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Effect of Grip strength on Work Efficiency in Hand Tools Tasks

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Abstract

The overarching goal of ergonomics is to enhance performance and ensure workplace safety during physical tasks, simultaneously minimizing musculoskeletal disorders and energy expenditure. Recently, concerns have arisen about body measurements contributing not only to musculoskeletal issues but also to a potential decline in energy and work efficiency. Hence, this study aimed to explore the impact of maximum grip strength (MGS) on activity energy expenditure (AEE) and work efficiency. AEE measurements, conducted using the Actiheart, were carried out with 10 subjects performing a drilling task in 12 coordinated postures involving the shoulder, trunk, and leg. Analysis through independent samples t-test and mean differences revealed that AEE decreased as subject's MGS increased. Individuals with higher MGS exhibited lower in AEE, suggesting greater efficiency in their performance.

Keywords: Grip strength, Energy expenditure, Work efficiency.

INTRODUCTION

Anthropometry, within the realm of ergonomics, is concerned with body metrics like height, strength, shape, mobility, flexibility and elasticity [1, 2]. The utilization of human body data in ergonomics and workplace design is crucial for achieving optimal human performance, safety and efficiency in work environments [1]. Keytel et al. [3] and Kroemer [4] further assert that anthropometry influences work productivity, taking into account individual differences such as gender, health age, height, fitness, environment, motivation and training. In the design process, anthropometric data is applied to ensure that workers have suitable interfaces with tools or equipment, especially in close proximity to reactive surfaces and within confined workspaces [1].

There's a growing concern that anthropometric patterns might not only contribute to the development of musculoskeletal disorders but also lead to a depletion of body energy and a

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decline in work efficiency. Recent studies have addressed hand strength in adults. For example, Shokshk et al. [5] found that there is a negative correlation between heart rate and MGS. Jürimäe et al. [6] stated that larger hands were associated with stronger hands. This result is consistent with research by Nicolay and Walker [7], which found that hand and arm size are generally better predictors of grip strength than weight and height. All of these studies examined the effects of body composition and anthropometric variables on hand strength. However, the reverse effect of MGS on AEE and work efficiency was not considered.

BACKGROUND OF STUDIES

Muscles are included in all mechanical work. Muscle prosecution depends on intensity, duration and frequency. Intensity determines oxygen work needed and shows power (Heavy, moderate, light), duration alludes to how long a muscle contraction keeps going (the overall time the muscle contracts), frequency alludes to how constantly the muscle contracts (number of work cycles per unit time). Mortal body position and development prosecution are grounded on the enactment of single or multitudinous muscles. Huge muscle bunches witness energetic contraction amid exercises similar as weight bearing and monotonous lifting. In this kind of bid, one's prosecution is generally constrained by the capacity to deflect and expend oxygen [8, 9].

The challenges faced by hand drill workers, particularly in the realm of musculoskeletal disorders, are notable [10, 11]. Various musculoskeletal issues can impact operators engaged in drilling operations [12, 13]. Recognizing the indispensability of hand drilling across diverse fields, Sasikumar and Lenin [14] emphasize the importance of mitigating related musculoskeletal disorders. In the realm of furniture drilling tasks in China, Yu et al. [15] shed light on the prevalence of semi-mechanical approaches, wherein workers still grapple with substantial physical labor, leading to inefficiency and fatigue. The exertion during drilling, characterized by high contact forces, poses a risk to the hand's functional structures. Factors such as the tool's weight, working posture, personal work habits and the interface between grip strength and hand pressure all contribute to this potential risk [16].

Handgrip strength, as depicted in Figure 1, is the outcome of the robust flexion of all finger, wrist, and thumb joints, as well as the maximal voluntary contraction of an individual when grasping a tool, such as a drilling machine, during task performance [17]. Most work tasks, whether repetitive or non-repetitive, require power grip [18]. Shahida et al. [2] concluded that age and gender are the primary factors influencing hand strength, regardless of the nationality and race of the population. Jürimäe et al. [6] reported that handgrip power is a valuable indicator of nutritional status and physical performance. However, several studies have deliberated on the influence of body composition and anthropometric variables on adult hand strength. For instance, Jürimäe et al. [6] demonstrated that individuals with larger hand sizes exhibited greater hand strength. This finding aligns with Nicoly & Walker [7] observation that hand and arm sizes typically serve as more reliable predictors of grip strength than body mass and height.

Figure 1. Hand grip strength.

In a study conducted by Khan et al. [18], the impact of elbow flexion and shoulder rotation on grip strength was examined, revealing that the two-way interactions of all primary shoulder and elbow factors are noteworthy. In an alternative academic discipline, Auyeung et al. [19] investigated the correlation between hand grip strength and cognitive function. Their findings revealed that decreased grip strength is linked to cognitive decline. Additionally, Shyamal and Yadav [17] conducted a comprehensive analysis of handgrip strength (both left and right) and 12 diverse human measurements among cricketers. They concluded that handgrip strength could serve as a reliable indicator of outstanding performance in cricket and a valuable criterion for player selection in this sport. Furthermore, a study by Shokshk et al. [5] established a negative relationship between subjects' maximum grip strength and heart rate during a drilling task. However, the potential impact of maximum grip strength on AEE (activity-related energy expenditure) and work efficiency is still in need of clarity.

MATERIAL AND METHODS

This study aimed to assess the impact of MGS on AEE during the execution of twelve coordinated postures. These postures involved variations in trunk forward bending (0° and 20°), shoulder flexion (0°, 45°, and 90°), and leg positioning (Leg 1= without support; Leg 2= with support). The specifics of each posture, their corresponding levels, and the assigned variable names are outlined in Table 1. For example, in posture 1, the interaction levels were (1, 1, 1), indicating 0° for shoulder flexion, 0° for trunk forward bending, and a leg position of 1. The variable name for posture 1 is indicated as S0-T0-1. In posture 4, the interaction levels were (1, 2, 2), corresponding to 0° shoulder flexion, 20° trunk forward bending, and a leg position of 2. The variable name for posture 4 is S0-T20-2. This representation applies similarly to the remaining postures, as detailed in Table 1.

Table 1. Twelve coordinated postures of shoulder, trunk and leg

Posture	Levels	Values	Variable name	Shoulder (°)	Trunk (°)	Leg
1	(1,1,1)	(0°,0°,1)	S0-T0-1	0	0	1
2	(1,1,2)	(0°,0°,2)	S0-T0-2	0	0	2
3	(1,2,1)	(0°,20°,1)	S0-T20-1	0	20	1
4	(1,2,2)	(0°,20°,2)	S0-T20-2	0	20	2
5	(2,1,1)	(45°,0°,1)	S45-T0-1	45	0	1

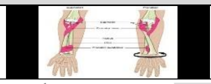
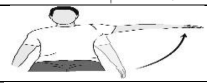
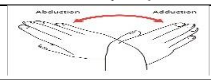
Posture	Levels	Values	Variable name	Shoulder (°)	Trunk (°)	Leg
6	(2,1,2)	(45°,0°,2)	S45-T0-2	45	0	2
7	(2,2,1)	(45°,20°,1)	S45-T20-1	45	20	1
8	(2,2,2)	(45°,20°,2)	S45-T20-2	45	20	2
9	(3,1,1)	(90°,0°,1)	S90-T0-1	90	0	1
10	(3,1,2)	(90°,0°,2)	S90-T0-2	90	0	2
11	(3,2,1)	(90°,20°,1)	S90-T20-1	90	20	1
12	(3,2,2)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

Controlled variables

Table 2 shows the controlled (Fixed) values of some variables.

Table 2. Controlled variables

Variable	Value	
Wrist supination and pronation	±5°	
Elbow supination and pronation	0°-10°	
Shoulder abduction out	0°-10°	
Neck extension and flexion	±10°	
Wrist Abduction	0°-5°	
The hole diameter	6 mm	
Material used	Plywood	
Environment	Room temperature	

Task Description

As shown in Figure 2, each participant is tasked with drilling a total of ninety holes, organized into three sub-tasks of thirty holes each. The recorded AEE for each sub-task provides insights into the energy demands of the drilling process. The inclusion of a 5-minute rest interval between sub-tasks allows for the participants' heart rates to return to their baseline levels.

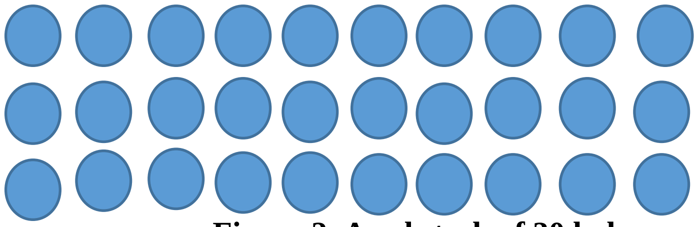


Figure 2. A sub-task of 30 holes

Subject Selection

Ten male participants from Universiti Putra Malaysia, with an average weight of 67.3 kg and age of 23.3 year, were chosen for the experiment (In the year of 2021). All selected individuals have no history of back or shoulder pain, providing a consistent baseline for the study. The determination of the sample size was conducted using G*power software [20, 21], emphasizing a systematic approach to statistical considerations.

Selection of Equipment and Tools

Figure 3 depicts the hydraulic dynamometer used to measure the MGS for subjects.

Figure 3. Hydraulic dynamometer

Drilling platform

The versatile platform shown in Figure 4 was employed for executing the horizontal drilling task. At the upper section of the platform, there is a configuration of angle bars specifically designed to fix the plywood work piece. The height of the drilled panel and the distance between the subjects' legs were customized to accommodate individual anthropometric measurements and ensure comfort. This adjustment accounts for variations in neutral height and arm reach. Given the diverse anthropometric differences, coupled with the investigation of various coordinated postures involving the shoulder, trunk, and legs, a flexible approach is essential. Consequently, standardizing the height of the drilled panel and the distance between the subjects' legs is not feasible; instead, these parameters must be tailored to each subject's unique anthropometry.

Figure 4. Drilling platform

Drilling machine

To conduct the drilling procedure on the plywood, a Bosch drill, specifically the GSR 120-LI Professional model, was employed, as depicted in Figure 5.

Figure 5. Drilling machine

Actiheart monitor

The Actiheart device, manufactured by Cambridge Nuro Technology in the United Kingdom (Figure 6), is a combined device equipped with an omnidirectional accelerometer and an electrocardiographic (ECG) signal processor. Worn on the subject's chest, this monitoring device records beats per minute (BPM), beat interval (IBI), and AEE. The sinoatrial node initiates the heart's pumping activity by sending electrical impulses to the heart muscle, resulting in contractions. These impulses are captured during heart rate measurements. The AEE for each epoch is estimated using a validated branched equation model Brage [22, 23]. Several studies assessing energy expenditure, such as walking and running in both children and adults, along with low- to moderate-intensity physical activities in adult children, have demonstrated the Actiheart acceptable reliability and validity [24]. The device features two clips that connect directly to standard ECG electrodes. Typically, one electrode is positioned in V1 or V2, while the other is placed approximately 10 cm away on the opposite side in V4 or V5 [25]. The placement can be adjusted for the participant's comfort (Figure 7).

Figure 6. Actiheart monitor (Cambridge Nuro-technology, Cambridge, UK)

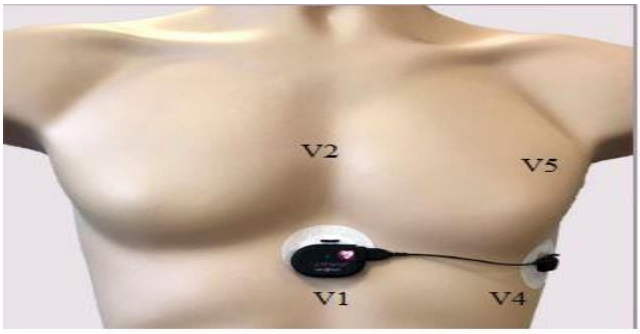


Figure 7. Upper and lower positions for Actiheart attachment

Analysis of Anthropometry

The primary objective of this study is to examine the relationship between the subject's MGS and AEE. This analysis builds upon the findings from the investigation into the impact of coordinated postures on AEE.

Variable Identification

In this study, the independent variable is the individual's MGS, while the dependent variable is AEE. The focus is on understanding how variations in MGS may influence the levels of AEE.

The Flow Chart of Methodology of MGS Investigation

Figure 8 illustrates the flowchart detailing the methodology employed to assess the impact of the subject's MGS on AEE. This visual representation provides an overview of the sequential steps and procedures undertaken in the testing process.

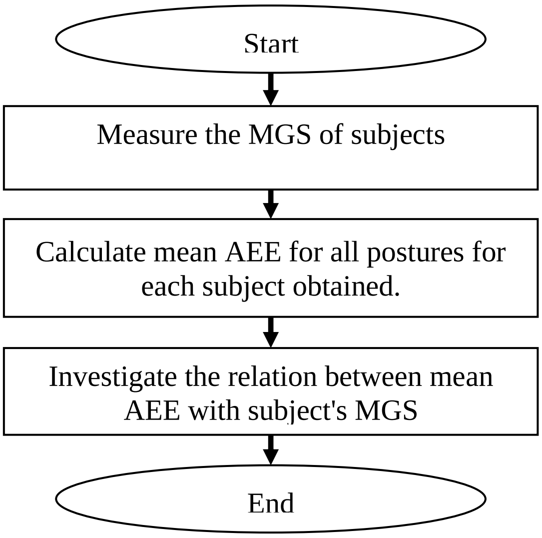


Figure 8. Flowchart of the methodology of the investigation of the subject's MGS on AEE.

Data Analysis Tool

To scrutinize the influence of MGS on AEE, the Independent Samples T Test and mean difference analysis are employed using Statistical Package for the Social Sciences (SPSS). These statistical methods are applied to compare the means of AEE between different levels of MGS, providing insights into potential associations or differences in energy expenditure based on varying grip strength.

RESULTS AND DISCUSSIONS

The primary goal of this study is to assess how MGS influences AEE. This analysis is conducted using data obtained from the AEE measurement experiment, where participants performed twelve subtasks across twelve coordinated postures. The aim is to unravel the impact of MGS on energy expenditure in diverse postural scenarios. Table 3 shows anthropometric measurements and average AEE for all coordinated postures for each subject of 10 subjects. MGS was measured for each subject before conducting the experiment using the dynamometer. The mean MGS of all subjects was 24.4 kg. The lowest MGS was 13 kg for subject 2. The highest MGS was 40 kg for subject 6.

Table 3. The anthropometry measurements of subjects

Subject	Age (year)	Weight (kg)	Height (cm)	MGS (kg)	AEE (j/kg/min)
1	24	63	171	20	92.88833
2	23	60	164	13	150.4192
3	23	73	183	30	63.40833
4	23	58	163	22	86.14417

Subject	Age (year)	Weight (kg)	Height (cm)	MGS (kg)	AEE (j/kg/min)
5	23	67	170	21	58.75833
6	23	72	169	40	70.58583
7	25	70	166	36	71.32167
8	23	79	170	14	26.96
9	23	65	174	24	55.03667
10	23	66	172	24	68.47417
Mean	23.3	67.3	170.2	24.4	74.40
STD	0.64	6.03	5.4	8.27	30.51

Figure 9 explains the relationship between MGS and average AEE for all coordinated postures for each subject. The correlation was negative (R^2 = -0.12). This relationship was not very strong, but provides a general trend that the higher MGS lead to decrease in AEE.

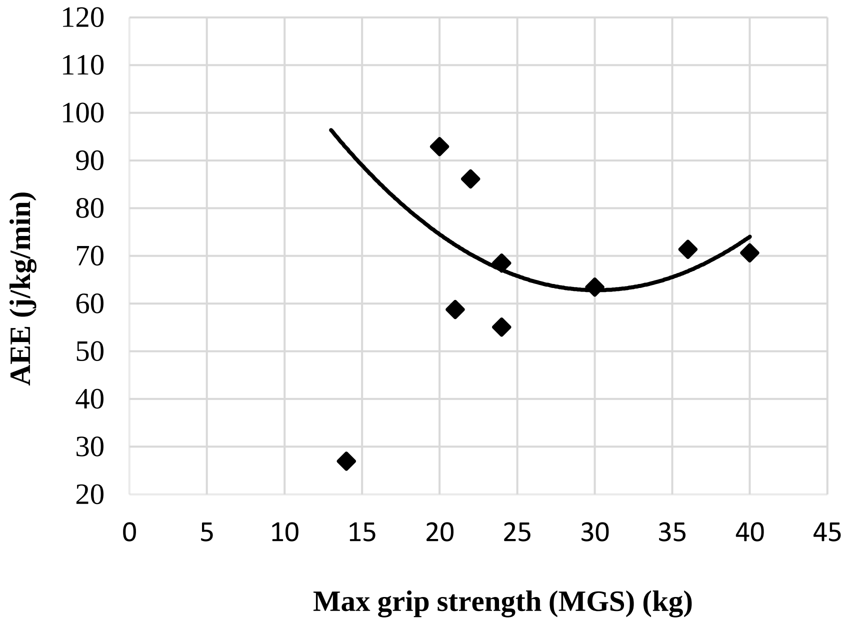


Figure 9. Subject's MGS vs. AEE mean

To better explain the relationship between MGS and AEE, subjects' MGS can be separated into three groups based on the subject's MGS low, medium and high, as shown in Table 4.

Table 4. Subjects groups' MGS

Category	MGS Range (kg)	Subjects
Low	>= 13 and <= 22	1, 2, 4,5 and 8
Medium	> 22 and <= 31	3, 9 and 10
High	> 31 and <= 40	6 and 7

Table 5 provides the mean differences in MGS between the low and high groups. There are significant differences in AEE between the two groups for all postures except points 11 and 12, which, as stated in above, represent a very uncomfortable posture. This may be because the mean differences decrease in very uncomfortable body postures. A significant difference in mean AEE between light and moderate was also noted. No significant difference was found between medium and high values.

Table 5. AEE mean difference between the Low and high of MGS

Posture	MGS Category	Mean AEE (j/kg/min)	STD.	Mean Difference
1	low	67.86	44.83	6.71
	high	61.15	25.81	
2	low	72.33	46.98	15.61
	high	56.72	18.7	
3	low	76.96	52.6	11.11
	high	65.85	14.35	
4	low	70.62	46.55	20.62
	high	50	6	
5	low	76.87	41.17	24.68
	high	52.19	4.27	
6	low	62.21	26.13	6.80
	high	55.41	4.31	
7	low	91.01	55.28	29.94
	high	61.07	21.04	
8	low	89.86	53.63	12.13
	high	77.73	10.39	
9	low	90.92	42.25	12.44
	high	78.49	10.7	
10	low	89.21	39.2	6.32
	high	82.9	37.05	
11	low	104.99	61.78	-1.36
	high	106.35	3.04	
12	low	103.56	51.54	-0.04
	high	103.6	9.62	

Individuals who have a higher MGS consumed less energy. This may be attributed to that stronger individuals exert less effort to do work compared to weaker ones. This result is consistent with those of Shyamal and Yadav [17] and Jürimäe et al. [6] concluded that grip strength may be a satisfactory indicator of performance. Furthermore, This study is agreed with the study of Singh & Khan [16], who concluded that grip strength may decrease the contact forces during drilling which produce strong pressure on the functional structures of the hand. Also, this study is consistent with the study of Karmegam et al., [1], Keytel et al. [3] and Kroemer [4] which assist that using anthropometry data in workplace design is essential to achieve betere efficiency, performance and safety. Absolutely, training and regular exercise play pivotal roles in reducing AEE and enhancing overall work efficiency for workers. Additionally, aligning job assignments in workplaces with a worker's MGS is crucial. Assigning tasks based on individual MGS levels allows for more effective task distribution matching higher MGS individuals with more physically demanding tasks and vice versa. This thoughtful approach not only optimizes workforce efficiency but also promotes the well-being of workers by considering their unique physical capabilities. It's a win-win strategy for both productivity and worker health.

CONCLUSION

Investigating the impact of individuals' MGS on AEE during a horizontal drilling task revealed a negative correlation between AEE and MGS. The findings suggest that individuals with higher grip strength tend to consume less energy, indicating greater efficiency across various postures. This efficiency is attributed to the notion that stronger individuals exert less effort in overcoming challenging situations compared to their lower strong counterparts. The study suggests that enhancing grip strength can significantly contribute to increased efficiency. Moreover, the recommendation to consider the distribution of work based on individual workloads and grip strength aims to reduce musculoskeletal disorders and enhance overall work efficiency and productivity.

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تأثير قوة القبضة على كفائة العمل في مهام الأدوات اليدوية

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ملخص البحث

يعد الهدف الرئيسي لبيئة العمل هو تعزيز أداء العمل وضمان سلامته في مكان العمل أثناء قيامه بمهامه العضلية وانفاق طاقاته في الوقتى نفسه. حيث نتجت مؤخرا عدة مخاوف متعلقة بتأثير مقاييس الجسم ليست في العضلات فحسب، بل كإنخفاض متوقع في طاقته بالاضافة الى كفاءة عمله. لذا، فان هذه الدراسة تهدف الى اكتشاف تأثير قوة القبضة القصوى (MGS) على انفاق طاقة النشاط (AEE) باستخدام (Actiheart) على عشرة (10) أشخاص يقومون بأعمال حفر في (12) وضعية متداخلة تشمل الكتف والجذع والساق. وأظهرت النتائج باستخدام اختبار T للعينات المستقلة وفروق المتوسطات انخفاض انفاق طاقة النشاط عند زيادة قوة القبضة القصوى للمتطوعين. هذه النتائج تثبت أن الأشخاص الذين لديهم قوة قبض أعلى ، يكون انفاقهم في الطاقة أقل، مما يؤدي الى كفاءة أعلى في أدائهم.

الكلمات المفتاحية: قوة القبضة، انفاق الطاقة، كفاءة العمل.