator consumed 0.735 l/min of oxygen, equivalent to a demand for 15.582 kJ/min of energy. The second and third operator recorded lower oxygen consumption and energy demand than the first operator. The second operator consumed 0.465 l/min of oxygen equivalent to a demand for 9.858 kJ/min of energy. The third operator consumed even less oxygen and energy when compared to the first and second operators as indicated by the results presented in Table 9. These results can be taken as the baseline for the oxygen consumption and energy expenditure of operators while performing the task at the existing workstation. It should be noted that these values are still within acceptable limits (about 20 kJ/min for the workload categorised under medium task [14]). However, these consumptions can still be improved to optimize the capability of operators while performing the tasks.

Table 9: Results of oxygen consumption evaluation (Before modification of the workstation)

Operator	*Oxygen consumption (l/min)*	*Energy expenditure (kJ/min)*
Operator 1	0.735	15.582
Operator 2	0.465	9.858
Operator 3	0.295	6.254

4.8 Results of Oxygen Consumption Evaluation (After Modification of the Workstation)

Table 10 presents the results of oxygen consumption evaluation when the operators perform the tasks at the modified workstation. From the tabulated results, it can be summarised that the first operator consumed oxygen of 0.291 l/min equivalent to an energy demand of 6.169 kJ/min. The second and third operators recorded slightly lesser oxygen consumption and energy expenditure than the first operator. The second operator consumed 0.336 l/min of oxygen or demanded 7.123 kJ/min of energy. The third operator recorded even less oxygen consumption when compared to the first and second operators as indicated by results presented in Table 10. From such presented results, it can be summarised that the oxygen consumption and energy expenditure of operators while performing task at the modified workstation are within acceptable limits.

Table 10: Results of oxygen consumption evaluation (After modification of the workstation)

Operator	*Oxygen consumption (l/min)*	*Energy expenditure (kJ/min)*
Operator 1	0.291	6.169
Operator 2	0.336	7.123
Operator 3	0.131	2.777

4.9 Improvement of Oxygen Consumption

A pre-post evaluation on oxygen consumption was conducted to determine the impact of modified workstation in relation to oxygen consumption and energy expenditure of operators. Figure 13 and Figure 14 show the comparison results of oxygen consumption and energy expenditure for all operators. The first operator consumed 0.735 l/min of oxygen while performing the task at the existing workstation, whereas 0.291 l/min of oxygen was consumed while performing the task at the modified workstation. The energy expenditure also showed the improvement, whereby 15.582 kJ/min of energy was demanded while performing the task at the existing workstation, reduced to 6.169 kJ/min while performing the task at the modified workstation.

The second operator consumed 0.465 l/min of oxygen while performing the task at the existing workstation, compared to 0.336 l/min of oxygen while performing the task at the modified workstation. On the other hand, the energy expenditure also showed the improvement, whereby 9.858 kJ/min of energy was demanded while performing the task at the existing workstation, reduced to 7.123 kJ/min at the modified workstation.

The third operator consumed 0.295 l/min of oxygen while performing the task at the existing workstation, reduced to 0.131 l/min of oxygen at the modified workstation. Consequently, the energy expenditure also showed the improvement, whereby 6.254 kJ/min of energy was demanded while performing the task at the existing workstation, decreased to 2.777 kJ/min at the modified workstation.

From the comparison results, it can be summarised that the energy expenditure for all operators are within acceptable limits while performing the task at the modified workstation. The findings showed that the modified workstation is capable of optimising oxygen and energy consumption of operators, thus enabling the operators to perform the given task with minimum oxygen and energy consumption.

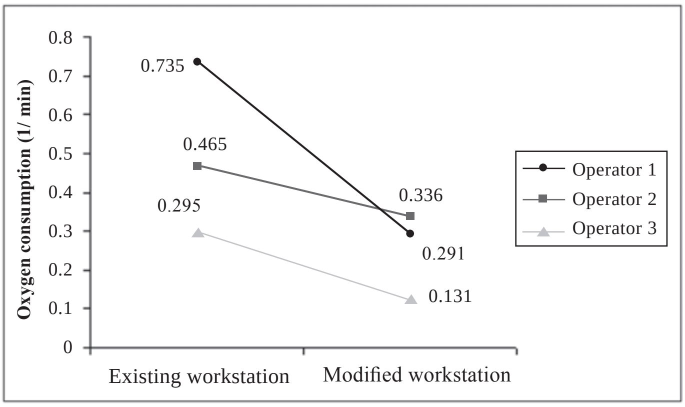

Figure 13: Comparison result of oxygen consumption for all operators

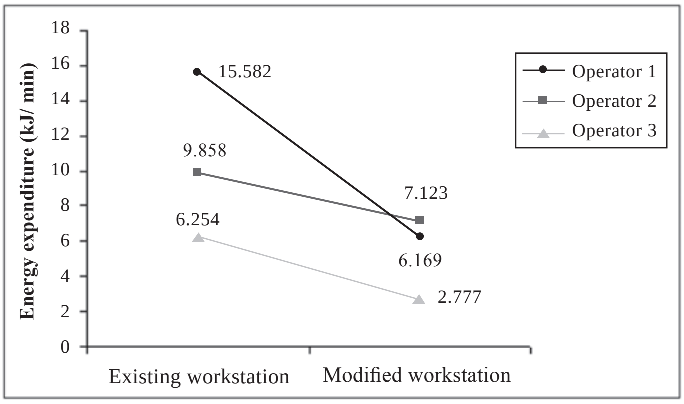

Figure 14: Comparison result of energy expenditure for all operators

5.0 CONCLUSION

This study has conducted two-phase evaluations to determine the impact of workstation design to working posture, muscle activity, and oxygen consumption of metal stamping operators while they perform their tasks. The first phase evaluation was conducted before the workstation was modified, and the second phase evaluation was performed after the modification. From the first phase evaluation, results show that bending posture has potential for significantly causing ergonomic injuries. The lower limb muscles especially the left and right erector spinae muscles are subject to high work/loading. This is due to the extra work/loading exerted on this muscle while the operators perform the task in bending posture. However, evaluation of oxygen consumption indicate the oxygen and energy consumed by the operators while performing the task was still within acceptable limits. Based on second phase evaluation, the results show that the modified workstation has improved the working posture, reduced the work/loading in the lower limb muscles, and required less oxygen and energy while performing the task. In conclusion, this study concluded that the implementation of this modified workstation had a positive impact on the physiological performance of the operators.

6.0 ACKNOWLEDGMENTS

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