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# Effect of Workers’ Weight on Work Efficiency

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# تأثير وزن العامل على كفاءة العمل

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## Abstract

The primary objective of the human factor is to optimize performance and ensure safety through physical work while mitigating the risk of musculoskeletal complaints and reducing energy expenditure. Lately, concerns have been raised that body capacities may not only contribute to an increased risk of musculoskeletal disorders but also to increased energy which leads to a decrease in work efficiency. Therefore, this study aimed to explore the impact of body weight on work efficiency, specifically in terms of activity energy expenditure (AEE). AEE amounts were conducted using the Actiheart device while subjects performed 12 coordinated trunks, shoulder, and leg postures during a drilling task. Statistical analyses, including independent samples t-test and mean differences, were employed to examine the effects of subject weight on AEE. The findings revealed a negative correlation between AEE and subject weight (free fat), with an R-squared value of 0.62. This indicates that as subject weight increases, AEE decreases. Interestingly, individuals with higher body weight (free fat) expended less AEE, suggesting a potentially more efficient use of energy during the task.

***Keywords***: *Energy, Efficiency, Weight.*

## الملخص

أحد أهداف بيئة العمل هو تحقيق الأداء الفائق وحماية العمل أثناء بعض المهام البدنية مع تقليل الاضطرابات العضلية الهيكلية وإهدار الطاقة. في الآونة الأخيرة، كانت هناك مخاوف من أن قياسات الجسم قد تساهم ليس فقط في زيادة الاضطرابات العضلية الهيكلية ولكن أيضًا في تقليل طاقة الفرد وكفاءة العمل. ولذلك، كان الغرض من هذه الدراسة هو دراسة تأثير وزن الجسم على كفاءة العمل من حيث إنفاق طاقة النشاط (AEE). تم إجراء قياسات AEE باستخدام Actiheart على 12 وضعية منسقة للجذع والكتف أثناء مهمة الحفر. تم استخدام عينات مستقلة من اختبار t والاختلافات المتوسطة لتحليل آثار وزن الموضوع على AEE. أظهرت النتائج أن AEE انخفض مع زيادة وزن الشخص (الدهون الحرة) ($R^2$ 0.62). وأن الأفراد الذين يعانون من ارتفاع وزن الجسم (الدهون الحرة) يكلفون أقل من AEE وبالتالي يكونوا أكثر فعالية.

**الكلمات الدالة:** الطاقة، الكفاءة، الوزن.

# 1. Introduction

Ergonomics aims to minimize musculoskeletal disorders and energy expenditure during specific physical tasks, ultimately striving for peak performance and ensuring occupational safety (Shaik, 2015). Increased physical exertion is accompanied by increased energy expenditure (Kahya, 2007). Awkward posture which can be applied by coordinated postures such as trunk and shoulder increases the level of physical effort (Shokshk & Shokshok, 2021). Assessing human work energy expenditure is an essential factor in determining workers' physiological effects (Eminoğlu et al., 2010). In a number of jobs, energy is misused on unfertile activities. For instance, fixed exertion, improper posture, shortage of work pauses, and incompetent use of equipment or approaches can cause to increased activity energy expenditure (AEE), resulting in decreased productivity and efficiency (Kahya, 2007). Lately, there are concerns that anthropometric patterns could potentially contribute not just to the rise of musculoskeletal issues but also to a decrease in overall body energy and efficiency.

Goldsmith et al. (2009) found that the accumulation of fat weight increases the strain on muscles and leads to elevated heart rates during physical activity. Hellesvig-Gaskell (2017) found that when the body weight consists predominantly of muscle, the workload tends to be lower because the capacity for mechanical work increases with muscle mass. Contrary to these findings, Hills et al. (2014) determined that larger individuals expend more energy than smaller ones. These conflicting results underscore the need for additional research into the relationship between individual body weight and AEE under various conditions, such as different postures during drilling tasks.

# 2. Background of Studies

## 2.1. Work Load and Metabolic Process

Estimating the energy of physical activity by checking heart rate is mutual, relatively cheap, and easy to usage. The subjects' heart rates vary significantly under various applied loads (Kumari et al., 2022). Energy measurements were made by monitoring heart rate based on an expected linear correlation amongst heart beats and oxygen ingesting as shown in Figure (1) (Hills et al., 2014). The relation depends on several individual factors, including gender, age, body composition, fitness level, and muscle mass (Sylvia et al., 2014). Heart rate has the advantage of being a physiological variable directly related to oxygen consumption. However, prolonged sitting and light work may lead to misestimating of energy expenditure measurement. Also, heart rate may increase due to other factors such as stress and environmental factors (Brage et al., 2004; Strath et al., 2005). Therefore, some researchers have proposed combining heart rate and accelerometers to improve physical activity energy expenditure estimates (Brage et al., 2004; and Strath et al., 2005).

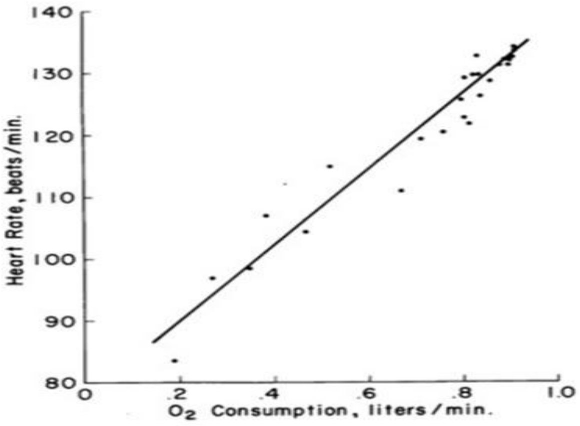

**Figure 1.** The correlation between heart rate and oxygen consumption.

## 2.2. Hand Tools

Musculoskeletal disease problems are common among hand drill workers (Rasool et al., 2017). Numerous musculoskeletal disorders can impact operators during drilling activities (Mathesan & Mohan, 2015). Sasikumar and Lenin (2017) discovered that hand drilling is a vital tool across various fields, underscoring the significance of mitigating associated MSDs. Yu et al. (2018) uncovered that the majority of furniture drilling tasks in China are conducted in a semi-mechanical manner. Despite this, workers are required to engage in significant physical exertion, making them susceptible to inefficiency and fatigue. The substantial contact forces experienced during drilling can exert intense pressure on the functional structures of the hand. This pressure may be influenced by various factors, including tool weight, pressure, grip strength, posture (Singh & Khan, 2012).

## 2.3. Body Weight

Additional weight in the form of fat can heighten stress on muscles and result in an elevated heart rate during physical exertion (Goldsmith et al., 2009). Garg et al. (1978) concluded that body weight stands as one of the primary factors influencing energy expenditure. Body composition refers to the ratio of fat to lean mass. Lean body mass (LBM) represents the percentage of the body not comprised of fat. An optimal body composition is characterized by a lower proportion of body fat and a higher proportion of lean body mass (LBM), encompassing muscles and bones (Bruso, 2017).

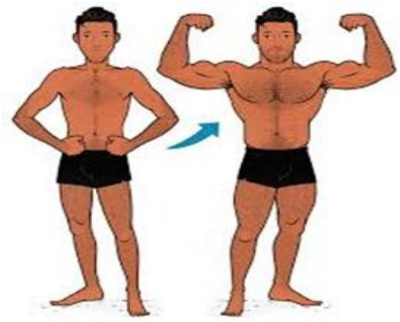

**Figure 2.** Lean body mass (LBM).

When a significant portion of body weight is comprised of muscles, the workload tends to decrease because the ability to perform mechanical work rises with muscle mass. (Hellesvig-Gaskell, 2017). This implies that the standards for bodily health and strength would elevate with an increase in LBM. Therefore, improving body composition, including strengthening the body, engaging in cardiovascular exercise, and implementing dietary interventions, is essential for conserving energy and enhancing work efficiency (Goldsmith et al., 2009).

Body Mass Index (BMI) is a commonly used, straightforward method for estimating body fat mass that accurately reflects the body fat percentage in most adult individuals based on their weight and height. BMI ranges categorize individuals as underweight, normal, overweight, or obese (Bruso, 2017), with a high BMI potentially compromising the accuracy of heart rate measurements (Sylvia et al., 2014). Recent research has demonstrated that individuals with obesity and high BMI tend to exhibit lower levels of physical activity and productivity compared to those with lower body mass indexes (Bustillos et al., 2015). The National Institutes of Health (NIH) and the World Health Organization (WHO) both acknowledge BMI as the primary standard for evaluating obesity. Garg et al. (1978) concluded that body weight significantly influences an individual's energy expenditure. However, these findings are inconsistent with those of Hills et al. (2014), noting that larger people require more energy than smaller people. In addition, Shokshk et al. (2020) revealed an inverse relationship between heart rate and body weight (free fat) in study participants. The contradictory results have prompted further investigation into the effect of individual weight and AEE on different loads, such as overlapping positions in drilling tasks.

## 3. Materials and Methods

### 3.1. Experiment of Measuring AEE of Twelve Coordinated Postures

The aim of this research was to assess the impact of anthropometric factors, particularly body weight, on AEE across 12 overlapping postures. those postures involved variations in shoulder flexion (0°, 45°, and 90°), trunk forward bending (0° and 20°), and leg statues (Leg 1= no support; Leg 2= support). Table (1) provides a breakdown of the specific postures, levels, and the designated variable names for each posture. For example, the interaction levels in posture 1 are [1, 1, 1], indicating 0° for flexing of shoulder, 0° for bending trunk forward, and a leg positioning of 1. Posture 1 was named as S0-T0-1. Posture 4 has the levels [1, 2, 2], indicating to 0° of shoulder, 20° of trunk, and 2 for position of leg. The name of posture 4 was

S0-T20-2. This illustration highlights postures 1 and 4, and similar procedures can be smeared to the rest postures as outlined in Table (1).

**Table 1.** The interaction postures

| Posture | Shoulder (°) | Trunk (°) | Leg | Levels | Variable name | Values |
|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | (1,1,1) | S0-T0-1 | (0°,0°,1) |
| 2 | 0 | 0 | 2 | (1,1,2) | S0-T0-2 | (0°,0°,2) |
| 3 | 0 | 20 | 1 | (1,2,1) | S0-T20-1 | (0°,20°,1) |
| 4 | 0 | 20 | 2 | (1,2,2) | S0-T20-2 | (0°,20°,2) |
| 5 | 45 | 0 | 1 | (2,1,1) | S45-T0-1 | (45°,0°,1) |
| 6 | 45 | 0 | 2 | (2,1,2) | S45-T0-2 | (45°,0°,2) |
| 7 | 45 | 20 | 1 | (2,2,1) | S45-T20-1 | (45°,20°,1) |
| 8 | 45 | 20 | 2 | (2,2,2) | S45-T20-2 | (45°,20°,2) |
| 9 | 90 | 0 | 1 | (3,1,1) | S90-T0-1 | (90°,0°,1) |
| 10 | 90 | 0 | 2 | (3,1,2) | S90-T0-2 | (90°,0°,2) |
| 11 | 90 | 20 | 1 | (3,2,1) | S90-T20-1 | (90°,20°,1) |
| 12 | 90 | 20 | 2 | (3,2,2) | S90-T20-2 | (90°,20°,2) |

Leg 1= without support; Leg 2= with support

**Note:** Drilling 30 holes is a sub-task; Leg without support=1; Leg with support=2.

### 3.2. Description of Task

In Figure (3), thirty (30) holes constitute one sub-task. Overall, each participant is required to drill ninety (30 holes × 3 sub-tasks) holes. AEE is documented for each sub-task, with a 5-minute break permitted between sub-tasks to allow the heart rate to revert to its baseline level.

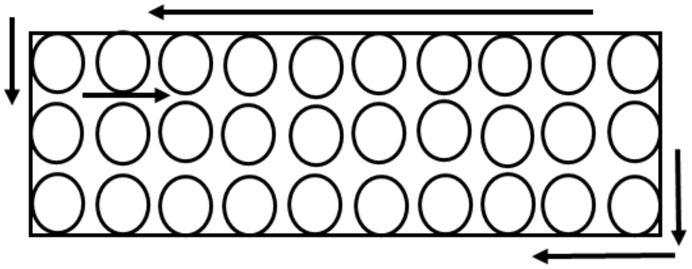

**Figure 3.** 30 holes as a sub-task

### 3.3. Subject Selection

Ten subjects, with mean weight of 67.3 kg, were selected for the experiment. None of the subjects have a history of shoulder or back discomfort. The size of sample was determined using G*power program (Shokshk & Shokshok, 2021).

### 3.4. Selection of Equipment and Tools

Figure (4) illustrates the weighing scale utilized for measuring the subjects' weight.

**Figure 4.** Weighing scale

### 3.5. Drilling Platform

The versatile platform shown in Figure (5) was employed for executing the drilling task. At the platform's apex are a series of angle bars intended to stabilize the plywood work piece.

**Figure 5.** Drilling platform

The vertical position of the drilled panel and the space between the subjects' legs and the panel were customized according to the anthropometric measurements and comfort of the individuals participating. This customization accounts for differences in anthropometric factors like neutral height and arm reach, as depicted in Figure 6. Given the diverse postures of the trunk, shoulders, and legs examined in this study, a flexible approach is required. Therefore, standardizing the height of the drilled panel and the distance between the subjects' legs is not feasible; instead, these parameters must be adjusted based on each subject's unique anthropometry.

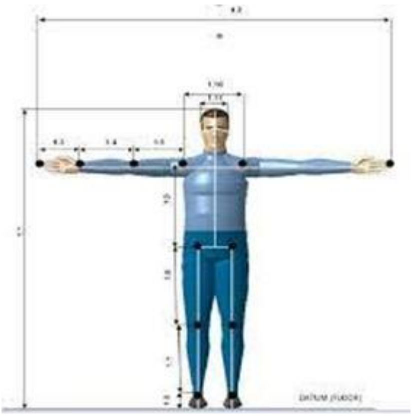

**Figure 6**. Individual anthropometry

### 3.6. Drilling Machine

For drilling into the plywood, a Bosch drill model GSR 120-LI Professional was utilized, as depicted in Figure (7).

**Figure 7.** Drilling machine

### 3.7. Actiheart Monitor

The Actiheart device (depicted in Figure 8) is a compact unit that includes an electrocardiographic (ECG) and an omnidirectional accelerometer. It is worn on the subject's chest to record metrics such as beats, interval, and AEE. The heart's rhythmic contractions originate in the sinoatrial node, which emits electrical impulses to trigger heart muscle contractions. These electrical impulses are captured during heart rate measurements. A validated branched equation is employed to estimate AEE for each time interval (Brage et al., 2005). The Actiheart device's reliability and validity have been confirmed by numerous studies measuring AEE during various activities such as running, walking, and low- to moderate-intensity physical activities in both adults and children (Brage et al., 2005). The Actiheart device features two clips that attach directly to standard ECG electrodes. Typically, one electrode is positioned in V2 or V1, while the other is placed approximately 10 cm laterally in V5 or V4. These positions adjust for the subject's comfort, as shown in Figure 9.

**Figure 8.** Actiheart device

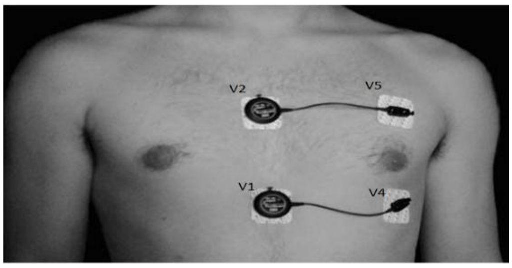

**Figure 9.** The positions of electrodes

### 3.9. Anthropometric analysis

The objective of this research is to examine the impact of subject anthropometry, specifically body weight, on AEE. This investigation is grounded in the findings of interaction postures on AEE.

### 3.10. Define variables

The independent variables are the patient's weight. The dependent variable is AEE. To avoid the influence of fat on AEE, all patients should have LBM or BMI values in the typical range (LBM = 60% to 90% or BMI = 19 to 25 $kg/m^2$) (Hellesvig-Gaskell, 2017). The LBM is calculated using Hume's mathematical formulas (Hume, 1966). For men and women as presented in Eqns. (1 & 2) respectively.

For men: $LBM= (0.3281\times BW) + (0.33929\times BH) - 29.53$ ….. (1)

For women: $LBM= (0.29569\times BW) + (0.41813\times BH) - 43.2933$ ….. (2)

Where;
BW = the body weight in kg;
BH = the body height in cm.

BMI is calculated by dividing the weight in kilograms over height in square meter as in Eqn. (3).

$$BMI=BW/BH^2\ (kg/m^2) \quad \text{….. (3)}$$

Where:
BMI = the body mass index;
BW = defined before;
BH = body height in meters.

### 3.11. Methodology Flowchart

Figure (10) shows the methodology flowchart for testing subject's weight at the AEE. LBM and BMI are calculated after measuring subjects' weight to determine whether these parameters are within the typical range in which subjects are rid of body fat. This ensures that the analysis has no influence of fat on heart rate and AEE.

### 3.12. Data Analysis Tool

The effect of subjects' weight on AEE is analyzed using independent samples t-test and mean difference. This statistical method enables the comparison of AEE means between groups of subjects categorized by their weight, determining if there's a significant difference in AEE based on weight status.

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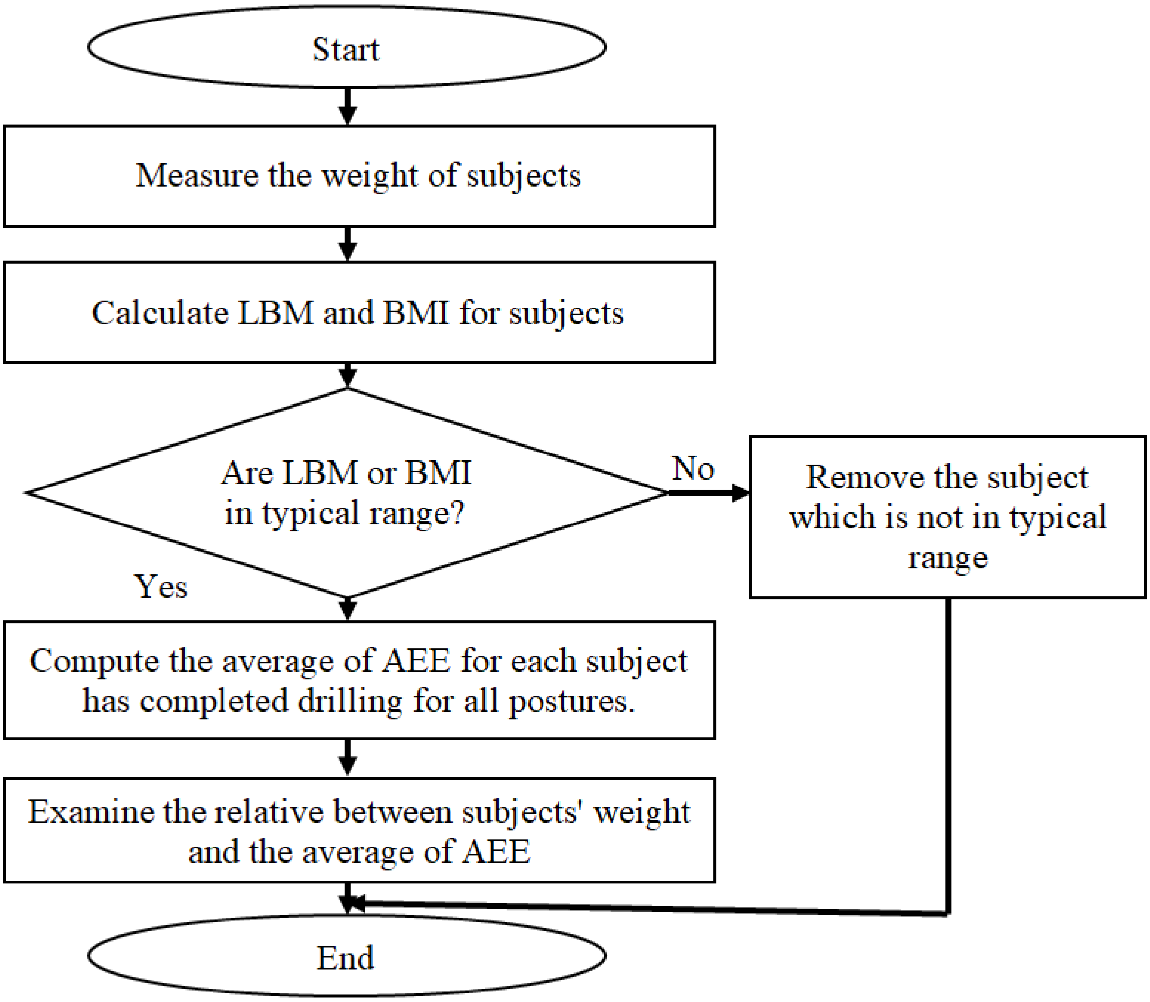

**Figure 10.** Methodology Flowchart

## 3. Results and Discussion

The aim of this study is to analyze the effects of anthropometry in relation to subject weight on AEE. This analysis is carried out based on the results of the AEE measurement experiment during the execution of twelve subtasks at twelve coordinated postures. Table (2) shows the anthropometric measurements of 10 subjects. Before conducting the experiment, body weight is measured for each subject using a weight scale. This ensures that the weight of each participant is accurately recorded and can be taken into account during data analysis. The average body weight of all participants was 67.3 kg. The lowermost weight was 58 kg for participant 4 and he was 1.63 m tall. The maximum weight was 79 kg for subject 8 and he was 1.7 m tall. LBM and BMI were calculated using the equations from 1 to 3. As shown in Table (2), all subjects were within the typical range (LBM= 60 to 90%; BMI= 19 to 25), except subject 7, whose BMI was 27, which was slightly above the typical range, while the same subject had an acceptable LBM value. Therefore, subject's total body weight can be considered as free fat. In other words, most of subject's weight is made up of muscles and bones. Therefore, the effect of fat on heart rate and AEE is minimal in all subjects (Goldsmith et al., 2009).

**Table 2.** The anthropometric amounts of participants

| Subject | Weight (kg) | Age (year) | Height (cm) | LBM (kg) | LBM to weight (%) (60-90) | BMI kg/m$^2$ (19-25) |
|---|---|---|---|---|---|---|
| 1 | 63 | 24 | 171 | 49.16 | 78.03 | 21.55 |
| 2 | 60 | 23 | 164 | 45.8 | 76.33 | 22.31 |
| 3 | 73 | 23 | 183 | 56.51 | 77.41 | 21.8 |
| 4 | 58 | 23 | 163 | 44.8 | 77.24 | 21.83 |
| 5 | 67 | 23 | 170 | 50.13 | 74.82 | 23.18 |
| 6 | 72 | 23 | 169 | 51.43 | 71.43 | 25.21 |
| 7 | 70 | 25 | 166 | 49.76 | 71.09 | 25.4 |
| 8 | 79 | 23 | 170 | 54.07 | 68.44 | 27.34 |
| 9 | 65 | 23 | 174 | 50.83 | 78.2 | 21.47 |
| 10 | 66 | 23 | 172 | 50.48 | 76.48 | 22.31 |
| **Mean** | **67.3** | **23.3** | **170.2** | **50.297** | **74.74** | **23.24** |
| **STD** | **6.03** | **0.64** | **5.4** | **3.26324** | **54.12** | **1.92719** |

Table (3) provides the mean and standard deviation of AEE of 12 postures for each subject. Subject 8 consumed the lowest amount of AEE on average of 26.96 J/kg/min for all postures. Subject 2 consumed the highest amount of AEE on average of 150.42 J/kg/min for the same postures. Remaining subjects consumed different amounts of AEE for the same postures. Figure (11) shows the relation between the weights of subjects with AEE. This relationship clearly showed that AEE declines with the increase in body weight ($R^2$= 0.62). This suggests that the larger subjects (without fat) in this experiment used less energy when drilling horizontally than the smaller ones.

**Table 3.** Average of AEE for each subject has completed drilling for all postures

| Subject | Mean of AEE (J/kg/min) | STD. |
|---|---|---|
| 1 | 92.89 | 11.26 |
| 2 | 150.42 | 30.17 |
| 3 | 63.41 | 16.89 |
| 4 | 86.14 | 16.11 |
| 5 | 58.76 | 14.22 |
| 6 | 70.59 | 17.7 |
| 7 | 71.32 | 25.35 |
| 8 | 26.96 | 9.44 |
| 9 | 55.04 | 12.22 |
| 10 | 68.47 | 25.94 |

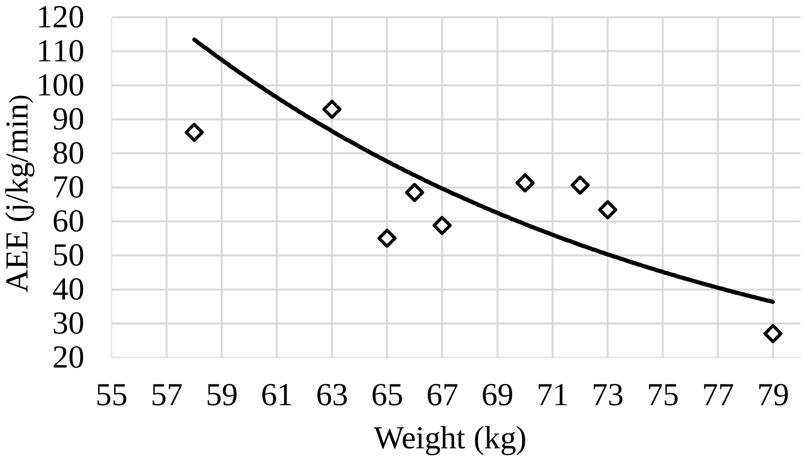

**Figure 11.** Participant's weight vs. AEE average

To better comprehend the relation between body weight and AEE, participant's body weight can be categorized into three groups: light, moderate and high as outlined in Table (4).

**Table 4.** Subjects groups' weight

| Category | Weight range (kg) | Subjects |
|---|---|---|
| Light | >=58 and <=65 | 1, 2, 4 and 9 |
| Moderate | > 65 and <= 72 | 5,6,7 and 10 |
| high | > 72 and <=79 | 3 and 8 |

Table (5) shows the average difference in AEE between the light group and high group for all postures. The results showed that the average variance in AEE among light and high is significantly high for all postures. Also, the AEE mean of the differences between light and moderate, and moderate and high found a quite high. This means that subjects with a higher body weight use less energy in all postures than subjects with a lower body weight.

These results are agreed with the study by Garg et al. (1978) concluded that weight is an important factor affecting a person's energy expenditure. This result is also consistent with Hellesvig-Gaskell (2017), who found that workload decreases when body weight is predominantly muscle (within the acceptable range of LBM and BMI), as the capability to perform physical work upsurges with the Gaining muscle increases mass, which leads to a decrease in AEE and an increase in work efficiency. This is also consistent with the study by Bustillos et al. (2015), who showed that overweight people are less productive as measured by BMI. In contrast, these results oppose those of Hills et al. (2014) established that an overweight person requires more energy than a light weight person, regardless of whether they are within an acceptable LBM or BMI range.

**Table 5.** Mean difference of AEE between light and high

| Posture | Weight Category | Mean AEE (J/kg/min) | STD. | Mean Difference |
|---|---|---|---|---|
| 1 | light | 84.58 | 32.81 | 64.33 |
| | high | 20.25 | 14.07 | |
| 2 | light | 89.6 | 38.23 | 56.57 |
| | high | 33.03 | 15.83 | |
| 3 | light | 97.88 | 40.36 | 63.53 |
| | high | 34.35 | 18.31 | |
| 4 | light | 87.08 | 39.21 | 52.4 |
| | high | 34.68 | 20.31 | |
| 5 | light | 89.8 | 36.04 | 41.61 |
| | high | 48.19 | 19.39 | |
| 6 | light | 75.65 | 8.74 | 32.79 |
| | high | 42.86 | 31.28 | |
| 7 | light | 109.1 | 44.88 | 63.21 |
| | high | 45.9 | 32.68 | |
| 8 | light | 103.36 | 47.63 | 52.73 |
| | high | 50.63 | 43.4 | |
| 9 | light | 84.58 | 32.81 | 37.3 |
| | high | 20.25 | 14.07 | |
| 10 | light | 89.6 | 38.23 | 38.48 |
| | high | 33.03 | 15.83 | |
| 11 | light | 97.88 | 40.36 | 53.26 |
| | high | 34.35 | 18.31 | |
| 12 | light | 87.08 | 39.21 | 55.33 |
| | high | 34.68 | 20.31 | |

## 4. Conclusion

Anthropometry has a significant effect on AEE. People with higher body weight (within an acceptable range of LBM and BMI) expended fewer energy. This can be recognized to the fact that bigger people put fewer exertion into getting effort done than smaller people. Exercises and training are important for employees to decrease AEE and rise work efficiency. In addition, it is important to select workplaces based on the employee's body weight, LBM and BMI. For example, higher weight workers (between the typical BMI and LBM ranges) are assigned to heavier jobs and vice versa.

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