ABSTRACT
Hand grinder is one of the tools used in manufacturing jobs, particularly for metal processing. Grinding is usually performed in the finishing process of a product, such as removing the ridges of welded joint. This tool has two main parts, namely the grinding disc and the electrical power motor for driving its spindle. Based on the work sampling in the several manufacturing shops, workers spent 20% of eight hours working time for grinding process. Observations and interview with several operators found some problems in the using of hand grinders such as fatigue and musculoskeletal complaints due to not ergonomic shape, size, vibration, and noise. This study aimed to improve a hand grinder design through ergonomic assessment. Twenty two parameters of assessment were identified by a questionnaire to 16 samples of hand grinder users. By considering those parameters and using the Microsoft Visual Basic 6.0, the ergonomic assessment software was created. The recommendations from the ergonomic assessment suggest that the hand grinders be modified by equipping them with two dumping covered handles. To determine the effects of the modification to the hand grinders, furthermore, the improved hand grinders were applied in the experimental research used treatment by subject design. Variables in the research were user physiological responses regard to musculoskeletal complaints, fatigue, energy expenditure, productivity and satisfaction. The research was conducted in March until August 2012 with 16 participated samples. The samples in the research were randomly selected from the students of Industrial Engineering Department of Atma Jaya Yogyakarta University. The data were analyzed statistically for descriptive analysis, normality test by Shapiro-Wilk, and the compare means analysis by t-paired test and Wilcoxon with significance level of 5%. The results of data analysis showed that the use of the modified hand grinder being yielded better results: 19.6% decrease in musculoskeletal complaints (p = 0.001), 17.7% decrease in fatigue (p = 0.004), 20.9% decrease in energy expenditure (p= 0.017), 15.97% increase in productivity (p=0.041) and 29.9% increase in satisfaction (p = 0.001). Empirically, it can be concluded that ergonomic based modification of hand grinders able to improve physiological responses in terms of musculoskeletal complaints, fatigue, energy expenditure, and increase productivity and user satisfaction.

Keywords: Hand grinder, ergonomic, physiological response, productivity, satisfaction

INTRODUCTION
The main activity of a business organization is the production process. For business organization, products plays a very important role: to achieve one of its goals, namely profit. The business will be profitable if its product is accepted by the market and sells well. How well a product meets the needs and wants of the consumers will determine the level of the consumers’ satisfaction. The consumers’ needs and wants as the environment change dynamically, so products have to be re-designed and developed continuously. Product design essentially seeks to identify the consumers’ wants and needs, which are then translated into measurable engineering characteristics embodied in the attributes and functions to be performed by a product.

One type of industrial products is hand tools such as grinders (hand grinder or angle grinder). Hand grinder is always used in the automotive industries or car body repair work and other metal manufacturing shop. Grinding is usually performed during the finishing process of a product, such as removing the ridges of welded joint. This tool has two main parts, namely the grinding disc and the electrical power motor for driving its spindle. Hand grinder speed at no load ranges from 10,000 to 12,000 revolutions per minute (rpm).

From my observation in Sleman district of Yogyakarta, all of the 12 welding shops have hand grinders and use them as one of its production tools. There are seven kinds of operations or processes carried out in the welding shop. Based on preliminary research using work sampling for 6 days (19 to 26 March 2012), it was found that the percentage of working time spent on each process is as follows: 1) measure the raw material (8%), 2) cutting the material
use a circle saw or hacksaw (17%), 3) bending the material use a roller or a vise (4%), 4) arc welding (33%), 5) grinding using hand grinder (20%), 6) cleaning or smoothing using sandpaper (7%); 7) painting and assembling (11%). The observation reveals that the grinding process requires a fifth of working time.

From the interviews with the 12 operators of hand grinder, several ergonomic problems were found. First, 10 operators (83%) felt sore and tired after using the hand grinders, especially in the wrist, fingers and palm of the right hand due to holding the tool. Further investigation revealed that the weight of hand grinder of 1.5 to 2.5 kg and the kind of hand grinder usually used without handle or only one handle available for left hand. The right hand had to hold the body of the grinder as if it were a handle. Second, the body diameter of hand grinder ranged from 55 mm to 73 mm.4 Research suggests that a comfortable handle size range from 30-45 mm.5 Larger handle size, therefore, causes inconvenience in its operation. Shape, position or orientation and size of the handle that does not comply with the conditions of the users’ hands can also cause discomfort. Improper position of the handle causes neither natural nor neutral work posture, so that flexion or extension may cause musculoskeletal disorders in the palm of the hand, wrist and arm.6 Third, the intensity of the sound generated when the hand grinder is used is 90-115 dBA. It was measured using a sound level meter that was placed close to the operator’s ear. Permissible noise for the skilled physical work is 75dBA.15 Noise exceeds the threshold limit value reduces ear sensitivity, and in the long run or exposure it can cause deafness.7

To overcome such problems, the design of an existing hand grinder has to be improved. In order to be right on target, an ergonomic assessment of the design of hand grinder should be performed as a basis for the improvement. A number of aspects have to be considered in the assessment of product design such as economic, technical, ergonomic, socio-cultural, energy-saving and environmentally friendly. Related to the ergonomic issues, the design process must apply the principles of ergonomics, such as the number of users, identification of user profiles, user requirements, fun to use, ease of use, product maintenance, user satisfaction, product conformity with the user, context of product use, user behavior, product safety, physical demands on the user, mental demands on the user, instructions and user feedback.8

To determine the ergonomic quality of a working system and design of product, ergonomic assessments should be performed objectively. Ergonomic quality of a work system or product is the fit of a work system or product conditions to the capabilities and limitations of users.9

Ergonomic assessment instrument for product design, especially for a hand grinder based on the principles of total ergonomic approach is currently not available.10 This study, therefore, aims to design an ergonomic assessment method and instrument or software that can provide information of the ergonomic quality of a hand grinder and give recommendations for necessary improvement in the design of hand grinders. The modification of hand grinder based on ergonomic assessment and total ergonomic principles may result in an ergonomic hand grinder. The use of an ergonomic hand grinder will be able to optimize the physiological response in terms of decreased musculoskeletal complaints and fatigue as well as an increase in user satisfaction.

METHOD

The results of the questionnaire responses by the 16 samples of hand grinder users were used to identify the assessment parameters. Based on the identification of the parameters, an ergonomic assessment software was designed using the Microsoft Visual Basic 6.0 to assess the parameters. The modification of hand grinder based on recommendation of ergonomic assessment result was performed by using five steps of the rational design method: (1) clarifying objectives; (2) establishing functions; (3) setting requirement; (4) generating alternatives; (5) evaluating alternatives.2 To determine the effects of the modification of the hand grinder, an experimental research by subject design11 involving 16 subjects was conducted March through August 2012. The samples were randomly selected from the students of the Industrial Engineering Department of Atma Jaya Yogyakarta University. In the first period, the subjects operated the existing and unmodified hand grinders and in the second period, the subjects operated ergonomically-modified hand grinders. In both periods the subjects used the hand grinders to remove welding ridges for 30 minutes. The data were statistically analyzed. The statistical analyses were the descriptive analysis, normality test by the Shapiro-Wilk and the mean difference test by the t-paired test and the Wilcoxon test with significance level of 5%.12

RESULTS AND DISCUSSION

Characteristics of Subjects

The subjects in this study were students of Industrial Engineering Department of Atma Jaya Yogyakarta University. They were doing the practicum Work Design and Analysis in the second semester of the 2011/2012 academic year. The mean
age of subjects was $20.13 \pm 0.62$ years. Data distribution of age is not subjected to normal distribution because they were students of the same batch and therefore they were of almost the same age. A person's physical capacity is directly proportional to age up to a certain point and peak at the age of 25 years. The subjects, therefore, were in the productive age range with optimal physical strength.\(^{13}\)

The height of research subjects in the study ranged between 161 cm and 182 cm with the mean of 171 cm $\pm$ 6.2 cm. The weight of research subjects ranged from 50 kg to 94 kg with a mean of 68.56 kg $\pm$ 14.58 kg. Ideal body weight can be determined by the formula: height (cm) - 100 - 10% $\times$ (height - 100). It means that the ideal weight ranged between 54.9 kg to 73.8 kg. Six of the subjects did not have ideal weight: two were underweight and four overweight.

Body Mass Index (BMI) is used to classify a person's body: normal, thin or fat. BMI is also an indicator of energy balance into the body through food intake with energy expenditure. BMI can be calculated based on height and weight, using the formula: \(\text{BMI} = \frac{\text{Weight (kg)}}{[\text{height (m)}]^2}\). According to WHO (2004), the normal BMI for adults ranged between 18.50 kg/m\(^2\) to 24.99 kg/m\(^2\).\(^{14}\) Based on the measurements in this study, the BMI of the subjects ranged between 17.7 kg/m\(^2\) to 31.1 kg/m\(^2\) and the mean of 23.34 kg/m\(^2\) $\pm$ 4.28 kg/m\(^2\). In this study one subject (6.25%) was underweight and three (18.75%) were overweight.

Table 1 Characteristic of Subjects

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Normality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (year)</td>
<td>20.13</td>
<td>0.62</td>
<td>Not</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>68.56</td>
<td>14.58</td>
<td>Normal</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>171.04</td>
<td>6.20</td>
<td>Normal</td>
</tr>
<tr>
<td>BMI (kg/m(^2))</td>
<td>23.34</td>
<td>4.28</td>
<td>Normal</td>
</tr>
<tr>
<td>Length of hand (cm)</td>
<td>18.44</td>
<td>1.07</td>
<td>Normal</td>
</tr>
<tr>
<td>Width of hand (cm)</td>
<td>9.56</td>
<td>0.56</td>
<td>Normal</td>
</tr>
<tr>
<td>Diameter of grip (cm)</td>
<td>3.96</td>
<td>0.22</td>
<td>Normal</td>
</tr>
</tbody>
</table>

SD: Standard Deviation
BMI: Body Mass Index

**Environmental Conditions**

The experiment was conducted in conditioned room of Laboratory Work Design Analysis and Ergonomics of Industrial Engineering Department of Atma Jaya Yogyakarta University, so the physical conditions can be adjusted and controlled as desired. Environmental variables that can be controlled include temperature, humidity, sound intensity and lighting intensity. The mean temperature in the conditioned room $24.35^\circ + 0.80^\circ$ C in the first period and $24.73^\circ + 1.00^\circ$ C in the second period so generally it is quite convenient for the Indonesian people. While the mean of humidity was $66.07\% + 5.25\%$ in the first period and $63.53\% + 4.39\%$ in second period, enough to give comfort. The intensity of illumination was set to match the type of work, which was 250 lx for rough work on toolmaking machine.\(^{15}\) The results of measurements of the lighting intensity in this research showed an average $270.50$ lx $\pm$ 8.64 lx in the first period and 273.96 lx $\pm$ 17.18 lx in the second period, so it was appropriate to the type of work.

The results of means comparison test for conditions in the first period and the second period showed three variables (temperature, humidity, and lighting) were not significantly different, which means there is no effect of the time so it does not affect on the results of the study. Sound intensity in both periods was significantly different, but it was caused by the behavior of the subjects in using the hand grinder, namely the greater pressure so that it produced louder sound (mean intensity of noise increased from 102.23 dBA to 103.5 dBA).

Sound intensity over 90 dBA will very likely cause very serious disorders in the auditory system.\(^7\) Impact of this disorder can be auditory (conductive hearing loss, sensory-neural hearing loss, Mixed hearing loss), or non-auditory (balance system, cardiovascular, sleep and psychiatric conditions). Because in this study the intensity of the sound is uncontrollable, the subjects are required to wear personal protective earplugs so the impact of noise to the research results can be minimized.

**Ergonomic Assessment for Hand Grinder**

Based on the responses to the distributed questionnaire to 16 samples of hand grinder operators, it was identified that 22 attributes need to be considered as assessment parameters.\(^{16}\) They are depicted in Table 2.

Table 2 Parameters for Hand Grinder Assessment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Weight</th>
<th>Parameter</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functionality</td>
<td>8.7</td>
<td>Operational cost</td>
<td>4.3</td>
</tr>
<tr>
<td>Safety</td>
<td>8.3</td>
<td>Price of grinder</td>
<td>4.0</td>
</tr>
<tr>
<td>Easy to produce</td>
<td>7.9</td>
<td>Size of grinder</td>
<td>3.5</td>
</tr>
<tr>
<td>Handle texture</td>
<td>7.5</td>
<td>Arm posture</td>
<td>3.2</td>
</tr>
<tr>
<td>Hand posture</td>
<td>7.1</td>
<td>Noise</td>
<td>2.8</td>
</tr>
<tr>
<td>Handle size</td>
<td>6.7</td>
<td>Arm involvement</td>
<td>2.4</td>
</tr>
<tr>
<td>Weight of grinder</td>
<td>6.3</td>
<td>Generated heat</td>
<td>2.0</td>
</tr>
<tr>
<td>Reliability</td>
<td>5.9</td>
<td>Pollution</td>
<td>1.6</td>
</tr>
<tr>
<td>Handle shape</td>
<td>5.5</td>
<td>Display</td>
<td>1.2</td>
</tr>
<tr>
<td>Vibration</td>
<td>5.1</td>
<td>Trigger / switch</td>
<td>0.9</td>
</tr>
<tr>
<td>Mantainability</td>
<td>4.7</td>
<td>Aesthetic</td>
<td>0.4</td>
</tr>
</tbody>
</table>
Since the assessment parameters and weight were known, ergonomic assessment by multi-criteria decision making method could be performed. Performance of each attribute should be evaluated by scoring in three scales: 1-3. The entirely performance of hand grinder is indicated by the status of ergonomic quality, in four levels: 1 = poor, 2 = fair, 3 = good and 4 = excellent.

**Modification of Hand Grinder**

The result of assessment program showed that ergonomic quality status of existing hand grinder was fair with the following seven recommendations for improvement.

1) Improve the handle size
2) Improve the handle shape
3) Improve the handle texture
4) Improve the trigger design
5) Improve the posture of hand
6) Reduce the noise
7) Improve the display design

**Figure 1 Existing Hand Grinder**

Modification of the hand grinder can be performed by applying the rational method design through the following steps:

1) Clarifying objectives
The main objective of hand grinder design is to produce an ergonomic hand grinder which its characteristics are effective, safe, comfortable and efficient as shown in Figure 2.

**Figure 2 Objective tree diagram**

2) Establishing functions
According to the clarified objectives, some functions can be established:
- Protect sharp or moving parts
- Absorb vibration
- Provide comfortable handling
- Reduce noise
- Provide guidance to use
- Improve working posture
- Improve transmission efficiency
- Make easy maintenance

3) Setting requirements
Required specification each part of hand grinder is determined base on the needs, such as size of grinding wheel, speed, motor power, size of handles are suited to the anthropometric data, weight of grinder, etc.

4) Generating alternatives
Generating alternatives is an essential activity in the product design. The solution alternatives are generated by exploring designer’s creativity or by using auxiliary tool of morphological chart to identify features and alternatives of means. An example of morphological chart for designing a handle as follows:

**Figure 3 Morphological chart for handle design**

One of many obtained alternatives is a cylindrical handle, which is made of steel and covered by foam.

5) Evaluating alternative
Some obtained alternatives be evaluated by using method of multi criteria decision making for selecting the best one.

**Figure 4 Modified Hand Grinder**
As a result of application the rational method in this improvement is a modified hand grinder which is equipped by two foam-covered handles and its power switch is moved to the upper-front of the hand grinder as shown in Figure 4. Furthermore the modified grinder must be evaluated again. The result showed that the modified hand grinder increased in the status of ergonomic quality from fair became good with one improvement recommendation, i.e. the noise needs to be reduced.

**Vibration of Hand Grinder**

Vibrations are mechanical oscillations produced by either regular or irregular periodic movements of a body about its resting position.\(^{15,18}\) From the points of application of vibration to the body, there are two points at which vibrations enter the body: feet or buttocks (when standing or sitting on vibrating place) and hands (when operating vibrating tools or machinery). The vibration characteristics that affect comfort are points of application, frequency, amplitude, individual frequency and duration of exposure.\(^{15,19}\)

There are three directions of translational and rotational vibration, depending on the direction of three Cartesian axes.\(^{18}\) In the use of hand grinder, a vertical rotational vibration and translational vibration occurred in the three axes directions. The most felt vibration is translational vibration in the vertical direction.

Vibration in the use of hand grinder was caused by the rotation of its spindle shaft and friction between the grinding wheel and grinded material. The longer the life service, the greater the vibration due to the wear on the shaft, bearings and transmission gears. The existing hand grinders were in new condition. The hand grinder was held directly on its body, producing hand-arm vibrations (HAV) of 115 mm/s\(^2\). Although this vibration is relatively small and less than the threshold limit value of comfort (2.5 m/s\(^2\)),\(^{20}\) the operators felt less comfortable especially in the use of more than five minutes.

Vibration at the motorcycle handlebars gripper can also induce discomfort. Other study showed that the motorcycle speed of 40 to 60 km/h produced vibration of 20 Hertz in the vertical direction and acceleration of 4.5 to 5.5 m/s\(^2\). According to the ISO 2631 (1985), exposure to that vibration is only safe for a period of 16 to 25 minutes.\(^{21}\) In the longer duration of exposure to vibration can induce white finger syndrome or carpal tunnel syndrome, the primary symptom of which is a reduction in blood flow to the fingers and hand due to vasoconstriction of the blood vessels. As a result there is loss of sensory feedback and decrease of performance.\(^{22,23}\)

The vibration can be reduced by minimizing the vibration source or decreasing vibration transmissibility of the conductor. The vibration transmissibility of handle can be reduced by applying dumping system on the handle.\(^{24,25}\) Installing the handle on the vibrating tools may serve as a shock absorber.\(^{26}\) Therefore, the addition of handles on the hand grinder can also reduce hand-arm vibration. This study suggests that vibration transmissibility of handle can be reduced by covering its surface with soft or flexible material. As a result a 8-mm foam (foam rubber) is the material most suited to vibration damping of hand grinder handle. Metal handle should be covered with rubber or leather to reduce shock and electrical conductance and increase friction. Meanwhile, a 4-mm foam covering on wooden-handled garden tools provide a significantly more uniform grip force distribution and lower ratings of perceived discomfort as compared to plain wooden handles.\(^5\) The appropriate material to fulfill the Indonesian National Standard (SNI) for gripper of motorcycle handlebar is a composite material of natural rubber (Natural Rubber) and synthetic rubber (Styrene Butadiene Rubber) with the same composition 1:1.\(^{27}\)

The result of this study showed that foam is the most suitable material for damping vibration on handle. Gloves are often used for hand tools for safety and comfort. According to the document HSE 246/31, wearing gloves can also reduce vibration at the user's hands when operating power tools. Safety gloves are seldom bulky, but gloves worn in subfreezing climates can be very heavy and may interfere with grasping ability. Wearing woolen or leather gloves may add 5 mm to the hand thickness and 8 mm to the handbreadth at the thumb. In some cases, by protecting the hand, gloves could improve operational speed. On the other hand, gloves consistently reduce torque production and reduce sensory ability of fingers. Thus, there is a trade-off to be considered in the wearing of gloves.\(^5\)

**Work Porture and Muscle Load**

The most involved parts of the body in the use of hand grinders are upper limbs, such as arms, hands and fingers. Therefore, the changes of posture assessment were applied in the hands posture, especially in the fingers and wrist. In the use of existing hand grinder, ulnar deviation of the wrist occurred due to directly holding the hand grinder body. Working in the not neutral posture condition causes high scores in action level on the posture assessment of RULA, REBA and OWAS, so it means that improvements are required. To create neutral hand posture, hand grinder should be equipped with
The size, shape and orientation of the handle affect the hand performance and comfort.28

The angle change in the motorcycle handlebar of 150° could reduce musculoskeletal complaints on the user’s hands.29 The inclination angle of the hand grinder handle for right-hand of 30° to the horizontal is suitable position to neutral wrist posture.30 The evaluation and improvement of work postures in the assembly process of electrical panel using RULA Mannequin Pro 2.10 software can reduce the action level and moment of the trunk, so it makes more comfortable for operators.31 Evaluation of work postures in the use of the modified hand grinder showed lower score of action level so that modification could be implemented.

Biomechanics analysis is needed to obtain the best working method for minimizing muscles load.32 The magnitude of muscles load is affected by external load, work posture and size of tools being used. The result of anthropometric measurements of subjects grip diameter at 5% percentile is 3.6 cm. An optimal handle diameter ranges of 25 mm up to 43 mm. At that size, the force of tendon fingers needed to grip handle would be minimum so that it is comfortable for working hands.33 The handle length is determined by the 99th percentile data of hands width of 11.0 cm and allowance of 10% should be added for convenient,34 so the handle length is a 13 cm.

The results of biomechanics analysis showed that the tendon force on the fingers (flexor digitorum profundus and flexor digitorum superficial) decreased due to the change in diameter of the grip. Similarly, sharing and decreasing load occurred at biceps muscles and the reaction at the elbow joints. Thus, the hand load becomes lighter and comfortable as well as improving the health quality of the user. In addition, muscle load in other body segments does not change because they are still in the similar posture.

Table 3 Results of Biomechanic Analysis

<table>
<thead>
<tr>
<th>Components of force</th>
<th>Existing</th>
<th>Modified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of grinder</td>
<td>1.70 kg</td>
<td>1.90 kg</td>
</tr>
<tr>
<td>Right biceps muscles</td>
<td>33.2 kg</td>
<td>21.6 kg</td>
</tr>
<tr>
<td>Left biceps muscles</td>
<td>0</td>
<td>23.5 kg</td>
</tr>
<tr>
<td>Reaction of right elbow</td>
<td>30.02 kg</td>
<td>18.42 kg</td>
</tr>
<tr>
<td>Reaction of left elbow</td>
<td>0</td>
<td>20.32 kg</td>
</tr>
<tr>
<td>FDP at distal phalanx</td>
<td>2.13 kg</td>
<td>1.13 kg</td>
</tr>
<tr>
<td>FDP at middle phalanx</td>
<td>4.58 kg</td>
<td>2.26 kg</td>
</tr>
<tr>
<td>FDS at middle phalanx</td>
<td>1.50 kg</td>
<td>0.75 kg</td>
</tr>
<tr>
<td>FDP at proximal phalanx</td>
<td>8.48 kg</td>
<td>2.96 kg</td>
</tr>
<tr>
<td>FDS at proximal phalanx</td>
<td>2.80 kg</td>
<td>0.98 kg</td>
</tr>
</tbody>
</table>

FDP: Flexor Digitorum Profundus
FDS: Flexor Digitorum Superficial

Musculoskeletal Complaints

The results of the mean comparison test of musculoskeletal complaints after working in the first period used existing hand grinders and after working in the second period used modified hand grinders as depicted in Table 4. It shows the value of p = 0.001 <0.05 and z = - 3.251, which means that the mean of two sets data are statistically significant different. This means that hand grinder modifications based on ergonomic assessment can reduce musculoskeletal complaints of users.

Table 4 Mean Comparison Test of Musculoskeletal Complaint Score

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Mean</th>
<th>SD</th>
<th>Difference</th>
<th>Value</th>
<th>Value p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period 1</td>
<td>43.00</td>
<td>8.61</td>
<td>8.44</td>
<td>-3.25</td>
<td>0.001</td>
</tr>
<tr>
<td>Period 2</td>
<td>34.56</td>
<td>4.37</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Musculoskeletal complaints can be identified from the symptoms, such as pain in the joints, pain in the wrist, shoulder and arm, numbness in hands and feet, fingers and toes become pale, back and neck become stiff and sore. Measurement for overall musculoskeletal complaints used tools of Nordic Body Map questionnaires that divide the body into 28 segments. Users were also asked if they had complaint felt in each segment.

The results reveal that total mean score of musculoskeletal complaints after working 43.00 ± 8.61 in the first period and total score mean of musculoskeletal complaints 34.56 ± 4.37 in the second period. The result of means comparison test showed total mean score of musculoskeletal complaints after working between first period and second period indicated that there was statistically significant difference in which the total score decreased 8.44 (19.6%). Thus, the hand grinder modifications based ergonomic assessment can optimize physiological responses in term of decreasing in users’ overall musculoskeletal complaints.

Perceived musculoskeletal complaints occur most commonly on the hands. This complaint is caused by the stretching of some muscles in wrist, particularly flexor carpi radialis, flexor pollicis longus and nerve radial nerve when using the grinder without the handle. On the other hand, shrinkage occurs on flexor muscles retinaculum and ulnar nerve.35,36

Table 5 Score of Hand Musculoskeletal Complaint

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Left hand Mean</th>
<th>Right hand Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period 1</td>
<td>102 6.38</td>
<td>222 13.88</td>
</tr>
<tr>
<td>Period 2</td>
<td>108 6.75</td>
<td>128 8.00</td>
</tr>
</tbody>
</table>
Total score of musculoskeletal complaints on hands after working in the first period was 324 or 47% (Table 5) of the total score of overall musculoskeletal complaints. Meanwhile the musculoskeletal complaints score on hands after working in the second period of 236 or 42.7% of the total score of overall musculoskeletal complaints. Thus, the modifications that have been made can optimize the physiological responses in term of decreasing hand musculoskeletal complaints, thereby improving heath quality of the users.

Fatigue

The results of the mean comparison test fatigue after working in the first period used an existing hand grinder and after working in the second period used a hand grinder that has been modified as shown in Table 6.

Table 6 Mean Comparison Test of Fatigue after Working

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Mean</th>
<th>SD</th>
<th>Difference</th>
<th>Value</th>
<th>Value</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period 1</td>
<td>67.75</td>
<td>20.07</td>
<td>12.00</td>
<td>-2.870</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td>Period 2</td>
<td>55.75</td>
<td>19.64</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The physiological fatigue is condition in which occurred unbalance between energy expenditure and energy produced by metabolism.37 It can be divided into two kinds, namely muscular fatigue and general fatigue.14 Japan Industrial Health Association (JAIH) recommend fatigue measurement using self-rating questionnaires of 30 items. The subjects responded to the questionnaires subjectively.38 The results of the analysis show that total score mean of general fatigue after working in the first period 20.07 + 67.75 and total score mean of general fatigue after working in the second period 55.75 + 19.64. The means comparison test results revealed that there was a statistically significant difference. The total score means of fatigue after work between first period and second period was down by 12.00 (17.7%). Thus, the hand grinder modifications that have been made can optimize the physiological responses in term of the decrease in fatigue, thereby improving the health quality of the users.

Energy Expenditure

The energy expenditure for grinding of 15cm welding ridges is calculated by multiplication of rate of energy expenditure per minute during work to working time. Both sets data of energy showed normal distribution (p> 0.05), then followed with a compare means test using paired samples t-test. The results of compare means test between first period used existing hand grinder and second period used modified hand grinder as in Table 7 showed reducing energy expenditure of 2.68 kcal (20.9%).

Table 7 Mean Comparison Test of Energy Expenditure

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Mean</th>
<th>SD</th>
<th>Difference</th>
<th>Value</th>
<th>Value</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period 1</td>
<td>13.41</td>
<td>5.39</td>
<td>2.80</td>
<td>2.68</td>
<td>0.017</td>
<td></td>
</tr>
<tr>
<td>Period 2</td>
<td>10.61</td>
<td>2.11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Increasing productivity of a work system can be achieved through: (1) raise the output and keep fixed inputs, (2) reduce the input and keep fixed output, or (3) simultaneously increase the output and reduce input. The output is a product (goods or services) resulting from a work system, whereas the inputs are resources (cost, time, energy, materials or information) used by a work system to produce output.39

The decrease in the energy expenditure has implication increase in productivity. Reducing the input elements and keep output is fixed in hand grinder modifications means directly improve the workers productivity. Since energy expenditure is one of input elements, decreasing the energy expenditure means increasing the productivity. For the companies, increased productivity leads to an increase in production capacity and ultimately increases profitability.40

User Satisfaction

Satisfaction is generally expressed as a gap between the expectations and perceive reality are obtained. The closer gap the higher customer satisfaction.36,41 Satisfaction is a subjective perception of a person, and can be measured using the questionnaires with the questions of which represent the expectations. Satisfaction is also related to subjective perception about quality of product. The five quality dimensions of service are tangible, reliability, responsiveness, assurance, and empathy,42 meanwhile quality of goods is related to the physically characteristics and performance of product, so it tends to focus on quality dimensions of tangible and reliability. Refer to the quality dimension of goods, in this study have been identified 20 questions related to the attributes of a hand grinder to measure the level of user satisfaction.

Unsatisfying is caused by the difference between expectation and reality. The user expectation is comfort in the using of hand grinder. The six factors most directly influence comfort in the use of hand tools are: (1) handle size; (2) handle shape; (3)
handle texture; (4) handle position; (5) vibration; (6) weight.

Regard to the six factors, in fact, the existing hand grinder could not meet user expectations, so that the users were unsatisfied. It is indicated by score mean of satisfaction about to six factors is only 1.86. After hand grinder have been modified by adding two covered handles, the user expectation of six factors could be met, so that the users were satisfied. It is indicated by score mean of satisfaction about to six factors increased to be 3.93.

The mean comparison test results of user satisfaction in the first period after used an existing hand grinder and user satisfaction in the second period after used modified hand grinder as shown in Table 8. There was a significant increase in satisfaction scores primarily on the questions related to the handle and the hand grinder vibration.

Table 8 Mean Comparison Test of User Satisfaction

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Mean</th>
<th>SD</th>
<th>Difference</th>
<th>Value</th>
<th>Value</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period 1</td>
<td>54.13</td>
<td>8.79</td>
<td>16.18</td>
<td>-3.442</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>Period 2</td>
<td>70.31</td>
<td>9.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Satisfaction in using tools can improve overall job satisfaction. Job satisfaction has positive psychological impact in improving workers' motivation and working spirit, which in turn will be able to maintain or improve workers morale so they always want to give the best for the company. The final benefit is obtained by increasing the productivity for the company which could potentially increase profitability. As a result, the welfare of all the company workers will increase.

Thus, in general it can be said that hand grinder modification based on ergonomic is able to improve the physiological responses, namely lower musculoskeletal complaints, lower fatigue, lower energy expenditure while at the same time higher productivity and user satisfaction.

CONCLUSIONS AND SUGGESTIONS

Conclusions
Based on the results, statistical analysis and discussion, the conclusions of the study, can be stated as follows:

1) Ergonomic base modification of hand grinder improves the physiological response which is showed by the decreased energy expenditure.

2) Ergonomic base modification of hand grinder increases the user satisfaction.

Suggestions
Based on the conclusions of this study, the following suggestions can be proposed:

1) The designer of hand grinder should consider the results of this study, because there are some attributes have to be improved in order to produce hand grinders capable of improving the physiological responses and increase user satisfaction.

2) This study is just first step effort to prevent ergonomic problems at the upstream level for a hand grinder, so it is still need to be developed to produce ergonomic assessment methods and instruments that can be used at the design stage of other industrial products.

Acknowledgment
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REFERENCES


