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PHYSIOLOGICAL RESPONSES ON LIFTING POSTURES DURING MANUAL LIFTING TASK

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Abstract

Despite the growth of automated technologies in many industries, manual lifting task activities still play an important part in their daily services. Lifting task contributed as one of the back injuries problems, which comprises the loss of productivity and increased the compensation cost for the employers. This study presented the result of physiological responses aimed at the lifting postures of stoop and squat on manual lifting task. The physiological aspects of lifting posture on heart rate and energy expenditure for the Malaysian population were studied. Different weight loads, lifting weights, frequencies and twist angle have been studied to identify and recommend the appropriate lifting tasks to be used by the workers. Experimental work was conducted involving 36 subjects between 20 and 40 years old with no history of back pain. The subjects performed lifting tasks with loads of 10 kg, 15 kg, 20 kg and 23 kg to a lifting height of 70 cm and 130 cm, with the frequency of 1 lift, 3 lifts and 6 lifts per minute and twist angle of 0° and 90°. The results of the study showed that heart rate is linearly related to the height of lifting, weights, frequency and angle of twisting. These findings can be used as a guide to design lifting tasks for the Malaysian population.

Keywords: Energy expenditure, Heart rate, Lifting, Squat, Stoop.

1. Introduction

Manual material handling (MMH) involves the act of lifting, lowering, bending, twisting, transporting, supporting and others activities in our daily life, whether in one time or regularly as part of normal work [1]. MMH occurs in many industries such as constructions, manufacturing, healthcare, hotels, farms, restaurants and other industries. Manual lifting has been recognized as one of the major contributors to injury in the workplace. In 1981, the National Institute for Occupational Safety and Health (NIOSH) recognized the growing problem of work-related back injury, musculoskeletal disorder (MSD). MSD involve the nerves, tendon, muscle and supporting structures of intervertebral discs that represent a wide range of disorder such as tenosynovitis and low back pain [2]. Low back pain and injuries attributed to manual lifting activities continue as one of the leading occupational health and safety issue [1]. This problem is contributing to tremendous medical costs and compensation, human suffering and lost productivity in the company.

According to Department of Labor's Bureau (DOL) report in 1982, back injuries accounted for nearly 20% of all injuries and illnesses in the workplace, and nearly 25% of the annual workers' compensation payments [1]. Although the number of injuries reported due to back pain is increased, there is still a lack of awareness in the workplace that contributed to the rising number of the cases. In Malaysia, the Social Security Organization (SOCSO) statistic, which comprises all the active and registered workers in Malaysia shows the number of occupational disease and accident had increased from 51,340 in 1980 to 95,006 in 2000. Specifically, the cases of musculoskeletal diseases were increased to 675 cases in the year 2014, the highest cases since the cases were recorded from the year 2005 [1, 3].

In lifting task activity, risk and back injury are exposed to the workers when they are doing the manual material handling of loads in an unfavourable ergonomic condition. The ergonomic risk factors like awkward working postures, excessive load, repetitive lifting and improper lifting techniques when transporting and supporting the load contribute to occupational injuries to employees involving various MSD. Out of various kind of manual material handling tasks, improper lifting technique or postures is often cited as a common cause of the low back problem and have been considered as a major occupational hazard to workers [2].

Many researchers tried to find out the best posture in manual material handling to minimize the effect of back injury. Despite any lifting parameters considerations, it is possible to generalize and to identify the safe methods of manual material handling tasks. Basically, two types of lifting postures that generally used for tasks that require lifting in daily routine tasks are stoop lifting and squat lifting [2, 4-7]. There is considerable debate as to which, is the best technique to employ when lifting low-lying objects off the floor.

Vecchio [8] reported that selecting the most appropriate lifting posture is an important part of safe lifting task. Garg and Moore [9] explained that the squat technique, where the back remains as erect as possible, in which, the knees are flexed. Meanwhile, van Dieen et al. [10] explained that the stoop is bent forward and down at the waist and maintaining straight leg. Since for the past 40 years, the squat lifting was presumed as the safest way to lift and regarded as the correct technique by a health

professional for the manual lifting tasks, but then many researchers in literature come to the argument about the 'correct technique' [7, 8, 11, 12].

Physiological response is associated with the response of the body within acceptable limits, the metabolic production of energy demands during the lifting and the stress on the physiological systems responsible for generating that energy. The physiological measurement and variables that have previously done by the other researchers were the pulmonary ventilation, oxygen consumption [7, 13-15], heart rate [13, 16] and energy expenditure [15].

Based on these factors, the postures used during lifting activities seem to play the biggest part of the back pain issue. This study measured the physiological response of stoop and squat posture during a lifting task.

2. Methodology

The material and method were setups for this experiment including posture, variables, procedures and the equipment are used in this experiment.

2.1. Subject screening and recruitment

This study was conducted in the Engineering Laboratory UPM that was set up based on the design experiment for the lifting task. The design experiments have been approved by The Ethics Committee for Research Involving Human Subjects, Universiti Putra Malaysia (JKEUPM).

Thirty six subjects voluntarily participated in the study were screening and only who had excellent physical health were recruited among the staffs and students from the Engineering Faculty UPM. Subjects consist of 18 males and 18 females with the age range between 20 to 40 years old with no history of any back injury. Table 1 shows the demographic data of the selected subjects.

All selected subjects were asked to read and sign the consent form approved by JKEUPM after they were given a clear explanation of the procedures of the study prior to the lifting task assessment. Moreover, they were given the opportunity to withdraw at any time for any reason during the lifting task assessment.

Subjects with occupational manual material handling experience were excluded because of their different lifting strategy [17]. None of the subjects reported any symptoms of pain during the lifting task. The anthropometric measurement of each subject was measured and collected before the lifting tasks session.

Table 1. Demographic data of subjects.

	Male (*n* = 18)		**Female (*n* = 18)**		**Overall (*n* = 36)**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Age (year)	25.4	3.5	23.6	4.8	24.5	4.3
Weight (kg)	67.2	12.8	52.1	12.8	59.6	14.7
Height (cm)	168.3	4.8	156	3.8	162.2	7.6

2.2. Measure and setup lifting task variables

The lifting task assessment was design based on the lifting variables in the NIOSH lifting equation. Table 2 shows the details of the lifting task variable, multipliers

and equation developed in NIOSH lifting equation [1]. The Value column indicates the data in the design experiment in lifting task assessment.

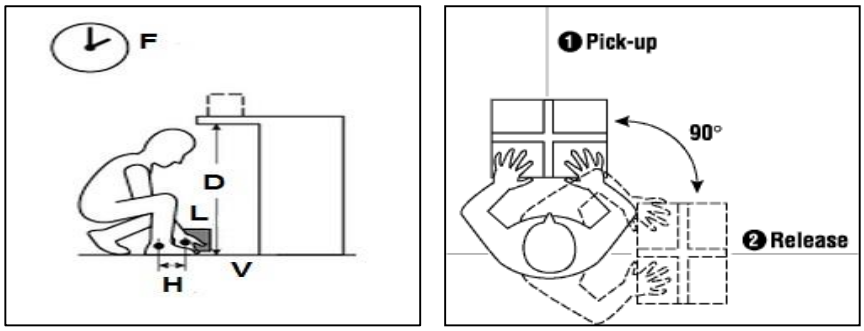
The variables used as the illustration in Fig. 1. Figure 1(a) shows the position of subjects, load, and variables used in the lifting task assessment, which are Horizontal Multiplier (HM), Vertical Multiplier (VM), Distance Multiplier (DM), Frequency Multiplier (FM) and Coupling Multiplier (CM), whereas, Fig. 1(b) shows the angle of Asymmetry, (AM) used in the lifting task assessment.

Two different positions of lifting height were design in this experiment, which is lifting from the floor to the height of knuckle height (70 cm) and shoulder height (130 cm), the most common height used in workplaces and the recommended vertical height of lift [1, 18].

The suitable load mass, lifting frequencies and lifting heights were properly chosen to ensure the muscles work in good experienced in examining its performance during a lifting task.

Table 2. Lifting variable.

Variables		Condition
Independent variable	Horizontal location (H)	40 cm
	Vertical location (V)	0 cm
	Distance (D)	70 cm, 130 cm
	Angle of asymmetric (A)	0º, 90º
	Frequency (F)	1, 3, 6 lifts/minute
	Weight load (L)	10 kg, 15 kg, 20 kg, 23 kg
Dependent variable	Energy expenditure	
	Heart rate	
Controlled variable	Posture	Stoop, Squat
	Box size	38×30×18 cm
	Coupling	Good



(a) Lifting variables. **(b) Twisting position.**

Fig. 1. Lifting variables and twisting position.

2.3. Lifting procedure

The lifting task procedure is shown in Fig. 2. This shows the flow of the lifting procedures from subjects screening until the lifting task sessions.

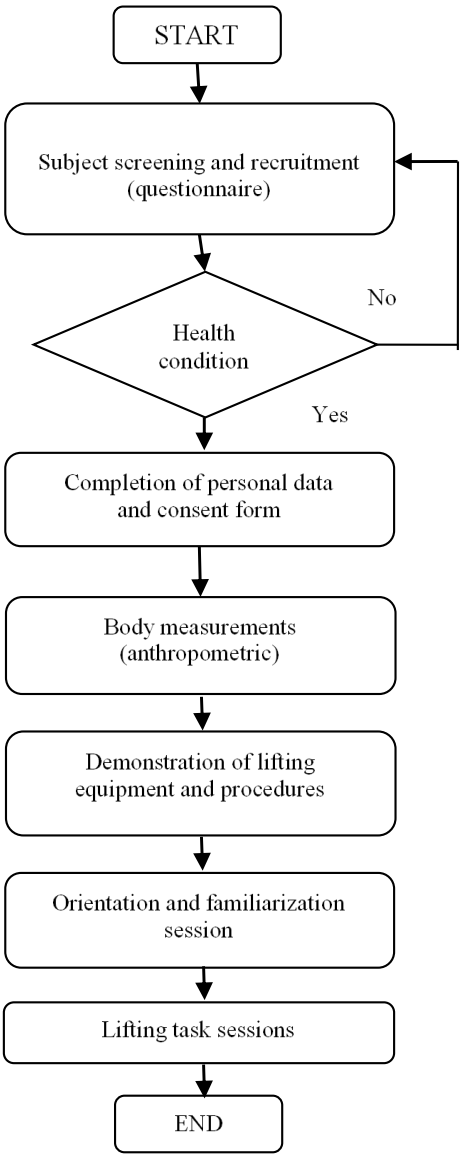


Fig. 2. Flowchart of lifting task procedures.

2.4. Experimental design

2.4.1. Material selection

This study was held in Engineering Laboratory UPM used several types of equipment during the lifting task assessment as in Fig. 3 to measure all of the Physiological output variables such as Shimmer EXG Development kit, Actiheart, Pulse Rate Oximeter, Anthropometer measuring set, adjustable table, loads and lifting box. Besides, the lifting task procedures were set up based on the lifting variables.

Fig. 3. Equipment used for lifting task assessment.

2.4.2. Procedures

The Actiheart (CamNtech) is a chest-worn monitoring device that records heart rate, measured in beats/min was placed in the subject's body as shown in Fig. 4. Actiheart has two clips, which attach directly to standard ECG electrodes. One electrode adheres at V1 or V2 (4^{th} intercostals) and the second electrode is placed approximately 10 cm away on the left side at V4 or V5, although this placement can be adjusted to be comfortable for the subject.

Figure 5 shows the steps of lifting task assessment and the lifting task assessments, which shows in Fig. 6 consisting of twelve sessions for each subject, under different condition of height, frequency, load and twisting angle. Subjects stood at a distance (horizontal location) of 40 cm from the table and lifted the box with dimension size of (38×30×18) cm from the floor to a 70 cm height table (distance location) with the lifting frequency was set to 1 lift per minute, 3 lifts per minute and 6 lifts per minute.

They performed asymmetric, in the sagittal plane by coupling the box from its handles using good grasp. Then, the lifting task repeated with the box lifted to 130 cm height table with a twisting angle of 90º. Heart rate before and after each lifting task assessments was recorded. The flowchart shows the lifting task assessment that evaluated in this study.

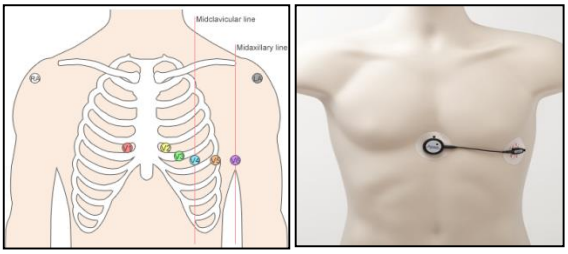


Fig. 4. ECG electrode placement.

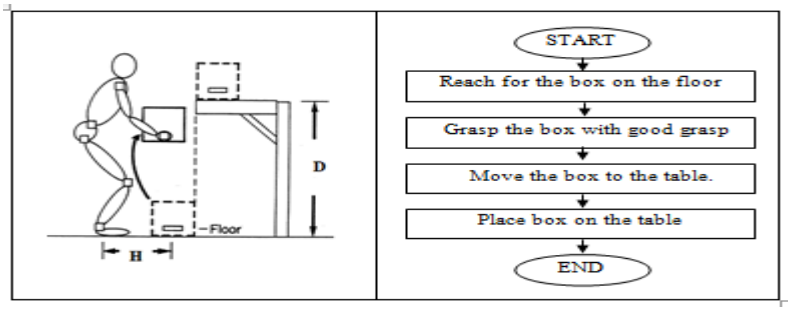


Fig. 5. Lifting task.

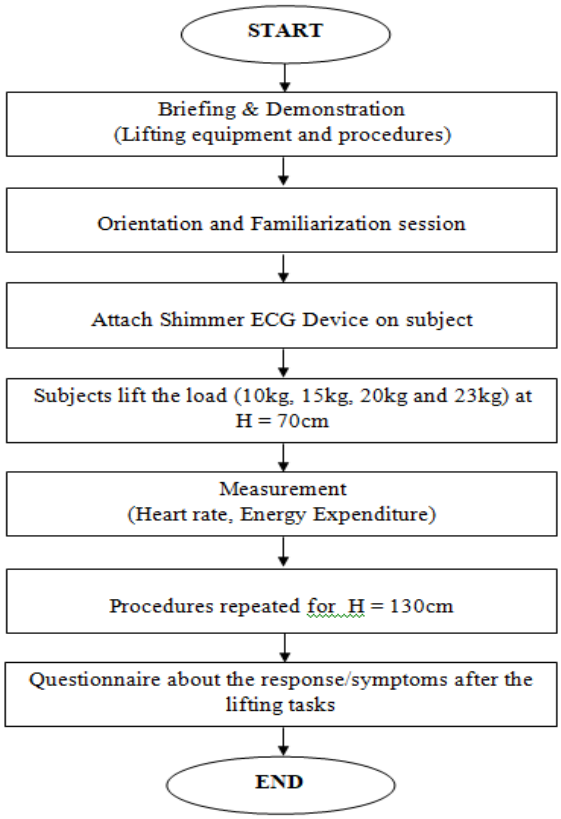


Fig. 6. Lifting task assessment.

3. Results and Discussion

The results of this study were based on the physiological response on both stoop and squat lifting posture. Subjects completed the lifting task based on the weight load adjustments, height, lifting frequency and twisting angle in 2-hour working duration. Their heart rates and metabolic energy expenditure were measured and recorded.

3.1. Heart rate

The mean heart rate for stoop and squat lifting varying with the weight load, height, lifting frequency and angle of twisting presented in Figs. 7 and 8.

3.1.1. Heart rate with fixed weight load

The subjects heart rate (beats/min) of the optimal condition lifting task were recorded with the load mass of 10 kg lifted at 1 lift per minute with 0° twisting angle (no twisting) at 70 cm lifting height for both stoop and squat lifting.

Figure 7 shows the heart rate of lifting task for both stoop and squat subjects that was recorded when subjects performing the lifting task with minimum load mass of 10 kg at the lifting height of 70 cm. The lifting tasks were varying the lifting frequencies of 1, 3 and 6 lifts per minute without twisting angle. The highest heart rate recorded during the 6 lifts per minutes of squat lifting and the lowest heart rate was recorded at 1 lift per minute of stoop lifting.

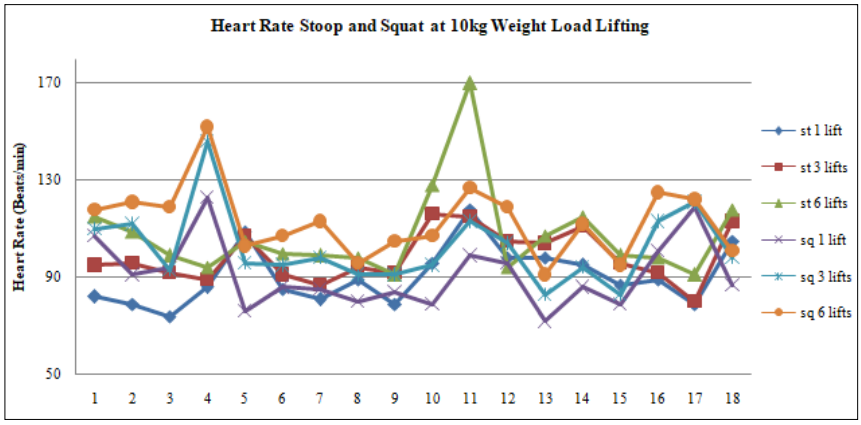
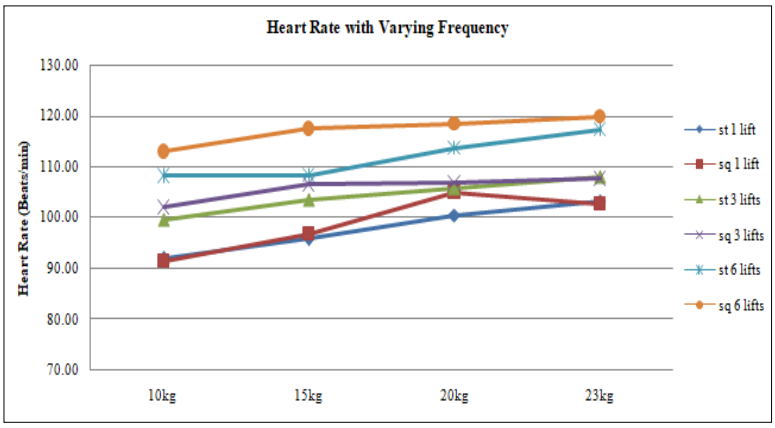


Fig. 7. Heart rate of stoop and squat lifting for 10 kg weight load.

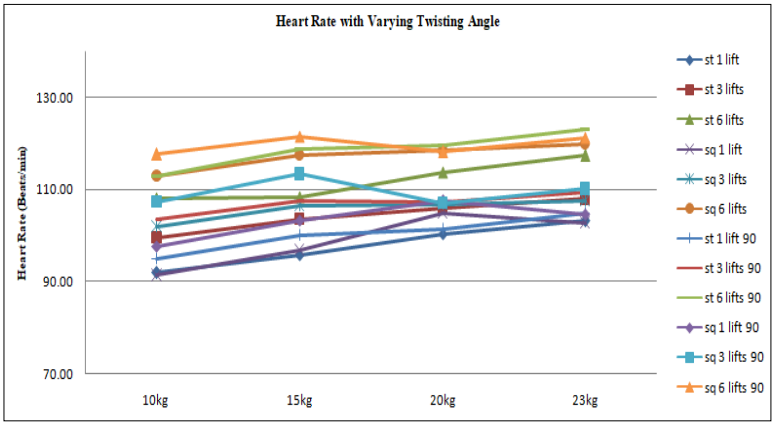
3.1.2. Heart rate with varying lifting height, frequency and twisting angle

Based on Fig. 8, the graph obviously shows that the heart rate of squat lifting is higher than stoop lifting for each weight load, lifting height, frequencies, and twisting angle. The stoop lifting was significantly produced lower heart rate compared to the squat posture as studies by numerous researchers. Indeed, heart rate of stoop posture is approximately 15-20% less in comparison to the squat posture [19, 20].

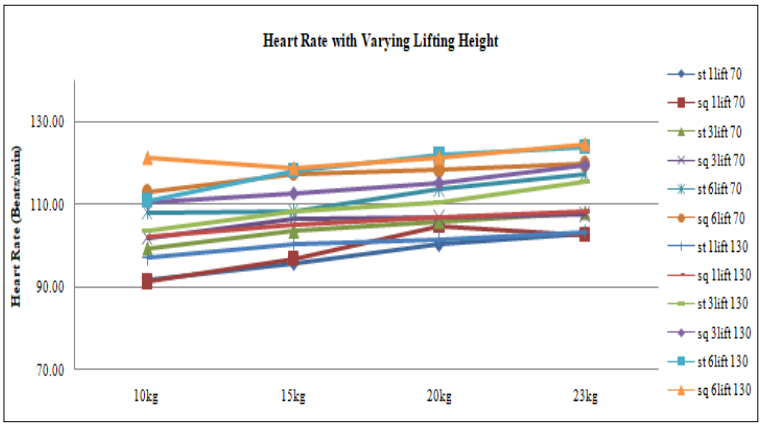
Although squat is recommended to be used in lifting task environment by health practitioner most employees tend to do the stoop lifting because it is likely that the squat lifting technique results in a higher heart rate and consequently higher levels of physiological strain in comparison to the stoop lifting technique. These shows that lifting height, frequency and load mass have a significant influence on heart rate during a lifting task. Furthermore, this result confirmed that squat lifting requires the highest oxygen consumption, highest inspiratory ventilation volume and was subjectively the most tiring than stoop [7, 20].



(a) Varying frequency.



(b) Varying twisting angle.



(c) Varying lifting height.

Fig. 8. Heart rate of varying lifting height, frequency and twisting angle.

3.2. Energy expenditure

The measured energy expenditure for stoop and squat lifting with varying the frequency and load mass discussed with varying the lifting height. Based on NIOSH Guidelines, the limited energy expenditure have been divided into two categorised, which are the height is less than or equal to 75 cm has the limited energy of 4.7 kcal/min, while the height of more than 75 cm has limited energy of 3.3 kcal/min. The graphs of Fig. 9 plotted shows the trend of energy expenditure when the lifting frequency at the lifting height of 70 cm for both stoop and squat lifting.

Stoop lifting consumed 2.08 kcal/min while squat lifting consumed 2.57 kcal/min for 1 lift per minute at 10 kg load mass. For 3 and 6 lifts per minute, stoop lifting consumed 2.51 kcal/min and 3.74 kcal/min while squat lifting consumed 3.02 kcal/min and 3.94 kcal/min. This trend was quite similar as the load mass was increased to 23 kg, stoop lifting consumed 4.10 kcal /min for 1 lift/min meanwhile the squat lifting consumed 4.41 kcal/min. The load limit for 70 cm lifting height that meets the requirements of NIOSH criteria is 23 kg for stoop lifting and below than 20 kg for squat lifting. It is because the load mass of 20 kg of squat lifting exceeds the 4.7 kcal/min of NIOSH requirement. The higher load mass for stoop lifting since the hip and trunk muscles are much stronger than the knee muscles as used in squat lifting. In addition, squat lifting can expedite the effects of fatigue on the quadriceps.

Figure 10 shows the measured energy expenditure for stoop and squat lifting at 130 cm. The trend was similar as the previous condition at 70 cm height but there were some differences when the lifting frequency was increased to 3 lifts per minute, some of the lifting tasks with varying frequency were exceeded the NIOSH requirement of load limit. The safe load limit for stoop lifting is below than 20 kg and 15 kg for squat lifting. However, in some condition of load lifting more than 20 kg, the energy expenditure of stoop lifting is higher than squat lifting possibly because of stability of squat posture as squad posture better suited to lifting heavy loads, limits strain on low back ligament and reducing the moment arm since the load positioned closer to the body [7, 21].

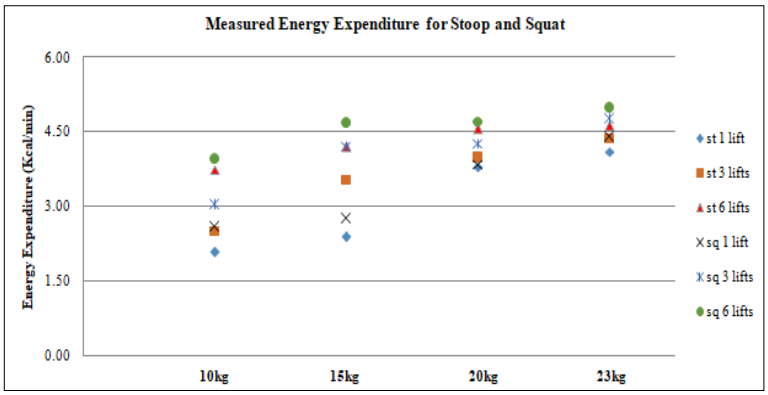


Fig. 9. Measured energy expenditure for stoop and squat lifting at 70 cm.

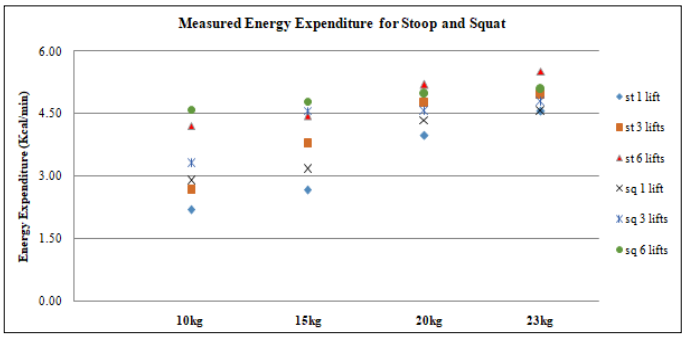


Fig. 10. Measured energy expenditure for stoop and squat lifting at 130 cm.

4. Conclusions

In Manual Material Handling (MMH) especially lifting task, the NIOSH recommendation guidelines and proper lifting techniques are important for employees to maintain safety and health at the workplace. Physiological response to lifting posture shows significant results for both stoop and squat lifting. The heart rate and energy expenditures increased as the weight of load, height and frequency of lifting are increased. The stoop lifting has more effectiveness as it reduced the change in potential energy of the lifter's body and less tired than squat. The stoop lifting significantly produced approximately 15-20% lower heart rate compared to the squat lifting.

In addition, the lifting capacity reduced in squat lifting compared to stoop lifting, since it reduced the muscular mass that can be recruited during the lifting task, but the stoop lifting required the more metabolic cost of energy expenditure in lifting heavier load capacity. Therefore, the implication of this study is to discover the optimum condition of lifting postures that can help to reduce and prevent the severity of back injuries and possible contributing factors among the workers.

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