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Determination of Recovery Time for a Simple Lifting Task Based on Weight, Frequency, and Duration of the Lift

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DETERMINATION OF RECOVERY TIME FOR A SIMPLE LIFTING TASK BASED ON WEIGHT, FREQUENCY, AND DURATION OF THE LIFT

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LIST OF ABBREVIATIONS

HRR: Heart Rate Recovery Time

LBP: Lower Back Pain

MAWL: Maximum Acceptable Weight of Lift

MMH: Manual Material Handling

MSDs: Musculoskeletal disorders:

RWL: Recommended Weight of Lift

WMSDs: Work-related Musculoskeletal Disorders

ABSTRACT

Musculoskeletal disorders (MSDs) are a leading cause of injury in American workplaces which cost the economy billions of dollars each year. Extensive research has shown that job fatigue is one of the causes of MSDs. Allocating frequent and adequate rest break is suggested to be an effective method in mitigating the work overload and fatigue prevention. The objective of this research was to determine rest periods for lifting tasks based on the activity heart rate and by using a set of task variables. Twenty-four university male students took part in this study. The two response variables were perceived level of exertion and the heart rate recovery time (which was the duration needed for the heart rate to reach a steady state after a lifting task). The independent variables were weight of the lift (10 and 20 kg), the frequency of the lift (6 and 9 lifts per minute), and the duration of the lift (5 and 10 minutes). Given the possible treatment combinations, a total of 8 treatments was obtained. Each participant performed one treatment of lifting a box from knuckle to shoulder height at a certain frequency, duration and weight. All eight treatments were equally replicated with three observations per treatment group, giving twenty-four observations. The results of the study indicate that a longer recovery time for the heart rate was needed as the frequency and duration of the lift increased; the effects of both factors were significant. A model for the heart rate recovery time based on significant factors and interactions was developed. The results of the study may be beneficial to the industry as it enables quantitative prediction of a rest period for a lifting task based on task characteristics.

CHAPTER 1: INTRODUCTION

Musculoskeletal disorders (MSDs) are injuries of muscles, tendons, ligaments, joints, and nerves which can affect almost all tissues and most often involve the arms and back (OSHA, 2000; Gatchel & Schultz, 2014). Work-related musculoskeletal disorders (WMSDs) are conditions in which the work environment or performance contribute to MSD (CDC, 2016). According to OSHA (2014), WMSDs are a leading cause of pain, suffering, and disability in American workplaces. In 2014 MSDs accounted for 32% of all injury and illness cases at the workplace (BLS, 2015). According to the same article, in 2014 there were 365,580 cases of musculoskeletal disorders with an incident rate of 33.8 cases per 10,000 full-time workers which resulted in a median of 13 days away from work per person.

Some professions sustain higher rates of injuries than others. For example, laborers and freight, stock, and material movers; nursing assistants, and heavy truck and tractor-trailer drivers incurred a higher number of MSDs in 2015 than any other profession (BLS, 2016). In addition to causing acute and chronic health problems to workers, MSDs result to high costs. Annual costs for MSD related workers' compensation is estimated to be about $20 billion a year for direct costs and $100 billion for indirect costs (OSHA, 2014). Direct costs are related to the actual cost of treatment and clinical cost and indirect costs are related to the impact of injury, lost earnings, the cost of time off work, and the burden on the economy (Dias et al., 2006; Sadeghniiat-Haghighi & Yazdi, 2015). In addition to physical injuries, research shows that workers who have prolonged absence from work as a result of MSD, are prone to suffer from psychological distress and disorders (Loisel & Anema, 2013).

Manual material handling (MMH) tasks are inseparable parts of many industries and in many cases, the human physical input is needed in performing such tasks. MMH can be defined

as moving objects from an origin to a destination by using body parts especially the hands. Generally speaking, there are two main types of manual material handling tasks: individual tasks and combined tasks (Iridiastadi & Aghazadeh, 2005). Examples of individual tasks are pushing, holding, pulling, lowering and lifting, whereas combined tasks can be a mixture of two or more individual tasks (Snook & Ciriello, 1991). Rajesh (2016) presents another classification of MMH based on the work environment characteristics, which are: task-related variables (frequency, duration, intensity), material related dimension (load and direction), and work system related dimension (layout and equipment).

According to Verbeek et al. (2012), MMH tasks, especially lifting, are associated with a high risk of lower back pain (LBP). Research shows that 70-85 % of the population experience back pain at some point in their lives and about 2% of the US workforce are compensated for back injuries each year (Andersson, 1999). Figure 1.1 shows the relative distribution of body parts injured in 2015, in which back incidents accounted for more than a fourth of all incidents.

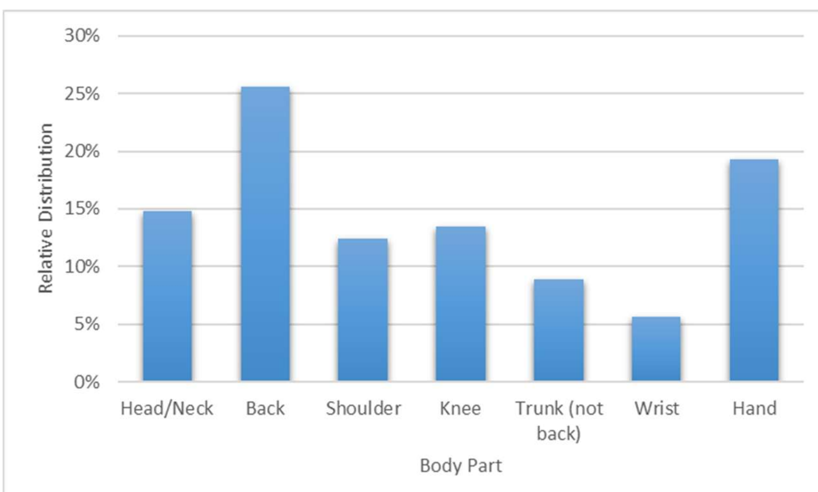

Figure 1.1: Distribution of body parts injured in all industries in 2015 (BLS, 2016)

In addition to LBP, workers who deal with MMH as a routine part of their job and are exposed to prolonged and forceful exertions are at a risk of developing cumulative trauma disorder (CTD) over the time. CTDs are damages to muscles, tendons, and joints of the upper extremity (Hales & Bertsche, 1992; Pulat, 1997). Stobbe (1996) names four major risk factors of CTD as force, frequency, duration and awkward posture.

CHAPTER 2: LITERATURE REVIEW

Five percent of all American workers miss at least one work day annually due to low back pain (Andersson, 1999) and the total cost of low-back pain in the United States exceeds $100 billion per year (Katz, 2006). In a given MMH task if a worker exerts forces beyond his or her capability, known as overexertion, the probability of getting injured increases. Table 2.1 summarizes the distribution of the injury sources in the workplace within all industries, in which overexertion accounts for more than a third of all causes. Repetition and overexertion in a physical activity can cause muscle fatigue and are major risk factors leading to MSD (Powell & Copping, 2016).

Table 2.1: Relative frequency of source of injury (BLS, 2016)

Event	Distribution
Overexertion	37.1
Falls, slips, trips	30.5
Contact with objects	26.7
harmful substances	5.1
Other events	0.6

Fatigue is a general term which is divided into two types: mental and physical. Examples of mental fatigue are depreciation in cognitive performance and inability to concentrate, whereas signs of physical fatigue are a lack of energy and a state of being weary (Hardy & Studenski, 2010; Konz, 1998). Linden et al. (2003) define mental fatigue as a change in the psychological state due to sustained performance. From a physiological viewpoint, repeated use of muscles affects muscle motor units and that leads to a transient decrease in the capacity to perform physical actions (Hirshkowitz, 2013; Enoka, 2008). Physiological fatigue is also defined as a failure of the functional organ, and a state of weakness (Shen et al., 2006; Phillips, 2015).

Eidelman (1980) defines fatigue from a cellular standpoint in which human brain constantly controls status of all parts of the body and monitors the remaining energy in the tissues and organs. Once fatigue starts to develop, the brain monitors a decreasing trend of latent capacity of tissues and organs which is translated as a gradual resistance to continuous activity, and that is known as fatigue. Fatigue should not be confused with sleepiness. Sleepiness is the tendency to fall asleep, whereas fatigue is the body's response to physical and mental exertion (Lerman et al., 2012).

Janaro & Bechtold (1985) state that workplace fatigue, regardless of type (physical or psychological), can affect worker's capacity and productivity. It is a known fact that fatigue can deteriorate productivity and work quality, increase the number of work errors and lead to workplace injury (Katic et al., 2013; Belenky et al., 2014). Bhatia and Murrell (1969) discuss the effectiveness of proper rest breaks on worker productivity and fatigue reduction. Considering that there is an association between muscle fatigue and task performed (Enoka, 2008) and that excessive fatigue at workplace can affect worker's health, productivity and safety (Lerman et al., 2012), serious efforts need to be made in finding proper work-rest schedules that not only ensures workers well-beings, but also help with lowering the economic burden of MSDs on society.

2.1 Three Approaches Towards Prevention of MSDs

Snook et al. (1978) suggest three major approaches for prevention of low back injuries in the industry, which are: training, ergonomics and worker selection. The effectiveness of each method in preventing MSDs is discussed below.

2.1.1 Worker Selection

One idea in reducing work injuries and fatigue is that workers should be hired based on their physiological fitness for jobs requiring them to perform straining manual tasks (Brouha,

1967). Chaffin (1979) states that employment screening, such as low back x-rays, does not have a justified validity when used as the sole criterion and will discourage job seekers in applying for certain jobs. He adds that screening should only be used for people with questionable low-back history. In another study done by Chaffin & Park (1973), no correlation was found between participants' anthropometry (height and weight) and musculoskeletal injury rate. Furthermore, choosing workers based on their physical capability for certain occupations might infringe Americans with Disabilities Act (ADA).

2.1.2 Training Interventions

Blangsted et al. (2008) studied the effects of different physical activity (exercise) interventions in reducing shoulder and neck symptoms, in which after a year, the duration and severity of neck and shoulder musculoskeletal symptoms were reduced among participants. Lahiri et al. (2016) reviewed the cost-effectiveness of a training intervention on 100 porters over a 2-year period in a pre-post study, in which the end results show a reduction in physical and mental scores of post-training and respectively, a huge saving in absenteeism.

Historically, the predominant culture is to design a workplace then try to fit the workers to the job by training and worker selection, but this approach has proved to fail. Workers can not be trained to perform tasks beyond their physical capability without risk of injury (Stobbe,1996). In a review by Mahone (1994) on MMH injury prevention, the author argues that quick fixes, such as the use of back belt and training should not be the primary approach, but the focus should be on ergonomic ways and proper job design.

2.1.3 Ergonomics

Ergonomics can be defined as the design of the work, workplace, work environment, and tools to match the physical, physiological, and mental capability of the workers to provide a safe

and productive workplace. Ergonomics intervention in MMH essentially work around designing the job to fit workers and can include task elimination, changes in lifting weight, posture changes, the use of mechanical aids, and the removal of the worker (Stobbe,1996). Ergonomic studies in MMH can be divided into two broad topics: first, studies that investigate the relationship between task factors and their effect on worker performance, and second, works that look at proper rest and relaxation times for workers to recover from a demanding physical or mental task.

2.1.3.1 Task Factors Studies

There are several studies focused on determining the relationship between task factors and their effect on workers' physiological responses and the safe limits that workers should perform a manual task safely without straining themselves. Waters et al. (1997) name certain assessment tools as ergonomic approaches in dealing with MMH injuries, which among those are revised NIOSH (1991) lifting equation and Snook table (Snook, 1978; Snook & Ciriello, 1991). Each of these tools provides a suggested and safe limit for a certain manual material handling task.

In 1981, the National Institute for Occupational Safety and Health (NIOSH) published a lifting equation (which later was revised in 1991) that was designed to provide recommended weight limits that healthy workers could lift over a period of eight hours without increasing the risk of MS injuries to the lower back (Waters at al., 1994). The NIOSH equation is based on a psychophysical, physiological, and biomechanical criterion which determines if a lift is safe for a given task, this equation uses several task variables to calculate the recommended weight of lift (RWL) and the lifting index (LI) as follows:

$RWL = LC\ (51) \times HM \times VM \times DM \times AM \times FM \times CM$

Lifting Index (LI): $Weight \div RWL = LI$

Where the task variables are:

LC= load constant, 23 kg or 51 lbs.

H = Horizontal location of the object relative to the body

V = Vertical location of the object relative to the floor

D = Distance the object is moved vertically

A = Asymmetry angle or twisting requirement

F = Frequency and duration of lifting activity

C = Coupling or quality of the workers' grip on the object

RWL is the load that 90% of the population can safely lift and the LI determines the safety level of the lift. If LI is greater than 1, administrative controls should modify the lifting task to make it safer for workers. NIOSH equation is a well-known approach in analyzing lifts, however, it fails to take into account tasks with large variations, individual risk assessment (e.g. weight, height, age) and one-handed lifting among others.

Many studies have tried to develop guidelines to determine the maximum acceptable weight of lift (MAWL) in a manual material handling task. The psychophysical method is the main tool in determining MAWL. Aghazadeh (1974) defines psychophysical method as the psychological study of the relationship between physical stimuli and sensory response. In this approach, participants perform a certain MMH task twice, once with an empty or light box and once with a heavy box. They are asked to adjust (add or remove) weights into the box while performing the task until reaching a maximum weight, where they feel comfortable to lift for a period of 8 hours in the real work situation. The average weight of the two trials is considered as MAWL. In some cases, participants are told to imagine the heavier they lift, the better they get paid.

In a series of research conducted by Liberty Mutual Insurance, Snook and Ciriello (1978, 1991), used psychophysical methods to outline the design goal for various manual handling tasks (lifting, lowering, pushing, pulling, and/or carrying). Snook tables can be used as a guide to compare a specific MMH task against the table values to determine the corresponding percent of the population who can perform a MMH task without strain. Based on Snook tables, standard MMH tasks should be designed for 75th percentile of the female population, which is essentially acceptable to the 90th percentile of males. Tasks which can not be performed by 75% of the female population, should be redesigned and revised to prevent any MS injuries.

Chaffin and park (1973) conducted a study over the period of 5 months on 135 workers working in five electronics manufacturing companies to find the maximum acceptable weight of the lift. Their study concluded that for lifts performed close to the body, the weight should not pass 35 lbs., and for the loads lifted 20 inches from the ankle, the maximum weight of the lift should be 20 lbs.

In a laboratory study by Garg & Banaag (1988), the effect of symmetry angel (30, 60, and 90 degree), frequency (3, 6, and 9 lifts/min) and lifting height (floor-81 cm, 81-152cm) on MAWL, rating of perceived exertion (RPE), static strength, and heart rate in a repetitive lifting task were examined. The results show that heart rate and RPE increased with an increase in the symmetry angel, while MAWL and static strength were decreased in asymmetric lifting. On the other hand, the frequency and lifting height had no significant effects on MAWL

Gallagher (1991) studied the effect of three task variables on MAWL and physiological responses such as heart rate and oxygen intake. The task variables included posture (stooping or kneeling), lift distance (35 cm or 60 cm) and task symmetry (symmetric or asymmetric). Eight male participants performed 8 treatments in a within-subject design. MAWL values were obtained

via psychophysical approach. The researcher concluded that heart rate was not significantly affected by posture and that physiological responses were lower in the case of kneeling. MAWL values were higher in asymmetric tasks and participants could lift less weight in 60 cm lift distance.

Wu (1997) studied the effect of box size and frequency on MAWL, heart rate and RPE scale on 13 male participants. There were three box sizes (300, 450, and 600mm wide) and three lifting frequencies (1,4, and 6 lifts/min). The data analysis shows a significant decrease in MAWL, with an increase in box size and lifting frequency. On the other hand, RPE did not significantly increase with an increase in the box size, however, overall RPE ratings increased significantly with the lifting frequency. Also, the mean heart rate increased markedly with the box size and lifting frequency.

Maiti & Bagchi (2006) examined the effect of three lifting parameters and their interactions on the working heart rate. Factors studied were lifting frequency (1, 4, 7 and 14 lifts per minute), vertical lifting distance (knee, waist, shoulder and maximum reach height), and load weight (5, 10 and 15 kg). Ten female construction workers were hired to perform 48 different treatments of lifts for a period of 10 minutes. The results show that the contribution of main effects was significantly higher than the interaction effects and among main factors frequency had the highest coefficient of determination. The interaction effects of different lifting parameters contributed to only 10% of the total variance of normalized working heart rate, in which 6% belonged to the interaction between weight and frequency.

In another MMH study conducted in Columbia (Saavedra-Robinson et al., 2012), the effect of lift factors on the maximum weight of lift was studied. The two independent factors were height (knuckle, shoulder, and maximum reach) and frequency of the lift (2,4, and 6 lifts per minute). Each of the 20 male participants performed all nine treatment combinations. The objective of their

study was to determine the maximum acceptable weight of lifting under pre-determined height and frequency conditions and to compare the results with the current standards in MMH. The results show that frequency had a significant effect on MAWL, in such way that the higher the frequency, the lower the weight was lifted. The results also show that standards on MAWL in Columbia had higher limits compared to the findings of their study and might need to be revised.

Another study investigated the effect of box size, the frequency of lifting, and height of lifting on the heart rate of male university students in Iran (Abadi et al., 2015). The results of the study show that the frequency of the lift and size of the box had a significant effect on the heart rate. Meanwhile, no significant difference was observed in terms of lifting height.

There are many more studies on task factors in MMH handling. However, the ones discussed were found to be relatively close to the area of this current research. Table 2.2 summarizes the MMH studies that investigated the effect of multi-level task factors on the response variable (s). Most of the MMH studies discussed target the MAWL as the response variables and test how different task factors will affect the response variable.

2.1.3.2 Work-Rest Studies

Determining a proper work-rest schedule can help workers to perform a strenuous task, mental or physical, safer and help in preventing accidents on the job. Bedny & Seglin (2001) suggest that the best way to evaluate the functional state of an organism (in this case human body) is through measuring energy expenditure. Energy expenditure is usually measured in kilocalories (kcal). According to the same article, the duration of break time should be based on an analysis of the energy expenditure. The energy expenditure is usually measured via indirect calorimetry-approaches. In these methods, the amount of produced CO_2 or the volume of consumed O_2 is analyzed to draw the values of energy expenditure in kcal/min. In practice, measuring the energy

expenditure by a VO_2 device during a lifting task can be cumbersome, for this reason, some studies use heart rate as a measure of energy expenditure.

Table 2.2: MMH studies on task factors

Author	Response Variable	Lifting Parameter	Main Findings
Garg & Banaag (1988)	MAWL, RPE, Static strength, heart rate	Symmetry angel, frequency, lifting height	With an increase in symmetry angel, HR and RPE increased, while MAWL and static strength were decreased
Gallagher (1991)	Heart rate, MAWL O_2 intake	Posture, lift distance, task symmetry	Task factors had no effect on the HR values, Job posture had a significant effect on the MAWL
Wu (1997)	MAWL, heart rate, RPE	Box size, lifting frequency	As frequency and box size increased, MAWL decreased and average HR increased. RPE was mostly affected by frequency, not box size
Maiti & Bagchi (2006)	Heart rate	Lifting frequency, vertical distance, load weight	Frequency is the most significant factor affecting HR
Saavedra-Robinson et al. (2012)	MAWL	Lifting height, lifting frequency	Frequency had a significant effect on MAWL (inverse relationship)
Abadi et al. (2015)	Heart rate	Box size, lifting frequency, lifting height	Frequency and box size had a significant effect on the heart rate

Getting an accurate work-rest formula has always been a challenge in human factors and work design. Murrell (1965) was a pioneer in developing a work-rest formula. He developed a formula that was based on the early work of a German researcher named Spitzer in 1951. Murrel (1965) states for jobs requiring an energy expenditure of more than 5 kcal/min, an appropriate recovery time should be provided. The duration of recovery is based on how much the energy

expenditure for a given task deviates from the base amount (5 kcal/min). Murrel's model is as follows:

a = w (b-s) / (b- 1.5)

where:

a = recovery time in minutes,

w = work duration in minutes,

b= average calorie expenditure per minute,

s = level of energy expenditure adopted as standard (5 kcal/min for the average male, 4 kcal/min for the average female)

The main weakness of this equation is the assumption that tasks with low energy expenditure (below the standard level) do not lead to fatigue; therefore, no rest is needed. For instance, a task that requires 3 kcal/min needs no rest.

Rohmert (1973) performed a laboratory research using physiologically oriented methods and developed a model for static muscular work based on 13 muscle groups (upper limbs, trunk, lower limbs):

$$RA = 18 \times \left(\frac{t}{T}\right)^{1.4} \times \left(\frac{f}{F} - 0.15\right)^{0.5} \times 100\% \qquad \text{if } f/F > 0.15$$

Where:

RA = Rest Allowance,

f/F = t/T = fraction of maximum voluntary contraction(force),

f: force applied (N),

F: maximum endurance limit of force (N),

t = holding time (working period) in minutes,

T = maximum holding time or endurance time) in minutes,

Based on Rohmert's study (1973) in a single static contraction a muscle can be exerted at 100% of its maximum voluntarily contraction (MVC) only for a few moments and for exertions less than the maximum, the muscle can tolerate more force. Also, Rohmert assumes that at 15% of maximum exertion, the muscle can tolerate the force for a longer amount of time (Chaffin and Anderson, 1991) and tasks that require less than 15% of the maximum voluntarily force (MVF), can be performed indefinitely. The same weakness of Murrell's model is present in Rohmert's work and that is no rest allocation for low-energy expenditure tasks, which does not sound practical in a work environment.

Pulat (1997) developed a set of formulas that was a combination of Murrell's and Spitzer's works. Each formula was based on the level of energy expenditure. The three categories of energy expenditure for Pulat's model are presented in Table 2.3. If the energy expenditure is less than the expected standard (4 kcal/min for females, 5 kcal/min for males), work-related rest allowances are not needed, and when the energy requirements exceed that limit, a rest is needed. Pulat model is presented as follows:

$R_T = 0$ for $K<S$

$$R = \frac{\left\{\left[\left(\frac{K}{S}-1\right)\times 100\right]+\left[\frac{T(K-S)}{(K-BM)}\right]\right\}}{2} \quad \text{for } S<=K<2S$$

$$R = \frac{T(K-S)}{(K-BM)} \times 1.11 \quad \text{for } K>=2S$$

Where:

R_T = Rest Time (min),

K = Energy cost (kcal/min),

S = Accepted standard (4 kcal/min for females, 5 kcal/min males),

T = work time (min),

BM = Basal metabolism (kcal/min) = 1.4 for females, 1.7 for males,

Table 2.3: Energy expenditure levels

Energy (Kcal/min)	Male	Female
Lower energy expenditure	0 - 5	0-4
Medium energy expenditure	5-10	4-8
High energy expenditure	>10	>8

Pulat also added a new component that accounts for the age of the participant in the form of a multiplier, that number is used to adjust the R_T obtained from the formula. Table 2.4 shows the multiplier for age. According to George (2014), the weakness of Pulat's model is in cases that the model yields longer rest period for medium energy expenditure tasks compared to high energy expenditure tasks under the same duration of work. For instance, a 30-year-old male worker performing a task that requires 9 kc/min (medium energy expenditure) for 60 minutes of work needs 56 minutes of rest. Whereas for the same duration of work for a task that requires 11 kc/min (high energy expenditure), the suggested rest period for that person is 43 minutes.

Table 2.4: Age multipliers for Pulat's formula

Age	Multiplier
20-30	1
40	1.04
50	1.1
60	1.2
65	1.25

Among manual laborers, construction workers are often subjected to harsh weather and laborious tasks. Therefore, to prevent overexertion and reduce the risk of muscle fatigue and injury, finding a work-rest schedule for them is of the great importance. Hsie et al. (2009) used genetic algorithm methods based on the worker's energy expenditure and developed equations determining the worker's maximum acceptable work duration (MAWD), and the rest time required for recovery from fatigue. The equations are presented below:

$$\text{MAWD(min)} = -2.09 + e^{6.59-5.60*RVO_2}$$

In which, RVO_2 is the relative oxygen uptake rate which is obtained by the following formula:

$$RVO_2 = (VO_{2work} - VO_{2rest}) / (VO_{2max} - VO_{2rest})$$

Additionally, in a modification of Murrell's formula for metabolic load, Hsie et al. (2009) developed a formula for rest allowance as follows:

$$R\ (\text{min}) = \text{worktime (min)} \times \frac{VO_{2work} - 0.33\ VO_{2max}}{VO_{2work} - VO_{2rest}}\ ;\ (VO_{2work} - 0.33 VO_{2ma}\ ) < 0,\ R = 0$$

According to Hsie et al. (2009) resting model, tasks that require less than 33% of maximum oxygen intake need no rest, and that is the weakness of their model.

It is important to note most of the work-rest equations discussed are based on the assumption that when workload exceeds beyond the base limit (33% of maximum VO_2 or 5kc/min), fatigue starts to accumulate (Saha et al., 1979; Price, 1990; Snook & Ciriello, 1991; Tiwari & Gite, 2006). Table 2.5 summarizes the work-rest models discussed above.

Despite the lack of studies on work-rest equations, there are several studies that compare the effect of different work-rest schedules on the subjective fatigue or physiological response. However, most of these studies are not in the area of material handling, but rather investigate areas such as office environment or video display terminal (VDT) user interface. Some studies use

measures other than physiological in determining the best work-rest schedule. Among those are performance and error rate. Kopardekar & Mital (1994) studied the effect of three different work-rest schedules on participants' performance. The three treatments tested were: 5-minute break after 30 minutes of work, a 10-minute break after 60 minutes of work, and 120 minutes of work with no break. The results show that the no-rest treatment led to a larger number of errors compared to the first two treatments. Also, the 5-minute break after 30 minutes of work was found to have an advantage over the 10-min break after 60 minutes of work in terms of performance and number of errors.

In another study, Balci and Aghazadeh (2003) compared the effect of three different work-rest schedules on the performance and perceived level of discomfort among 10 VDT users. The three schedules were: 60-minute work / 10-minute rest, 30-minute work/ 5-minute rest, and 2-hours work/ micro breaks. The micro breaks consisted of three breaks of 30 seconds after every 15 minutes, a longer break of 3 minutes within an hour, and a 14-minute regular break after two hours of VDT work. The overall results show the work schedule including micro breaks was superior to the other two for showing lower discomfort in upper extremities and better results in terms of speed, accuracy, and performance.

Tiwari & Gite (2006) compared different work-rest schedule for workers operating a rotary power tiller. They used heart rate as their physiological measure and a 10-point discomfort survey as their subjective measure. Among the 4 schedules compared, the rest periods of 15 minutes were found superior over 10 minutes' ones, and it was concluded that work durations for power tiller operation should not exceed 75 minutes, or they will cause discomfort.

Table 2.5: Work-rest formulas

Author	Specific Work Content	Formula	Description
Murrell (1969)	Heavy work exceeding energy expenditure, b>5kcal/min	$a = \frac{w(b-s)}{b-1.5}$	a: min. of recovery time required per shift (min) w: work duration (min) s: energy requirement of a standard task (5kcal/min) b: energy expenditure rate (kcal/min)
Rohmert (1973)	Static muscular work	$RA = 18 * (fMHT)^{1.4} * (fMVC - 0.15)^{0.5} * 100\%$ fMHT=t/T fMVC = f/F	RA = Rest Allowance fMHT: Fraction of max holding time t: holding time T: max holding time fMVC: fraction of max voluntary contraction f: force applied F: max endurance limit of force
Pulat (1997)	Low energy expenditure work	$R = 0$ $If\ K < S$	R: Rest Time (min) K: Energy cost of work (kcal/min) S: Standard energy expenditure S_f = 4kcal/min S_m = 5kcal/min T: Total duration of task (min) BM: Basal metabolism (kcal/min) BM_f = 1.4 BM_m = 1.7
	Intermediate energy expenditure work	$R = \frac{1}{2}\left\{\left(\frac{K}{S} - 1\right) * 100 + \frac{T(K-S)}{K-BM}\right\}$ $If\ S \leq K < 2S$	
	High energy expenditure work	$R = \frac{T(K-S)}{K-BM} * 1.11$ $If\ K \geq 2S$	
Hsie et al. (2009)	Heavy dynamic work	$RA = \frac{(VO_{2work} - 0.33VO_{2max})}{(VO_{2work} - VO_{2res})} * 100$ where, $(VO_{2work} - 0.33VO_{2max}) < 0, R = 0$	RA = Rest Allowance VO_{2max}: max oxygen consumption VO_{2work}: max oxygen consumption at work VO_{2rest}: max oxygen consumption at rest

In a thesis research by Bahmani (2013), the effect of four different rest periods in a repetitive manual material handling task was studied. The lifting task had a fixed duration of 20 minutes and the rest periods were: 5, 10, 15, and 20 minutes. Rest periods were compared with each other with respect to heart rate elevation, perceived exertion, arm strength, and grip strength. The overall results show that the 15-minute rest had an advantage over the rest.

Sheahan et al. (2016) compared three different standing rest-break on a group of people who performed prolonged seated work. The treatments were as follows: 5 min of standing rest every 30 min, 2.5 min of standing rest every 15 min, 50 seconds of standing rest every 5 min. The self-reported LBP scores show that frequent, short rests were more helpful in reducing symptoms of LBP; however, the EMG data of trunk muscles did not show any significant difference between treatments.

Table 2.6 summarizes work-rest comparisons studies. As it was discussed, most of the studies on work-rest schedule only compare some pre-designated schedules with each other and the ones which try to develop a resting formula (Table 2.4), rely on the calories expenditure or oxygen consumption.

Table 2.6: Work-rest comparison studies

Study	Specific Work Content	Measures	Schedules Compared	Findings
Kopardekar & Mital (1994)	Directory assistance operator's task with a VDT	Performance and error rate	30 min work/ 5 min break, 60 min work/ 10 in break, and 120 min work/no break	The 5-minute break was found superior

(Table cont'd.)

Table 2.6 continued: Work-rest comparison studies

Study	Specific Work Content	Measures	Schedules Compared	Findings
Balci & Aghazadeh (2003)	VDT users	Discomfort in upper extremities, performance, speed, and accuracy	60 min work / 10 min rest, 30 min work/ 5 min rest, and 2-hour work/ micro breaks (three 30 seconds break each 15 minutes + 3 minutes after an hour, and a 14-minute break after 2 hours of work).	The 2-hour work with micro breaks was found superior
Tiwari & Gite (2006)	Workers operating a rotary power tiller	Heart rate and a subjective discomfort survey	Total duration of 6-Hour work broken down into 90, 60, 75, and 45 minutes sessions, followed by either 10 min or 15 min rest in between sessions	The 15 min rest periods were superior over 10 min ones. Work durations should not exceed 75 minutes
Bahmani (2013)	Manual material handling	Heart rate elevation, perceived exertion, and changes in arm strength and grip strength	Work duration of 20 minutes followed by four different rest periods: 5, 10, 15, and 20 minutes.	The 15-minute rest had an advantage over the rest.
Sheahan et al. (2016)	Prolonged seated work	LBP survey	5 min of standing rest every 30 min, 2.5 min of standing rest every 15 min, 50 s of standing rest every 5 min.	Frequent, short rests were more helpful

CHAPTER 3: RATIONALE

When the workload increases beyond the maximum oxygen capacity in a given task (beyond 33%), the anaerobic process becomes predominant. As a result, a pressure is put on the cardiovascular system causing the heart rate to elevate and initiating muscle fatigue (Brouha, 1967; Saha et al, 1979). Chaffin & Park (1973) state when individuals apply exertion beyond their physical capability, the risk of MSD increases.

Many authors claim that giving frequent and adequate breaks, even as short as few seconds, may prevent fatigue, overload, and lower the risk of injury (Henning et al., 1997; Rosa et al., 1998; Cal/OSHA, 2003). Lerman et al. (2012) state that taking frequent breaks may be more beneficial in heavy physical activities than in lighter activities. Bedney and Segline (1997) studied and proved the effectiveness of the pulse rate method in assessing physical workload and concluded that more break time was needed when the average pulse rate exceeded 100 beats/min. Heart rate is proved to be a useful and convenient method for measuring the physical workload and environmental stress on the body when studying dynamic physical work (Brouha, 1967; Rohmert,1973; Bedney & Segline, 1997; Eastman Kodak Company, 2007). Also, Rohmert & Laurig (1975) work suggests that the pulse rate, when the load level is zero, can be used as an indicator of the stress level. As a result, we can say the longer it takes for the pulse rate to return to inactivity rate (resting), the higher stress must have been experienced. This finding will be used as the general guideline for this study.

As it was discussed in the literature review section, many researchers have studied the effect of different task variables in calculating the maximum acceptable weight of lift (MAWL) or the heart rate values and some have reviewed the proper rest periods based on the metabolic characteristic of workers (such as oxygen uptake or calories needed). However, there has not been

any studies up to this date that determines the appropriate resting breaks in a manual material handling jobs (in this case, lifting) based on both task variables or cardiovascular response (changes in the heart rate). This study focused on analyzing the effect of three major task components on the heart rate recovery time

3.1 Research Objectives

In order to decrease the number of workplace injuries and workers' sufferings, and to lessen the burden of MSDs from the economy, many studies propose techniques and solutions for safer manual material handling. This study investigated the effect of three task factors (duration, frequency, and weight) on the heart rate recovery time. The objective of this research was twofold: the first objective was to determine heart rate recovery time by conducting a series of lifting experiment, and the secondary objective was to develop a model to predict rest periods for lifting tasks based on the activity heart rate and by using a set of task variables. To meet these objectives, we conducted several manual lifting tasks consisted of continuous lifting using human participants. To meet the objectives of the study, following steps were carried out:

- Find which of the main three independent variables (frequency, duration, and weight), significantly affect the responses (recovery time and Borg scale).
- Determine if the interactions between main factors, significantly affect the responses.

CHAPTER 4: METHODS AND PROCEDURE

This study focused on measuring the heart rate recovery time after performing various lifting tasks to find a relationship between task factors and recovery time. It also investigated to determine if any of covariates had any effect on the response variable. In this project, participants were lifting a crate filled with a certain weight, for a certain duration and at a certain frequency. Several measurements were captured before as well as after each experiment. Since this study required human participants, a permission from LSU institutional review board (IRB) was obtained before conducting the experiment. A copy of this permit is in Appendix A.

4.1 Experimental Design

A 2^3 factorial design was used for this research. Aghazadeh (1986) used this design in his MMH study. In his work, three independent variables of height, frequency, and container type, each at two levels, were used to predict the maximum acceptable weight of lift (MAWL). In the current study three main factors of frequency (lifts/min), duration (min), and weight (kg), each at two levels, were used to predict the heart rate recovery time (HRR). Each of these variables had a high and a low level. Giving the possible treatment combinations, eight (2^3) treatment combinations were obtained in the experiment and all of them were utilized. Each participant was randomly assigned to only one treatment (between subject design). The randomization was done by an online tool (Random.org). Table 4.1 shows the treatments. The experiment was conducted over three days, and on each day the full set of eight treatments was used (by 8 participants). Therefore, the design structure of the experiment is a randomized complete block design (RCBD). Blocking was accounted for by using the variable day as a random effect in the model. No data were disregarded in the analysis, and so all eight treatments were equally replicated with three observations per treatment group, giving twenty-four observations.

Table 4.1: Treatment combinations

Treatment #	Frequency(lift/min)	Duration(m)	Weight(kg)
1	6	5	10
2	9	5	10
3	6	5	20
4	9	5	20
5	6	10	10
6	9	10	10
7	6	10	20
8	9	10	20

Table 4.2 presents the experimental layout design. As discussed, each participant only performed one of the eight treatment combination on each day. In pilot studies, it was observed that test participants would get disinterested when they are scheduled to perform all treatment combinations within several days. Therefore, this experiment was designed in a way that only a single treatment was assigned to each individual to prevent the carry-over effect and experiment mortality over the course of the experiment.

4.1.1 Dependent and Independent Variables

Anna (2013) considers job requiring repetitive, forceful, or prolonged exertions of the hands; frequent or heavy lifting, pushing, pulling, or carrying of heavy objects, as a major risk factor of WMSD. According to the same author, the level of risk depends on the intensity, frequency, and duration of the exposure to these conditions. Subsequently, frequency, duration, and the weight of the lift were selected as the key characteristics (dependent variables) of this study and were used to investigate how they affect a person's recovery time and the subjective fatigue. Each task factor had a low-end and a high-end value (Table 4.3).

Table 4.2: Experimental design layout

participant #	Duration							
	5 min				10 min			
	weight				weight			
	10 kg Frequency		20 kg Frequency		10 kg Frequency		20 kg Frequency	
	6	9	6	9	6	9	6	9
1								X
2						X		
3					X			
4				X				
5	X							
6							X	
7		X						
8			X					

Table 4.3: Independent variables of the study (task-related)

Variable	High End	Low End
Frequency (lifts/min)	9	6
Weight (Kg)	20	10
Duration (min)	10	5

In this study, the values of frequency and weight of the lift were picked from Snook tables (Snook & Ciriello, 1991). Before using Snook tables, we had to find what part of the table represent our task the best in terms of lifting type and vertical and horizontal distance of the lift. For this task, the first row and the second column matched our lifting task characteristics (Figure 4.1). Based on the table, for lifts from knuckle to shoulder with a horizontal distance of 75cm and

vertical distance of 76cm (closest to our horizontal value of 63cm and vertical distance of 70cm), 10 kg is the weight that can be lifted by the 90^{th} percentile of healthy male adults in the industry when the lift is performed every 9 seconds (nearly 6 lifts per minute). As a result, 10 kg and 6 lifts per minute were picked as the base values for weight and frequency of this experiment. In order to have a clear distinction between the low-level and high-level, 20 kg was picked as the high level of the weight. On the other hand, based on pilot studies conducted by the experimenter, doubling the frequency (to use as the upper-level frequency) was not practical, and 9 lifts/ minute was found to be the highest frequency that could be performed and was used as the high-level frequency. The third task factor was the duration of the lift and based on pilot studies, 5-minute duration was found to be the smallest time for a lifting task that would get the heart rate to reach a peak value and it was picked as the lower level of the duration. Subsequently, 10-minute duration was selected as the high-end.

The first response variable was the heart rate recovery time. Pulat (1997) explains in a sub-maximal physical activity, the heart rate is at a stable range before the activity and will reach to a steady high level while the activity is in progress, and after finishing the activity it will reach to some steady state (Figure 4.2). However, based on the nature of the task and individual characteristics, the heart rate might not get back to the same steady state as in the pre-activity phase and remains at a range above the resting level for some time (Brouha, 1967). Discovering the duration before reaching a steady state was of the interest of this experiment. In this experiment, the steady state is defined as a phase on the heartbeat graph (upon completion of the task) that the heartbeats form a semi-horizontal line while fluctuating within a 10% range for a duration of at least two minutes. For instance, upon completion of a given treatment (lifting task), if the heart rate reached a phase with values between 65-75 beats per minute after 40 seconds and stayed in

that range for 2.4 minutes, that phase was defined as the steady state and the duration between the end of the task to the beginning of the steady state (which in the above scenario was 40 seconds) was recorded as the heart rate recovery time.

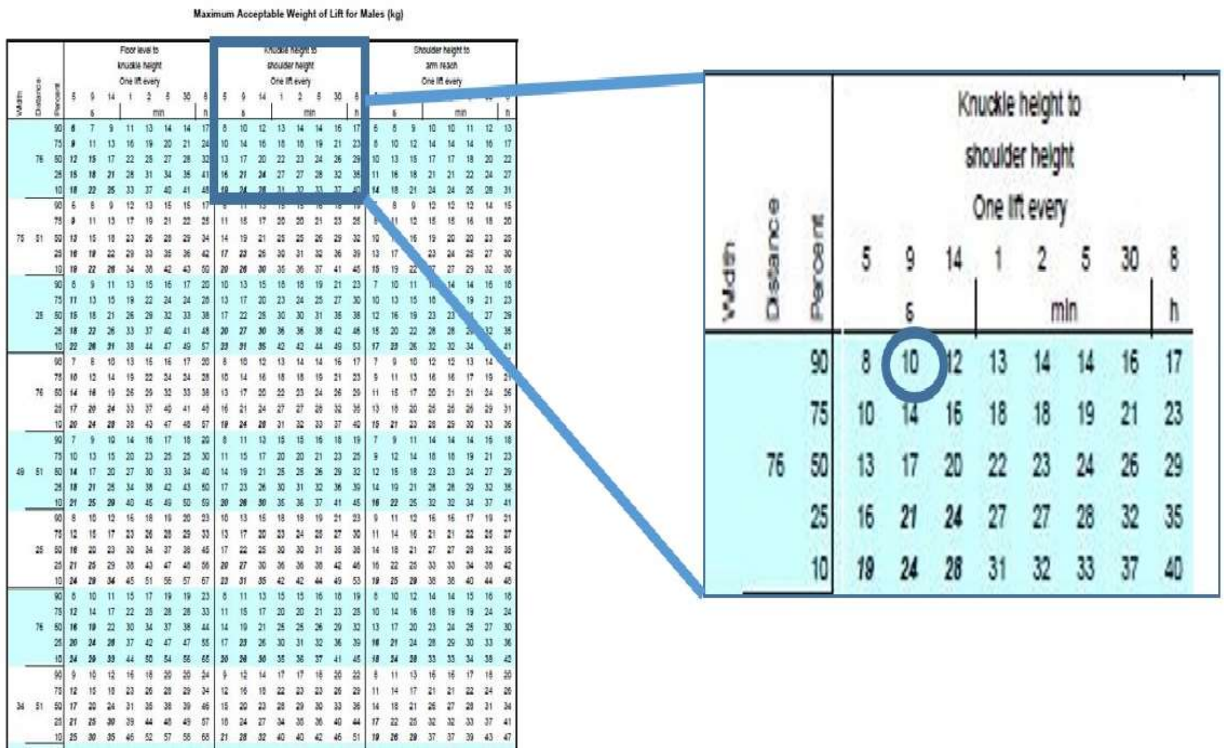

Figure 4.1: Snook table for lifts (Snook & Ciriello, 1991)

The secondary response variable was the perceived level of exertion. A common method for rating the difficulty of a manual task is the use of Borg scale (Borg, 1982). The original Borg Scale ranges from 6 to 20 points, but a modified version of Borg Scale called Borg CR10 was used in this study, which employs a response format that ranges from a value of 0 (no exertion at all) to 10 (maximal exertion). A copy of the Borg CR10 is provided in Appendix C.

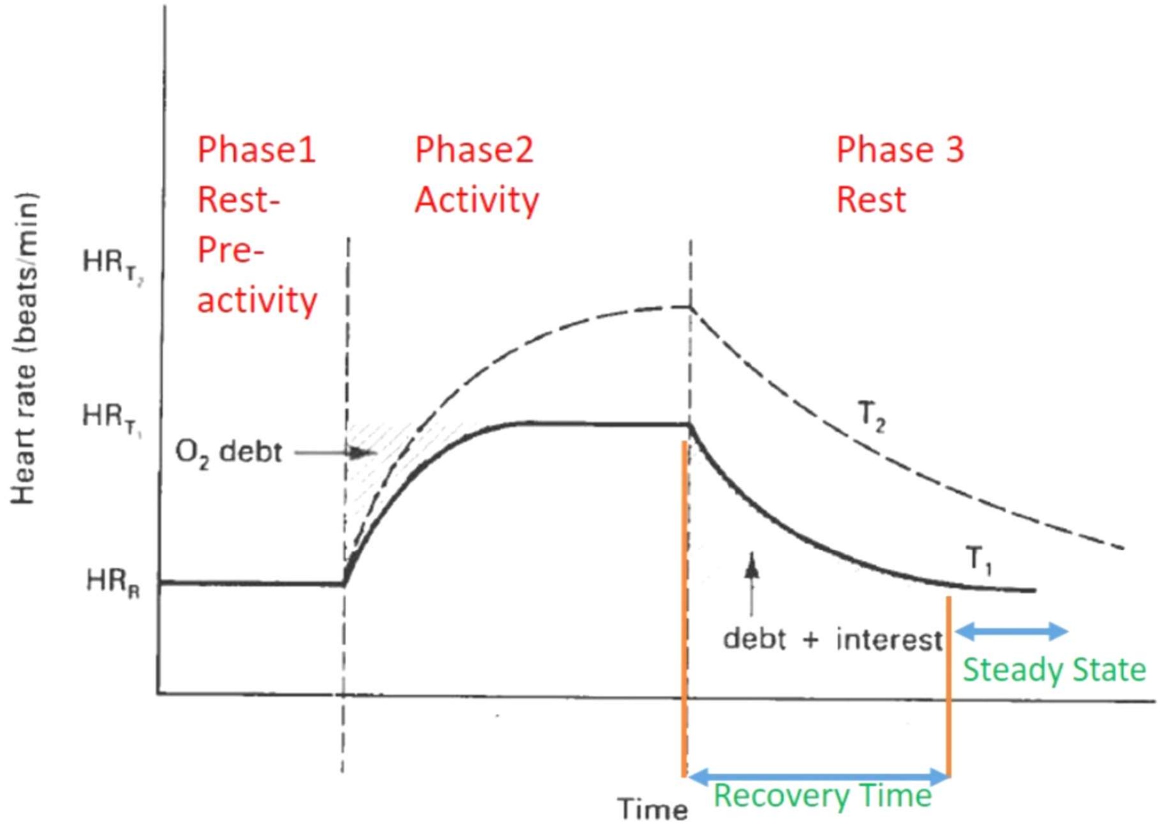

Figure 4.2: Heart rate in a sub-maximal physical activity (adopted from Pulat, 1997)

There were four operator-related variables captured before each experiment which were not the main focus of this study. These confounding factors were studied to determine if they had any significant effects on the heart rate recovery time. These variables were as follows: static arm strength, grip strength, Body Mass Index (BMI), and the Physical Activity Rating (PA-R). According to Ayoub (1986), using the results of static and dynamic strength tests are common methods in determining the lifting capacity, job design, and employment placement. For instance, measuring maximum two-handed static strength is a common method for determination of human static strengths (Lee, 2004). Moreover, recording grip strength is a common method in pre-employment screening and/or determining post-injury rehabilitation and job return (Ekşioğlu, 2016; Mohammadian et al., 2016).

The other two operator-related variables were BMI and PA-R. BMI is a measure of body fat based on a person's weight with respect to the stature and is calculated as body mass in kilograms divided by the square of stature in meters. There are mixed results on how a person's BMI might affect the risk of developing LBP over the time as a result of performing MMH tasks (Xu et al., 2008). While the effect of BMI on the physical strength or lower back pain are usually well described in the literature, there are not that many studies that evaluate the effect of BMI on the heart rate recovery time. A thorough search in the literature only found one study that evaluated the effect of BMI on the heart rate recovery time. Lins et al. (2014) studied the effect of BMI on the heart rate recovery time in a treadmill exercise testing. The results of their study show an inverse relationship between a person's BMI and the heart recovery time. The current research included BMI to test if it has any effect on how participants' heart rates recover following a lifting task. Since fitness of an individual is an important factor in determining the level of physiological reaction to a physical activity (Brouha, 1967), the subjective physical activity rating (PA-R) was taken into account to find how the physical activity of a participant may affect the recovery time. PA-R was validated and used by Jackson et al. (1990) in a study on NASA/Johnson Space Center employees. A copy of the PA-R form can be found in Appendix D.

In summary, there were two dependent variables in this study: heart rate recovery time (HRR) and Borg scale. Independent variables of this study were duration, frequency, and the weight of the lift which were all task-related. There were also four operator-related variables such as BMI, hand strength, static strength, and subjective PA-R which were studied as covariates. Table 4.4 summarizes the variables of this study.

Table 4.4: List of all variables

Dependent Variables	
HRR	Heart rate recovery time in minutes: duration it takes for the HR to reach a steady state after the lifting task.
Borg Scale	Perceived difficulty of the task from 0-10
Task- Related Independent Variables	
W	Weight of the lift (in kg)
F	Frequency of the lift (lifts/minute)
D	Duration of the lift (in minutes)
Covariates	
BMI	Body Mass Index
SS	Static Arm Strength (in kg)
HS	Hand (grip) Strength (in kg)
PA-R	Subjective physical activity rating

4.2 Tools and Equipment

The tools that were used in this study are as follows: a platform with adjustable shelves, a wooden box, Gymboss timer, stopwatch, heart rate monitor, various weights, grip strength dynamometer, and static strength platform.

A wooden platform with adjustable shelves was used for the lifting task. The bottom shelf was adjusted to the average knuckle height (77.8 cm) and the top shelf was adjusted to the average shoulder height (147.6 cm) of test participants. Figure 4.3 shows the lifting platform.

Figure 4.3: Platform with adjustable shelves

A wooden crate was used to hold various weights for the treatment performed by each participant. The crate measures 45.5cm x 30.5cm x 20.5cm and has two handles installed on each side of the crate, cushioned by racquet grip tape. Figure 4.4 shows the crate used for the experiment.

Figure 4.4: Crate with cushioned handles

In order to alert a participant of the cycles (frequencies) of a lifting task, an IPhone application was used. Several applications were tried, and the Gymboss Interval Timer was selected as the best interval timer that provided enough flexibility for the exercises required for this research. This version of the Gymboss timer is a free/no cost download. A screenshot of this interval timer is presented in Figure 4.5.

Figure 4.5: Gymboss interval timer

Polar H7 Bluetooth heart rate monitor was worn by each participant throughout the experiment. This device transmits data to a smartphone interface (Polar app) and the collected data (participant's heart beats) can be transferred to Microsoft Excel. The default frequency of recording is a date point for every second. In order for this device to work accurately, the middle part should be placed on the sternum. The heart rate monitor and the Polar Beat app are pictured in Figure 4.6.

Figure 4.6: Polar H7 heart rate monitor and Polar Beat app.

A variety of weights were used to fill the crate as part of the experiment for each participant to perform a lifting task with a certain weight (10 or 20 kg). A sample of some of the weights used is presented in Figure 4.7.

Figure 4.7: A sample of weights used

The IPhone timer was used to keep a track of the duration of the tests and to inform the participants of the end time of the experiment (Figure 4.8).

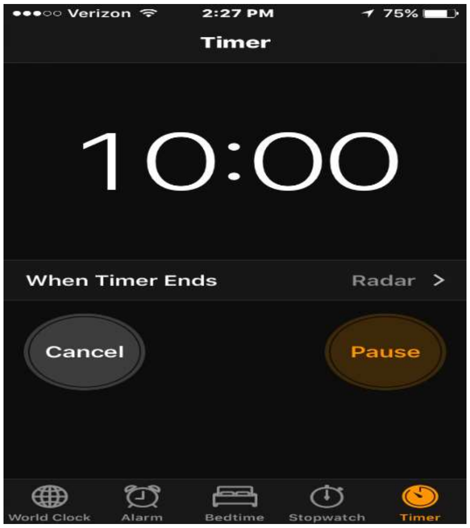

Figure 4.8: IPhone stopwatch

In this study, the grip strength and static arm strength of the participants were measured before the lifting task. Both strength measurements were administrated three times and if the coefficient of variation ($^{\mu}/_{\sigma}$) was less than 10%, the average of three trials was calculated; otherwise, we would continue to the fourth trial. Grip strength was measured by a digital grip dynamometer (Trailite, China) as depicted in Figure 4.9.

Figure 4.9: Digital dynamometer

Figure 4.10 shows the Static strength measurement platform along with the ST1 force monitor (Dynadex Corp, Ann Arbor, MI), this platform was used to measure the static arm strength of participants.

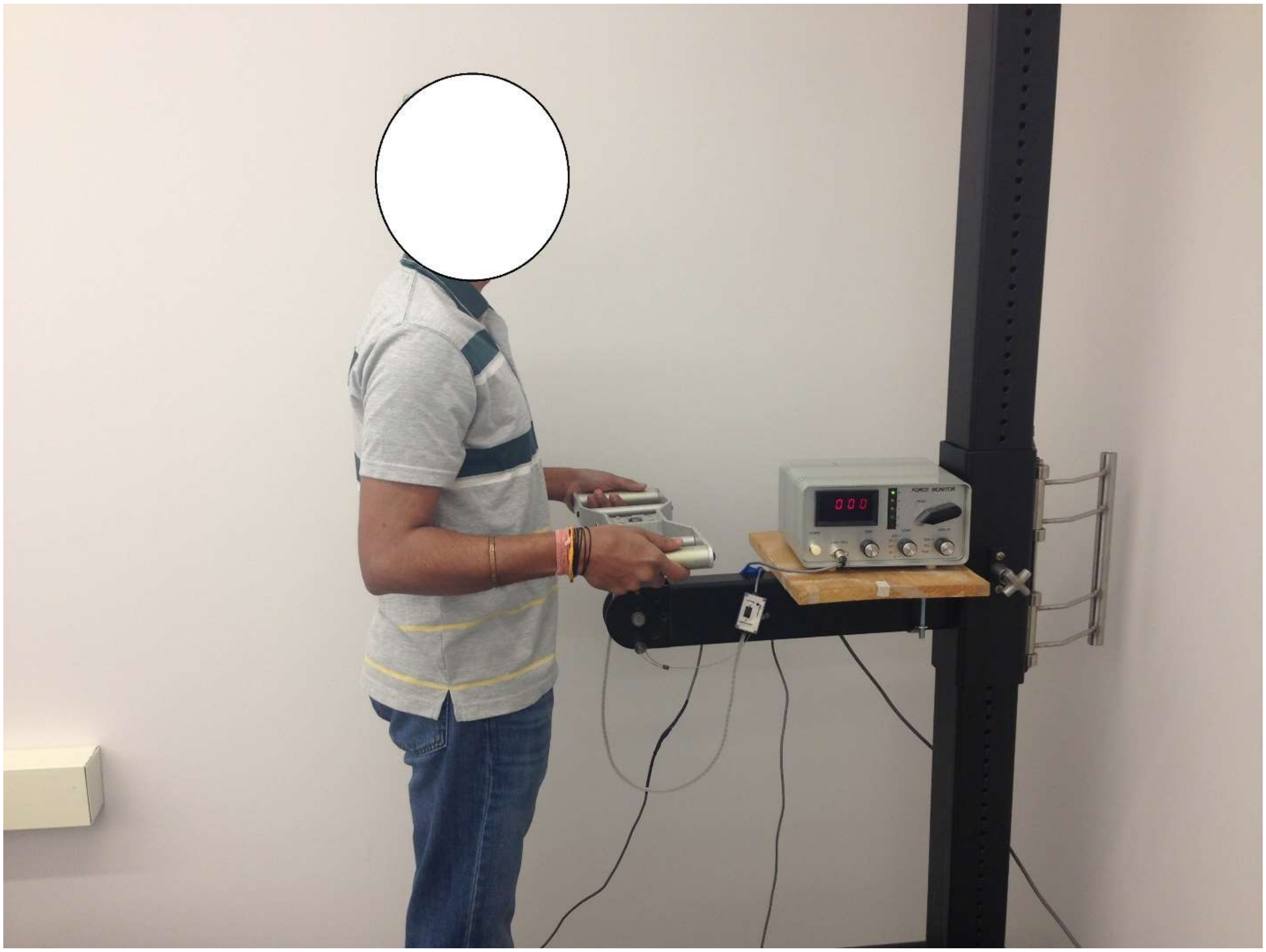

Figure 4.10: Static strength measurement platform

4.3 Research Hypotheses

For each dependent variable (the heart rate recovery time and Borg-ratings), the following hypotheses were tested:

Hypothesis 1 for Frequency Main Effect

- $H1_0$: The means of two levels of frequency are equal.

- $H1_1$: The mean of one lifting frequency is significantly different from the other.

Hypothesis 2 for Weight Main Effect

- $H2_0$: The means of two levels of weight are equal.
- $H2_1$: The mean of one lifting weight is significantly different from the other.

Hypothesis 3 for Duration Main Effect

- $H3_0$: The means of two levels of duration are equal.
- $H3_1$: The mean of one lifting duration is significantly different from the other.

Hypothesis 4 for Frequency and Duration Interaction Effect

- $H4_0$: There is no significant interaction between the frequency and duration effects.
- $H4_1$: There is a significant interaction between the frequency and duration effects.

Hypothesis 5 for Frequency and Weight Interaction Effect

- $H5_0$: There is no significant interaction between the frequency and weight effects.
- $H5_1$: There is a significant interaction between the frequency and weight effects.

Hypothesis 6 for Duration and Weight Interaction Effect

- $H6_0$: There is no significant interaction between the duration and weight effects.
- $H6_1$: There is a significant interaction between the duration and weight effects.

Hypothesis 7 for Duration, Weight, and Frequency Interaction Effect

- $H7_0$: There is no significant interaction between the duration, weight, and frequency effects.
- $H7_1$: There is a significant interaction between the duration, weight, and frequency effects.

4.4 Participants

In this experiment, a total of twenty-four male college students between the ages 20-37 were selected. The full demographic data for participants is presented in Appendix E. Table 4.5 shows a summary of participant data. The reason for not having any female participants is that based on pilot studies, the general strength of female students was found to be less than their male counterparts and as a result, the test protocol (e.g. weights lifted) needed to change for certain treatments to accommodate females (e.g. females lifting less weight) and since one of the goals of this study was to test heart rate elevation while lifting heavier weight, it was decided that only male participants be used.

Table 4.5: Participant data summary

Data	Average	S.D	Data	Average	S.D
Age	22.5	3.2	Shoulder Height (cm)	147.6	5.7
Height (cm)	177.9	5.8	BMI	25	3.2
Weight (kg)	79.4	12.4	Grip Strength (kg)	45	9.2
Knuckle height (cm)	77.8	4.2	Static Strength (kg)	26.7	6.8

In order to screen any person with an existing health condition or medical history that might be affected adversely by the experiment situation, a copy of consent form approved by the LSU institutional review board (IRB) was handed to participants to read and sign prior to the experiment. Section five of the consent form (subject inclusion) determines if a person is medically ready to perform physical activities and checks for some health problems including the heart condition, dizziness, chest pain, or fractures. If a selected participant answered yes to any of the

questions, he would be excluded from the test. Based on the completed consent forms, all twenty-four participants were qualified for this study, however, they were told that they are free to quit the test at any point if they felt physical discomfort. A copy of the consent form is attached in Appendix B.

4.5 Experimental Task

The task consisted of repetitive freestyle lifting of a box from knuckle to the shoulder height (Figure 4.11), while no lowering was required. A helper lowered the box from the other side of the lifting apparatus throughout the experiment. Banks and Aghazadeh (2009) describe freestyle lifting as applying the posture that feels "most suitable" or "most natural". Lifting was chosen due the fact that is pervasively used in material handling despite of advancements in work mechanization (Aghazadeh et al., 1998). Other MMH tasks such as lowering or pushing can be tested in the future. Each person performed the lifting for a predetermined amount of weight, with a specific frequency over a certain amount of time. Two responses were captured as a result of this study: heart rate recovery time and Borg scale.

This experiment proceeded as follows:

1. Initiation: Upon arrival of the participant at the test place, the consent form was handed to the participant and if no impeding medical history/condition was reported, the entire experiment was explained to the participant. Demographic data such as height, weight, and age, PA-R were also recorded. In addition, the grip strength and the static strength tests were conducted.
2. Attaching the heart rate monitor: The heart rate transmitter was attached to the participant's chest and was worn through the experiment.

3. Warm up: Each participant was asked to walk on the treadmill with the speed of 3 miles per hour (light jogging) for five minutes. This was meant to prevent any strains or injury as a result of the lifting task.
4. The participant was asked to sit back and rest after warming up for at least fifteen minutes.
5. After the participant was well rested, the Polar Beat app was activated to capture the heart rate activity before starting the task (for 5 minutes), throughout the experiment, as well as after the task (for 10 minutes).
6. After 5 minutes of monitoring the heart rate, participant was then proceeded to perform the lifting task. Each person performed one exclusive assigned task (for example, "lift 10 kg for 10 minutes at 6 lifts per minute"). The participant began the lifting with the activation of the interval timer. The Gymboss app would announce the start of each lift cycle with a beep sound.
7. Exercise completion: Upon completion of each treatment, the participant was asked to rate the difficulty of the exercise using the Borg scale. During the recovery, the participant was asked to sit and relax with no distraction (cell phone use, eating, taking, etc.) for 10 minutes. According to London & Bhattacharya (1985), in physical tasks which are not excessively fatiguing, the heart rate should stabilize after approximately 5 minutes. In this experiment, all test participants rested for 10 minutes after performing the lifting task while their heart rate was monitored.

Subsequent lifting tasks: Each participant performed one of the total 8 lifting tasks (treatments). On day two and three, the exact procedure was repeated by other participants.


Figure 4.11: The lifting experiment

4.6 Heart Rate Data Processing

The heart rate activity for each test participant, regardless of the assigned treatment, was monitored for 5 minutes before the task, during the lifting task, and 10 minutes following the task to give us a standard protocol in finding the recovery time. The heart rate monitor used in this study captures a reading (data point) for every second. In order to find the heart rate recovery time, the heart rate graph (beats against time) was drawn in Excel and a smoothing algorithm was applied to the graph. This experiment used the simple moving average method with time frames of 30 seconds. Then, the recovery duration was determined using the Excel gridlines. The technique used was to find how long it takes for the heart rate to return to a steady state after the lifting task was completed. The steady state was defined as a phase on the heartbeat graph (smoothed one) that the heartbeats form a semi-horizontal line while fluctuating within a 10% range. The minimum

length (time) for a phase to be considered "steady", was decided to be 2 minutes. For further illustration of the used technique, Figure 4.12 presents the rough graph of the heart rate drawn for a 5-minute lifting task and Figure 4.13 shows the heart rate graph for the same task after smoothing.

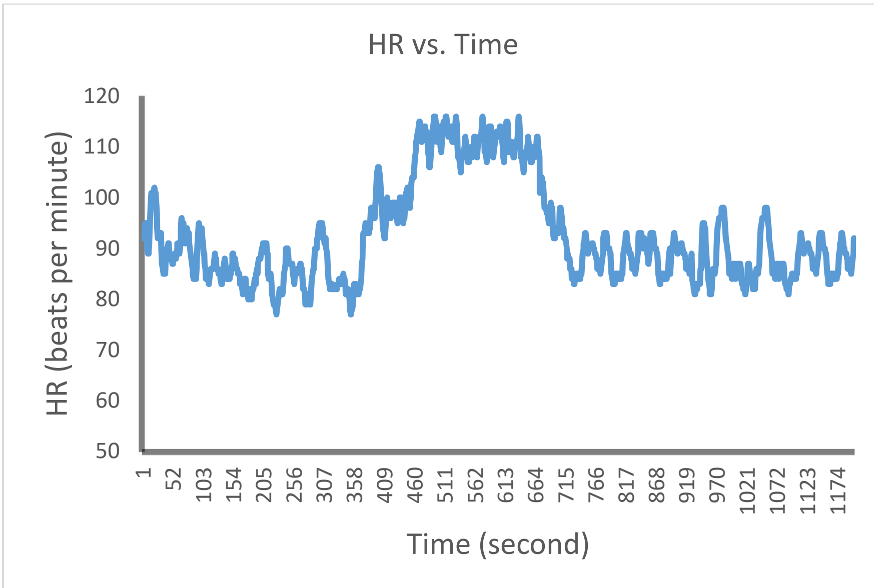

Figure 4.12: An example of rough graph of the heart rate

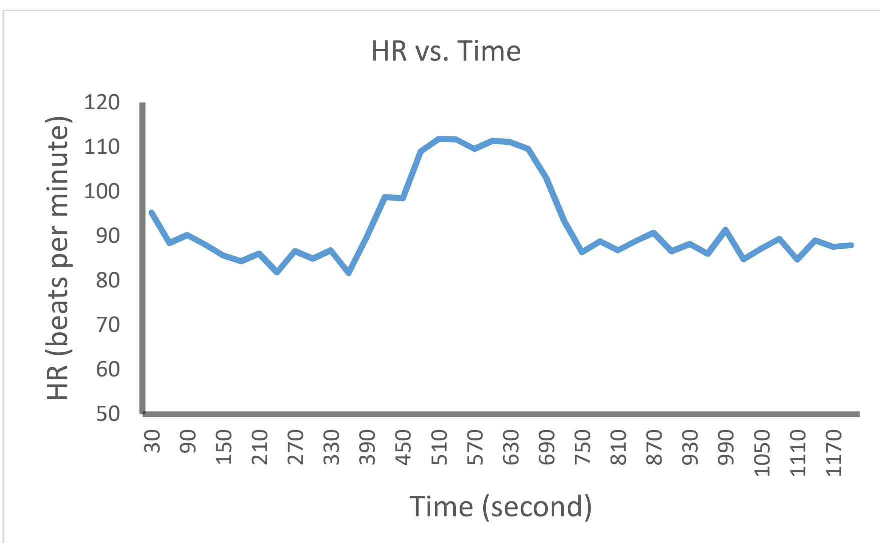

Figure 4.13: An example of smoothed heart rate graph

CHAPTER 5: RESULTS AND ANALYSIS

The acquired raw data are presented in appendices section which are for all variables (Heart rate recovery time and Borg scale: Appendix F, Confounding factors: Appendix G). Table 5.1 presents the average heart rate recovery time (HRR) and standard deviations associated with each treatment. The results show that treatment 8, which includes the high level of each factor, had the largest average recovery time compared to other treatments.

Table 5.1: Average HRR for each treatment

Treatment	Weight (kg)	Frequency (lpm)	Duration (min)	HRR	
				Average (min)	S.D.
1	10	6	5	1.92	0.4
2	10	9	5	1.67	0.3
3	20	6	5	2.33	1.2
4	20	9	5	2.85	0.6
5	10	6	10	1.19	0.3
6	10	9	10	2.50	0.9
7	20	6	10	1.92	0.6
8	20	9	10	2.92	0.6

Figure 5.1 shows the bar graphs associated with the average recovery time based on the design layout presented in Table 4.2. Figure 5.2 and 5.3 depict the changes in the HRR for different frequencies and weights within each level of duration. In this chapter the results and analyses for all dependent and independent variables are presented under the following sections:

5.1 Evaluation of Task-Factors Effects on the HRR

5.2 Evaluation of Task-Factors Effects on Perceived Exertion

5.3 Confounding Factors Analysis

5.4 Model Development

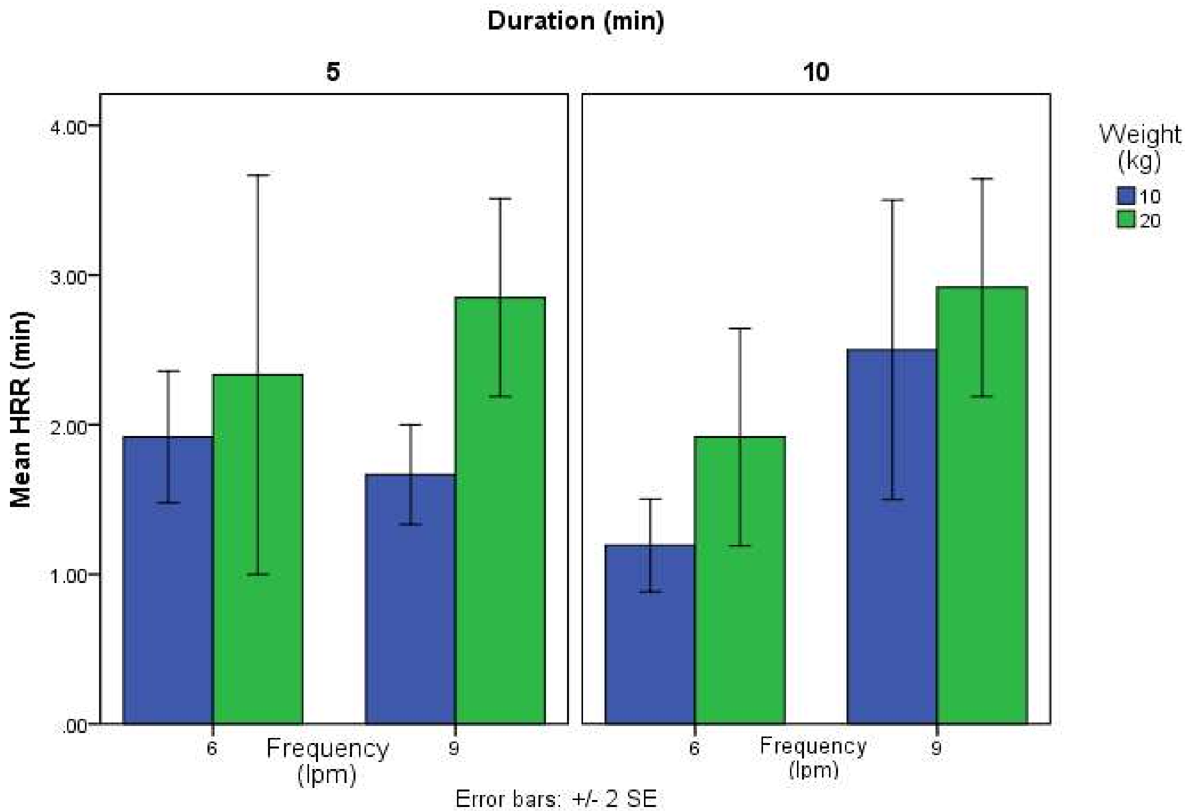

Figure 5.1: Bar graph for HRR

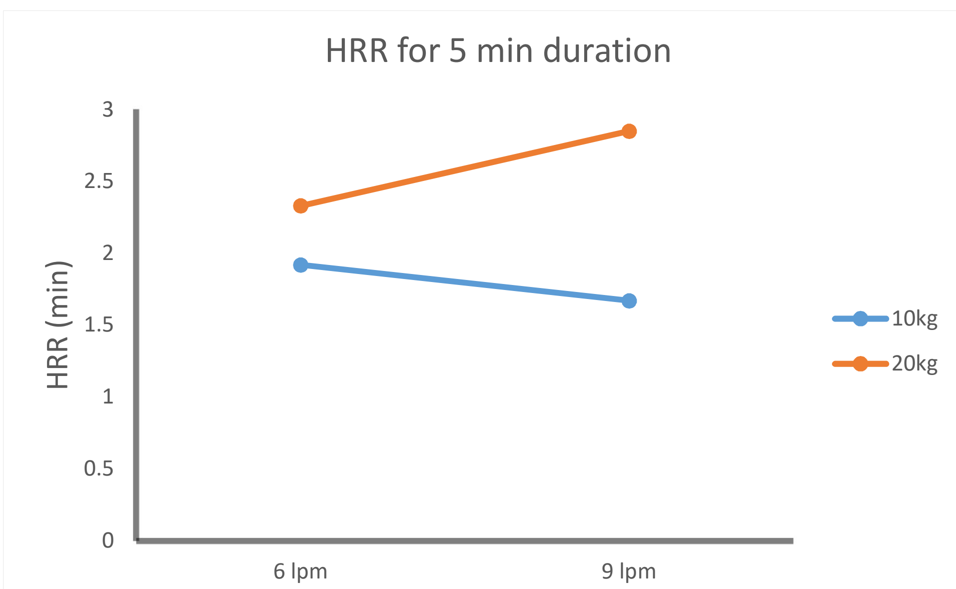

Figure 5.2: Changes in the HRR at 5-minute duration

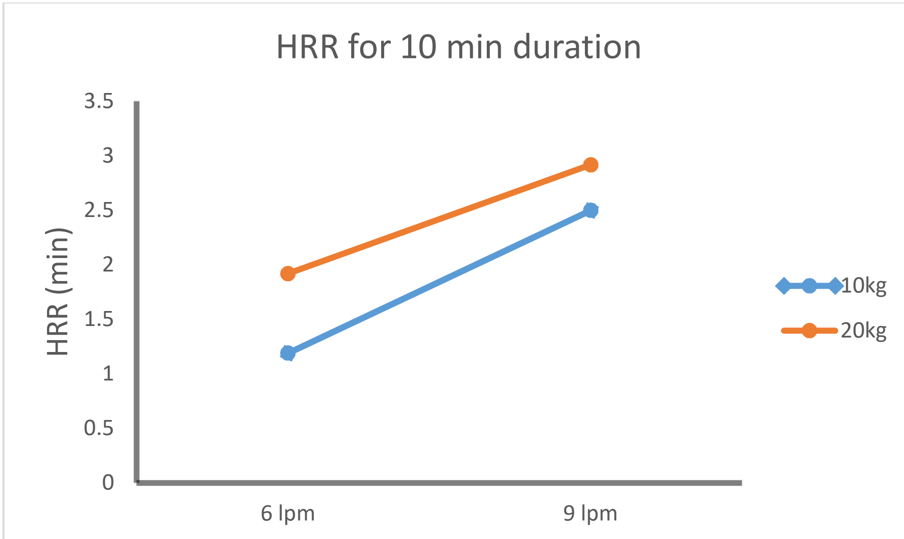

Figure 5.3: Changes in the HRR at 10-minute duration

5.1 Evaluation of Task-Factors Effects on the HRR

In order to assess the effects of main factors of the study (frequency, duration, weight) and their interactions on the HRR, a Mixed Model ANOVA was used (Table 5.2). This analysis was done in SAS Enterprise Guide software. P-value was set at a 10% level and based on the factorial design explained in section 4.1, the day of the study was considered as a random effect and blocking factor. The residuals plots were also included with the ANOVA (Figure 5.4). It can be seen from the graph that the residuals show skewness to the left and some outliers are spotted within the quantile plot.

Table 5.2: Mixed model ANOVA for the HRR (initial model)

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
Weight	1	14	8.11	0.0129
Freq	1	14	7.15	0.0181
Dur	1	14	0.06	0.8066
Weight*Freq	1	14	0.23	0.6399
Weight*Dur	1	14	0.23	0.6399
Freq*Dur	1	14	4.50	0.0523
Weight*Freq*Dur	1	14	1.24	0.2834

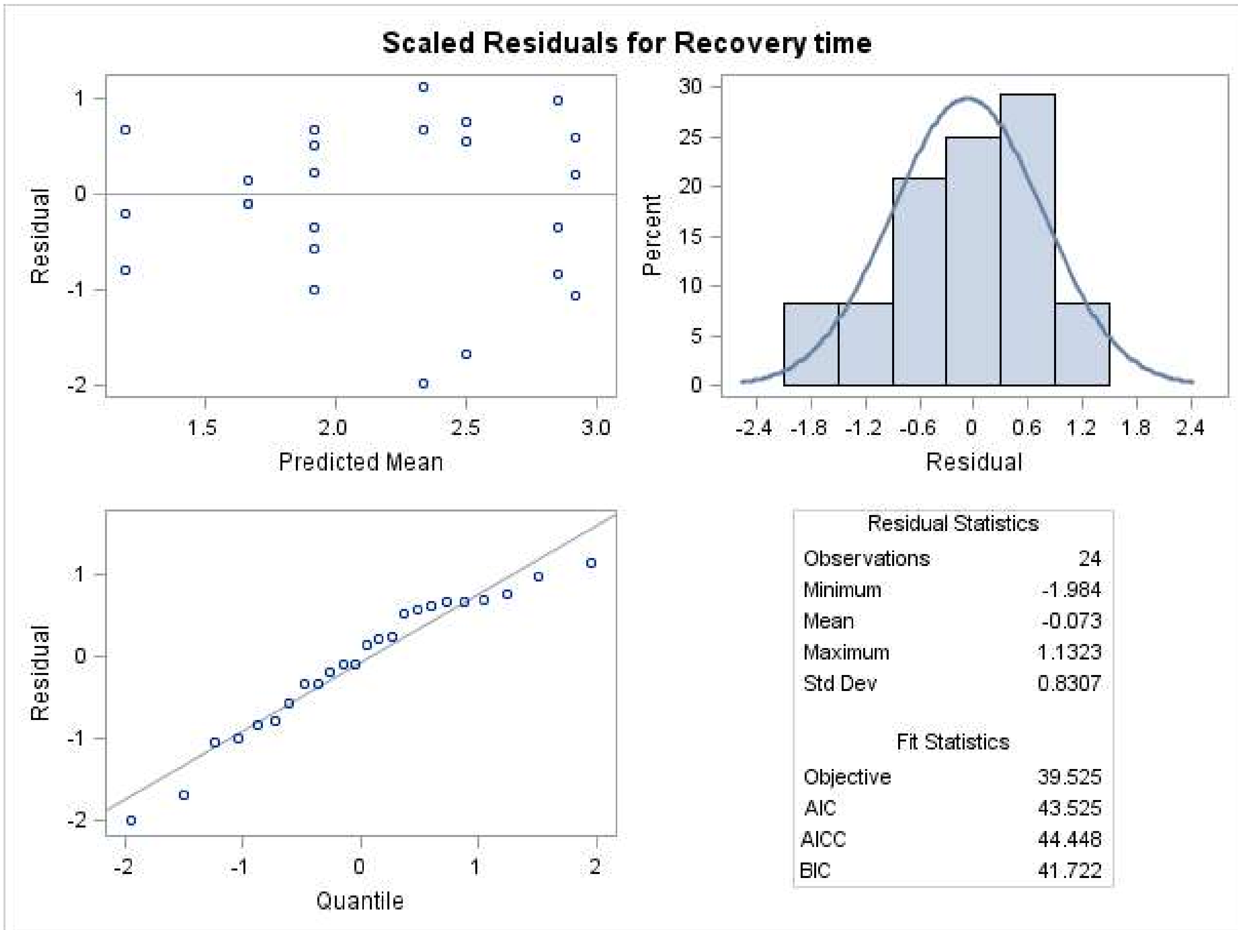

Figure 5.4: Residual plots for HRR (initial model)

Based on the ANOVA results (Table 5.2), at 90% confidence interval, weight (p-value= 0129), frequency (p-value=0181), and the interaction between frequency and duration (p-value=0523) are significant, while other interaction effects and the main effect of duration are all insignificant (p-values larger than 0.1). At this point, another ANOVA (Table 5.3) was conducted by including only significant factors to further investigate the effects of significant factors on the HRR. Duration was included in the new model despite being non-significant. The reason was that duration involved in a significant interaction with frequency. Parameter estimates were also added to the new analysis (Table 5.4) Based on the results of the second ANOVA (Table 5.3), we

essentially draw the same qualitative results on significant factors but with smaller p-values. Weight is still the most significant factor (p-value= 0.0087). Frequency (p-value=0.0128) and the interaction between frequency and duration (p-value= 0414) are also significant.

Table 5.3: Mixed model ANOVA for the HRR (adjusted model)

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
Weight	1	17	8.78	0.0087
Freq	1	17	7.75	0.0128
Dur	1	17	0.07	0.7983
Freq*Dur	1	17	4.87	0.0414

Table 5.4: Parameter estimates of mixed model ANOVA for the HRR (adjusted model)

Solution for Fixed Effects											
Effect	W	F	D	Estimate	S.E	DF	t Value	Pr > |t|	Alpha	Lower	Upper
Intercept				3.0508	0.3134	2	9.74	0.0104	0.1	1.7025	4.3992
W	10			-0.6850	0.2312	17	-2.96	0.0087	0.1	-1.1727	-0.1973
W	20			0	.	.	.	.	.	.	.
F		6		-1.1533	0.3269	17	-3.53	0.0026	0.1	-1.8430	-0.4636
F		9		0	.	.	.	.	.	.	.
D			5	-0.4500	0.3269	17	-1.38	0.1865	0.1	-1.1397	0.2397
D			10	0	.	.	.	.	.	.	.
F*D		6	5	1.0200	0.4623	17	2.21	0.0414	0.1	0.04460	1.9954
F*D		6	10	0	.	.	.	.	.	.	.
F*D		9	5	0	.	.	.	.	.	.	.
F*D		9	10	0	.	.	.	.	.	.	.

Based on the residual plots of the adjusted model (Figure 5.5), we still observe skewness towards left while having fewer outliers compared to the full model. To further investigate possible outlier in our model, we included two influence diagnostic tools in the ANOVA analysis. These diagnostic tools were Restricted likelihood distance and Cook’s distance. According to the influence plots (Figure 5.6 and 5.7), observation (participant) 8 was an influential factor affecting

the recovery time. By deleting this observation, we conduct the ANOVA model one more time to see the changes (refer to Table 5.5).

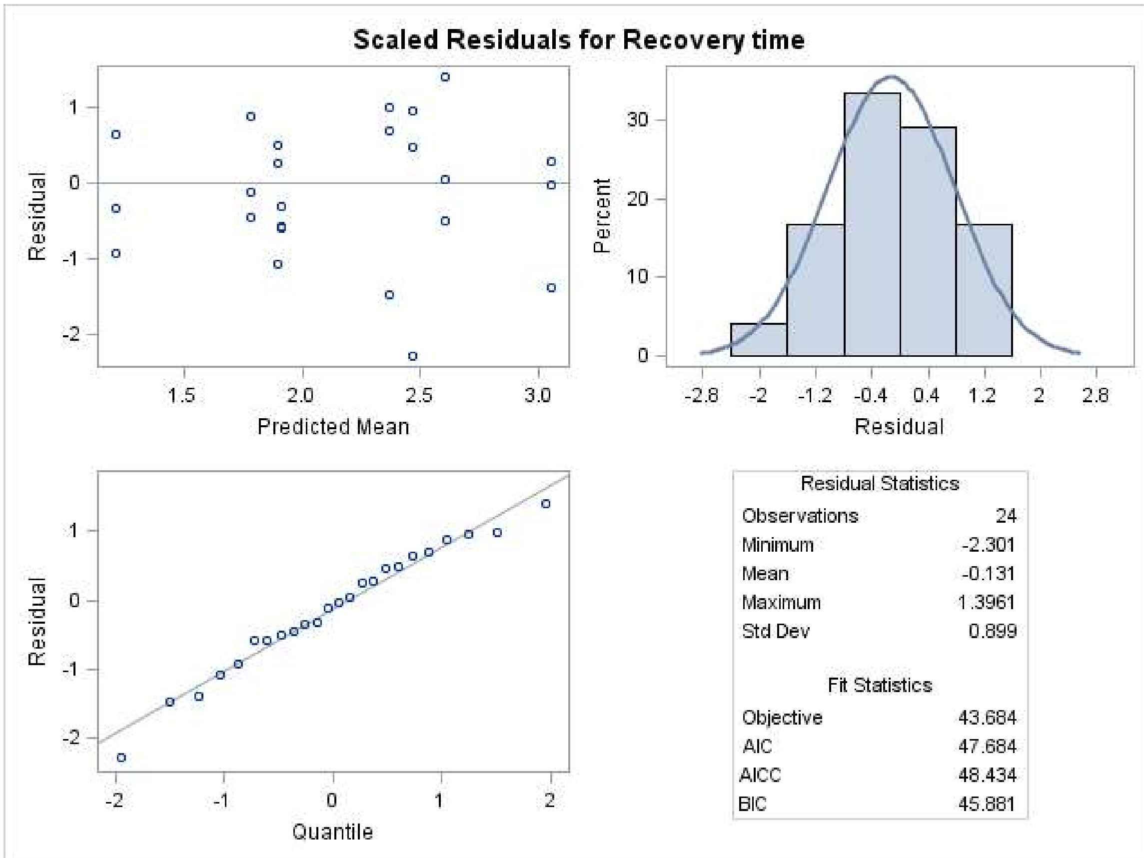

Figure 5.5: Residual plots for HRR (adjusted model)

We essentially receive the same qualitative results after removing observation 8. At the 10% significant level, the p-values for weight and the interaction between frequency and duration decreased significantly, while the p-value of frequency increased slightly. The graph of residuals (Figure 5.8) looks more symmetric after deleting observation 8 and no major outliers are observed within the quantile plot. Within the new restricted likelihood distance plot (Figure 5.9), the difference between largest two distances are lower (less than 0.5) compared to the earlier analysis where observation 8 was included (the difference was 3 units). In other words, no particular observation seems to influence the response heavily by itself (similar results is observed in Figure

5.10). Figure 5.11 depicts the plot of restricted likelihood distance with and without having observation 8.

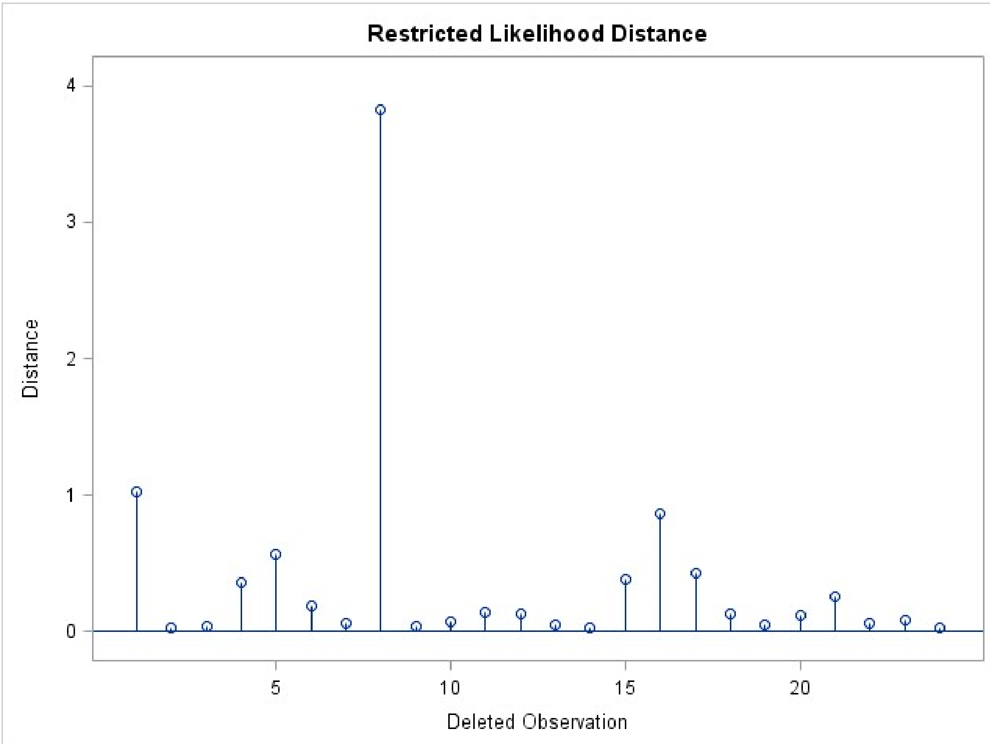

Figure 5.6: Restricted likelihood distance (with 24 Obs.)

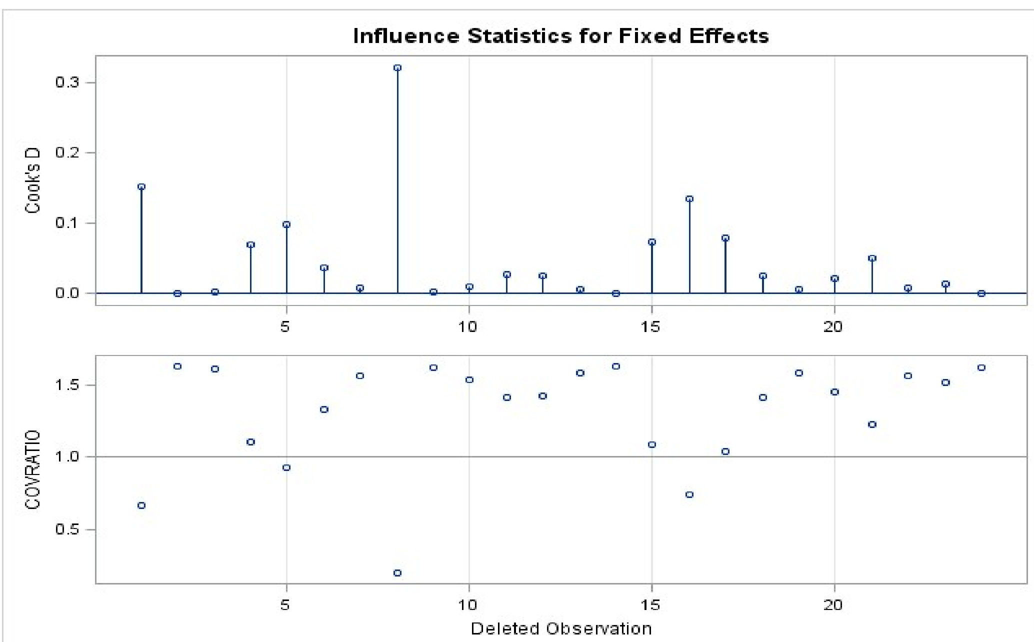

Figure 5.7: Cook's distance (with 24 Obs.)

Table 5.5: Mixed model ANOVA for the HRR (reduced model with 23 Obs.)

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Weight	1	16	17.36	0.0007
Freq	1	16	6.37	0.0225
Dur	1	16	1.04	0.3236
Freq*Dur	1	16	10.79	0.0047

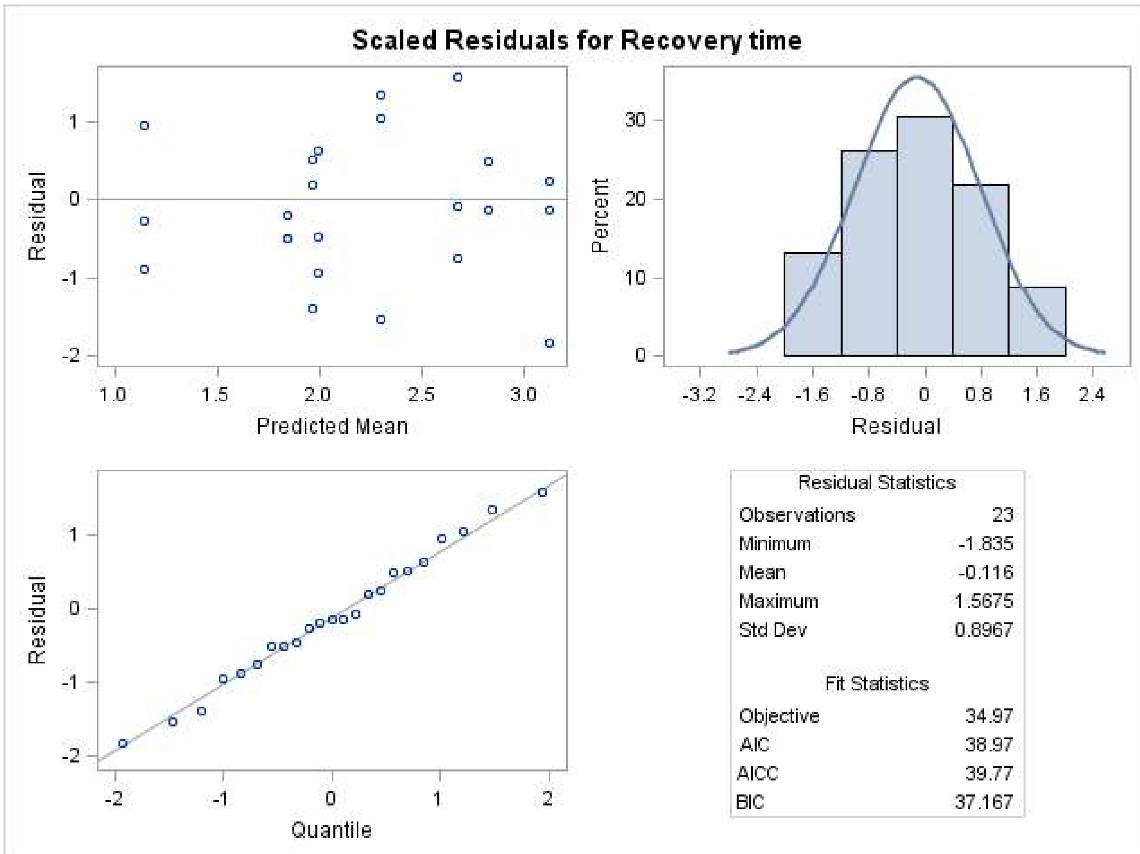

Figure 5.8: Residual plots for HRR (with 23 Obs.)

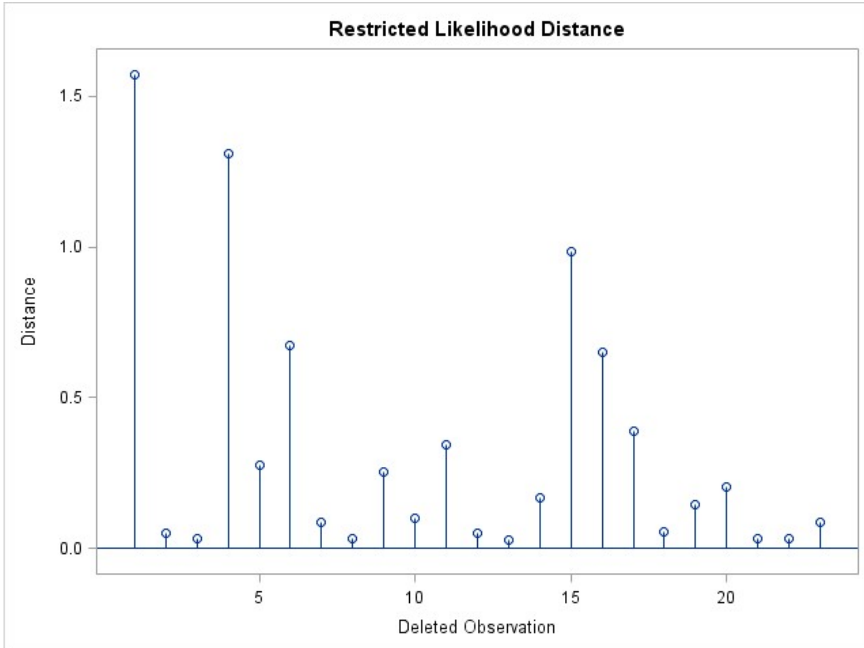

Figure 5.9: Restricted likelihood distance (with 23 Obs.)

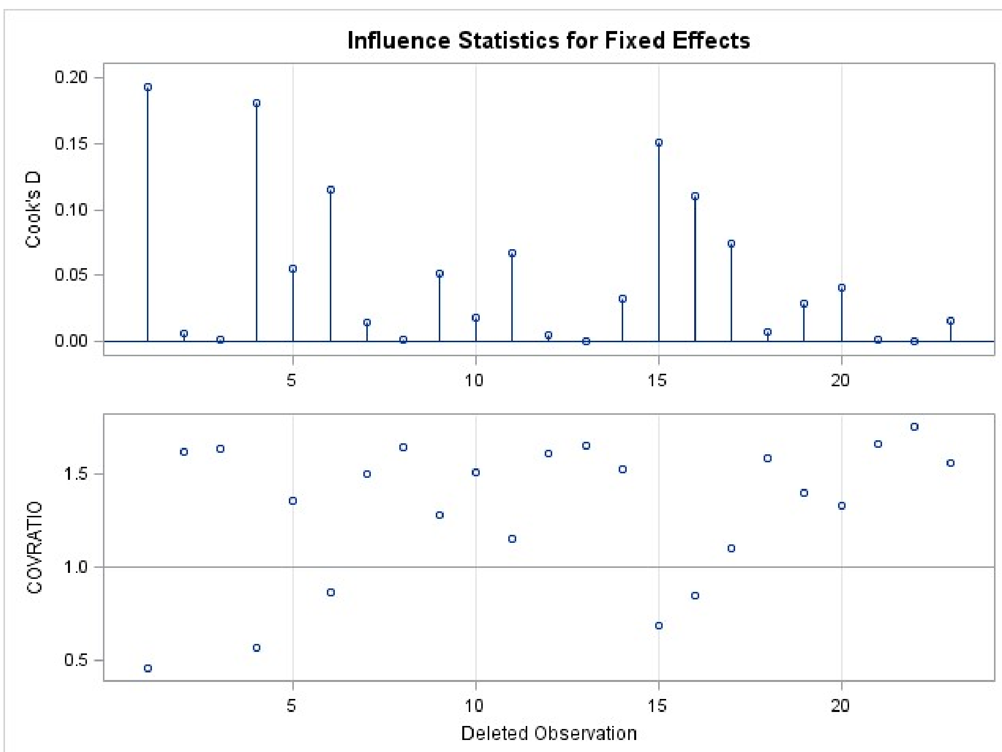

Figure 5.10: Cook's distance (with 23 Obs.)

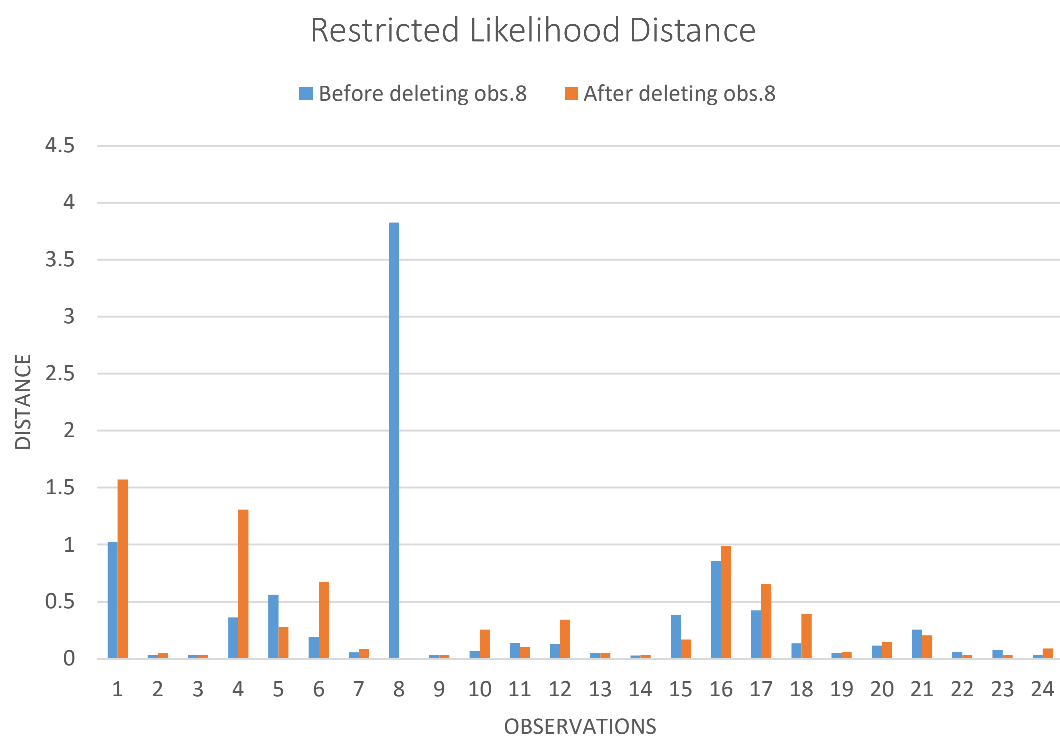

Figure 5.11: Restricted likelihood distance with and without Obs.8

5.2 Evaluation of Task-Factors Effects on Perceived Exertion

After the lifting session, participants were asked to rate their perceived exertions on the Borg CR-10 scale. Table 5.6 presents the average Borg-ratings and standard deviations associated with each treatment. Treatment 1 (lifting 10 kg for 5 minutes at 6 lifts per minute) was perceived as the

Table 5.6: Average Borg scores for each treatment

Treatment	Weight (kg)	Frequency (lpm)	Duration (min)	Borg	
				Average	S.D.
1	10	6	5	5	2
2	10	9	5	6.7	0.6
3	20	6	5	7.7	0.6
4	20	9	5	6.7	0.6
5	10	6	10	5.7	0.6
6	10	9	10	6.3	1.2
7	20	6	10	7	3.6
8	20	9	10	7	1

the least strenuous task (5), followed by treatments 5 (5. 7) and 6 (6. 3). The highest Borg rating was associated with treatments 3 (lifting 20 kg for 5 minutes at 6 lifts per minute) with an average score of 7. 7. A mixed model ANOVA was carried out for the Borg scale (Table 5.7). The results show that at 10% significant level, only weight of the lift had a significant effect on perceived level of exertion (p-value=0.0894).

Table 5.7: Mixed model ANOVA for Borg

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
Weight	1	14	3.33	0.0894
Freq	1	14	0.27	0.6102
Dur	1	14	0.00	1.0000
Weight*Freq	1	14	1.70	0.2134
Weight*Dur	1	14	0.07	0.7981
Freq*Dur	1	14	0.00	1.0000
Weight*Freq*Dur	1	14	0.61	0.4472

5.3 Confounding Factors Analysis

In order to investigate if the covariates of this study (BMI, static strength, hand strength, PA-R) had any possible effect on the HRR, an analysis of covariance was carried out in SPSS. The results (Table5.8) show that none of the confounding factors had a significant p-value.

5.4. Model Development

All the analysis presented in this section are based on the full factorial set (24 data points) and the methods used to develop the model are based on Maiti & Bagchi (2006) study. First, to analyze the main effect of each lifting factor, the grand average of the heart rate recovery time with respect to each individual lifting parameter (at two levels) was calculated and three linear graphs were drawn. (Figure 5.12-5.14). Then, the best-fit equation for each graph was obtained (Equations 5.1-5.3).

Table 5.8: ANCOVA for operator-related variables

Tests of Between-Subjects Effects					
Dependent Variable: Recovery time					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	8.699[a]	11	.791	1.642	.203
Intercept	1.300	1	1.300	2.699	.126
Static Strength(KG)	.277	1	.277	.574	.463
BMI	.514	1	.514	1.068	.322
Grip Strength (KG)	.783	1	.783	1.625	.226
PAR	.067	1	.067	.140	.715
Weight	2.285	1	2.285	4.744	.050
Freq	2.794	1	2.794	5.801	.033
Dur	1.359E-5	1	1.359E-5	.000	.996
Weight * Freq	.472	1	.472	.979	.342
Weight * Dur	.083	1	.083	.172	.686
Freq * Dur	1.142	1	1.142	2.371	.150
Weight * Freq * Dur	.011	1	.011	.024	.880
Error	5.781	12	.482		
Total	126.627	24			
Corrected Total	14.480	23			
a. R Squared = .601 (Adjusted R Squared = .235)					

The best-fit equation of graph 5.12 for the average HRR based on two levels of weight is as follows:

HRR for weight response:

$$y = 0.1584 \text{ Weight} + 0.2623 \quad (5.1)$$

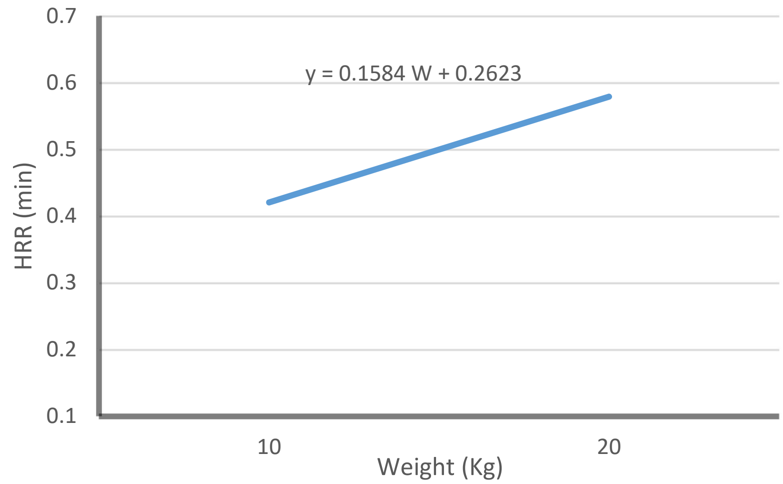

Figure 5.12: Effect of weight on HRR

The best-fit equation of graph 5.13 for the average HRR based on two levels of frequency is as follows:

HRR for frequency response:

$$y = 0.1488 \text{ Frequency} + 0.2768 \quad (5.2)$$

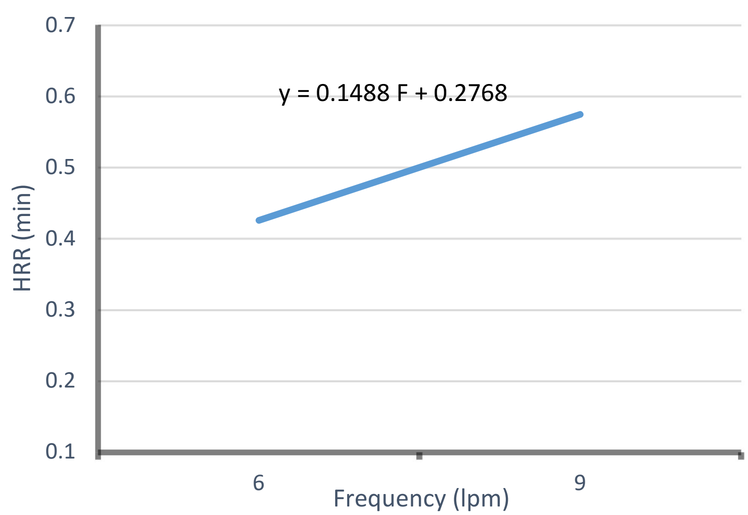

Figure 5.13: Effect of frequency on HRR

The best-fit equation of graph 5.14 for the average HRR based on two levels of duration is as follows:

HRR for duration response is as follows:

y = -0.0139 Duration + 0.5208 (5.3)

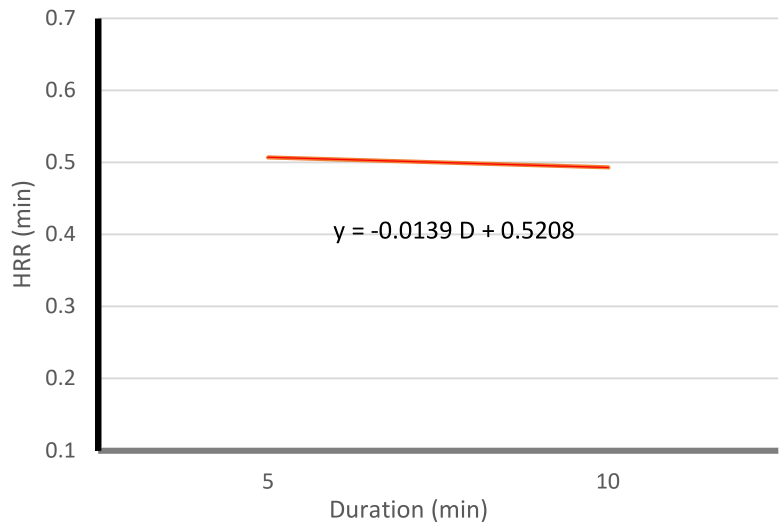

Figure 5.14: Effect of duration on HRR

For the model building process, first, a multiple linear regression (Table 5.9) was conducted just by including the main factors and without considering any interactions. Equation 5.4 shows the output of this model.

Recovery time = -0.384 + 0.068 Weight + 0.214 Frequency - 0.212 Duration (5.4)

Next, a stepwise linear multiple regression was used to determine the effect of main factors on HRR. Minitab was used for this analysis and backward elimination method was selected with the criteria of maximum adjusted R-squared and least standard error of estimate. The full analysis can be found in Appendix H. Table 5.10 summarizes the results of stepwise regression The results show that model d which included all main factors and the interaction effect between frequency and duration was the best predictor of HRR by yielding the largest adjusted R-squared value.

Table 5.9: Linear regression for main factors

Parameter Estimates						
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate
Intercept	1	-0.38417	0.91632	-0.42	0.6795	0
Weight	1	0.06850	0.02763	2.48	0.0222	0.44094
Freq	1	0.21444	0.09209	2.33	0.0305	0.41412
Dur	1	-0.01200	0.05526	-0.22	0.8303	-0.03862
R-Squared= 0.3674 (Adjusted R-Squared =0.2725)						

Table 5.10: Stepwise Regression Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
a	.718a	.516	.304	.66183
b	.697b	.4862	.318	.661568
c	.693c	.4807	.351	.646347
d	.689d	.4752	.371	.632419

a Predictors: (Constant), WFD, F, D, W, WF, WD, FD,
b Predictors: (Constant), F, D, W, WF, WD, FD
c Predictors: (Constant), F, D, W, WD, FD
d Predictors: (Constant), F, D, W, FD

A separate multiple regression analysis was carried out based on the factors identified in model d. Table 5.11 shows this analysis. Based on the regression analysis, the heart rate recovery equation is as follows:

Recovery time = 3.44 + 0.0685 Weight - 0.296 Frequency - 0.522 Duration (5.5)

+ 0.0680 Frequency*Duration

Table 5.11: Multiple regression for model d

Parameter Estimates						
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate
Intercept	1	3.44083	2.11727	1.63	0.1206	0
Weight	1	0.06850	0.02582	2.65	0.0157	0.44094
Freq	1	-0.29556	0.27215	-1.09	0.2911	-0.57076
Dur	1	-0.52200	0.26330	-1.98	0.0621	-1.68009
Freq*Dur	1	0.06800	0.03442	1.98	0.0629	1.94221
R-Squared= 0.4752 (Adjusted R-Squared =0.3647)						

CHAPTER 6: DISCUSSION

In an exhaustive review of the literature, no previous study was found that attempts to quantify the heart rate recovery time in a manual task by the use of task factors. The goal of this study was to determine heart rate recovery time based on the collected data from a series of lifting experiments and to further quantify the heart rate recovery time. Task factors used in this study were frequency, duration, and weight of the lift. In addition to that, for further clarification, an attempt was made to investigate the relationship between the heart rate recovery time and three task factors. The discussion chapter is divided into the same order of sub-categories as in the result section.

6.1 Effect of Task Factors on the HRR

Table 6.1 summarizes the average recovery time values based on each factor of the study. According to this table, except for duration, the average recovery time within the higher level of each factor is larger than the lower level. On average, for all participants, doubling the weight (from 10 to 20 kg) led to an approximate increase of 37% in the recovery time, while increasing frequency from 6 to 9 lifts per minute increased the recovery time by almost 35%. On the other hand, increasing the duration from 10 minutes to 20 minutes, resulted in a 2.7% decrease in the average recovery time.

The result of Tests of Fixed Effects" in Table 5.3 reveals that weight (F=8.780, p=0.0087), frequency (F=7.750, p=0.0128), and the interaction between frequency and duration (F=4.870, p=0.0414) significantly affected the recovery time, while duration as a main effect did not have a significant effect on the HRR (F=0.07, p=0.7983). According to the Solutions for Fixed Effects in Table 5.4, based on the lower and upper limits, we are 90% confident that the average recovery time is anywhere between 0.1973 to 1.727 longer when larger weight (20 kg) was lifted compared

to when lower weight (10kg) was lifted. Also, we are 90% confident that the average recovery time is anywhere between 0.46 to 1.84 longer when lift was performed at a higher rate (9 lifts/min) compared to a lower rate (6 lifts/min).

Under the analysis of mixed model, we adjusted the full model by keeping the factors that were significant and removing those which were not significant. Within the adjusted model, participant 8 was found to be a major outlier. This person was assigned treatment three by lifting 20 kg at 6 lifts per minute for 5 minutes. Surprisingly, this participant had a quicker recovery (1 minute) compared to the other two persons performing the same lift. This could be due the fact that reportedly this participant was used to doing manual labor and was not as amateur as the rest. As depicted in Figure 5.8, after removing this participant from the mixed model analysis, the graph of residuals became more symmetric and no major outliers were observed.

By comparing the MMH studies discussed in the literature review (Table 2.2) with the findings of this study, we observe that the ANOVA results for frequency of the lift support findings of Garg and Bannag (1988), Wu (1997), Maiti and Bagchi (2006), and Abadi et al. (2015). The aforementioned studies concluded that frequency of the lift has a significant effect on the average heart rate values. Similarly, the ANOVA results of the current study show that frequency of the lift significantly affected the heart rate recovery time. For the main factor of weight, the results of Maiti and Bagchi (2006) study show that weight of the lift has a significant effect on the normalized heart rate values. Similarly, in the current study weight of the lift show a significant effect on the heart rate recovery time. On the other hand, the effect of lift duration on the recovery time can not be compared with the literature, because to the best of our knowledge none of the MMH studies have studied lift duration as a task factor.

Table 6.1: Average recovery time among different levels of each factor

Factor	Level	HRR (min)	Percentage change
Weight	10	1.82	+37.4%
	20	2.50	
Frequency (lpm)	6	1.84	+34.8%
	9	2.48	
Duration (min)	5	2.19	-2.7%
	10	2.13	

6.2 Effect of Task-Factors On the Perceived Exertion

The second independent variable of the study was Borg scale. Table 6.2 summarizes the average Borg-rating values based on each factor of this study. According to this table, except for the weight, there is no meaningful difference in the perceived level of exertion when we compare the high level and low level of each task factor. In the case of weight of the lift, doubling the weight (from 10 to 20 kg), led to a 20% increase in the average Borg scale among test participants.

Similar to the HRR, a mixed model analysis was performed for this variable based on the full factorial model (Table 5.7). The results show that among main factors and interactions, just weight of the lift had a significant effect on the Borg values (p-value =0.08) and none of the other main factors or interactions had a significant effect on the perceived level of exertion. In other words, based on the results of the subjective survey, participants experienced more exertion when the larger weight was lifted. The insignificant p-values for the frequency of the lift did not support findings by Garg & Banaag (1998) and Wu (1997) that frequency of the lift significantly affects the rating of perceived exertion. Unlike to the HRR, additional ANOVA models were not developed for Borg rating since among all factors, just weight of the lift was significant.

Table 6.2: Average Borg score among different levels of each factor

Factor	Level	Avg. Borg score	Percentage change
Weight (kg)	10	5.9	20.1%
	20	7.1	
Frequency (lpm)	6	6.3	6.3%
	9	6.7	
Duration (min)	5	6.5	0%
	10	6.5	

6.3 Confounding Factors Effect

Covariates or confounding factors are continuous variables that are not the focus of an experiment but can be investigated to learn if they have any significant effects on the response variable. Unlike the independent factors of a study, covariates cannot be manipulated, instead, they come with test subjects. Covariates of this study were BMI, static strength, hand strength, and the PA-R. According to the Analysis of Covariance (ANCOVA) in Table 5.8, none of the covariates had a significant effect on the heart rate recovery time. In other words, the average duration for the heart rate to get to a resting stage was not affected by participants' physical characteristics such as static strength and BMI. This was not surprising due to the limited number of participants.

6.4. Models Interpretation

Based on the results of heart rate recovery time with respect to the grand average of each lifting parameters (Equation 5.1-5.3), frequency and weight both had a positive relationship with the recovery time while duration had an inverse relationship meaning that the longer the task was,

the shorter recovery time was needed. With respect to duration, participants commented that they were getting used to a task after a few minutes of performing it.

By comparing the R-squared values between the initial model including only the main factors (Equation 5.4) and the final model including main factors and one interaction effect (Equation 5.5), we observe larger values of R-squared in the second model, meaning that the variations in the response (HRR) are better explained in the model with the interaction effect of frequency and duration (Equation 5.5).

The results of stepwise regression (Table 5.10) support the findings of the mixed model analysis as three main factors and the interaction between frequency and duration were factors that stayed in the model. However, contrary to the results of ANOVA, the main effect of frequency was not significant in the regression model (Equation 5.5), while the main effect of duration was significant at 10% significance level. This discrepancy can be explained by the fact that the t-test and F-test are testing different null hypotheses and their p-values may be different, especially in this case where there was a meaningful interaction effect between frequency and duration.

Based on Equation 5.5, duration and frequency had negative coefficients while weight of the lift had a positive coefficient. However, we can not conclude that frequency and duration have a negative effect on the recovery time since they are involved in an interaction with each other which has a positive coefficient. On the other hand, weight of the lift stands in the model only by its main effect (and no interaction), therefore it can be stated that weight of the lift positively affects the recovery time, meaning that heavier weight needs more recovery time.

Since independent variables had a different measuring unit and range, we use the standardized beta coefficients to determine the relative importance of each factor. By examining the absolute values of the standardized coefficient in Table 5.11, we observe that the interaction

between frequency and duration had the largest standardized coefficient (B=|1.94221|), meaning that the interaction effect between frequency and duration was the most important determinant of recovery time in model d.

6.4. 1 Further Analysis of the Rest Model

To further analyze the rest period model (Equation 5.5), we compared the predicted and observed recovery times based on both original values from the factorial design and some new values. Values from the factorial design were the ones discussed in section 4.1 (e.g. frequencies of 6 and 9, weights of 10 and 20, durations of 5 and 10), and new values were defined as values other than the ones used in the factorial design (e.g. duration of 8 or 12).

First, the rest period equation was tested by using the original values of each lifting parameter to make a comparison between predicted and observed rest periods (Table 6.3). As observed in Table 6.3, when a 10 kg weight was lifted at a frequency of 6 lifts per minute for a duration of 5 minutes (treatment one), the average observed recovery was 1.92 minutes, while the predicted recovery time for the given treatment is 1.78 minutes. Similarly, for other treatments in Table 6.3, there was a slight difference between the observed and predicted recovery time when we inserted the original independent values of the study into Equation 5.5.

Table 6.3: Predicted vs. observed rest periods based on Equation 5.5

Treatment	Weight (kg)	Frequency (lpm)	Duration (min)	Predicted HRR (min)	Average values for observed HRR(min)
1	10	6	5	1.78	1.92
2	10	9	5	1.91	1.67
3	20	6	5	2.46	2.33
4	20	9	5	2.6	2.85
5	10	6	10	1.21	1.19
6	10	9	10	2.36	2.5
7	20	6	10	1.89	1.92
8	20	9	10	3.05	2.92

Now we consider a case that values in between the original values (within the range) are placed into the equation. Table 6.4 presents a few example of this scenario. For instance, by using a weight of 18 kg, a frequency of 8 lifts/minute, and a duration of 4 minutes, we get 2.43 minutes as predicted (suggested) rest period. This set of given values is the closest to the values of treatment four (weight: 20, frequency: 9, duration: 5) which had an observed rest period of 2.85 and a predicted rest period of 2.6 minutes. Within this particular example, we can conclude that the task which is less strenuous needs less recovery time.

Table 6.4: Predicted rest periods for mock inputs based on Equation 5.5

Weight (kg)	Frequency (lpm)	Duration (min)	Predicted HRR (min)
18	8	6	2.43
14	7	7	2
13	8	9	2.16

Lastly, we consider a scenario when given values are outside of the factorial range of this study. For instance, by giving a weight of 30 kg, a frequency of 5 lifts and a duration of 20 minutes, a rest period of .38 minutes would be predicted. This short predicted recovery time does not provide adequate rest period considering the intensity of the defined task. This indicates that values outside of the range of the study can not be good predictors of rest periods. In other words, the obtained rest period model is merely based on the heart rate response of a limited number of participants and due consideration should be given when applying this model to the real work setting. Particularly in case of duration which had a negative effect on the recovery time within the observed tests.

CHAPTER 7: CONCLUSIONS

A literature survey shows much evidence that suggests forceful and prolonged exertion in manual material handling is a major risk factor for fatigue, injury, and WMSD. Giving frequent and adequate rest breaks is suggested to be an effective method for mitigating the work overload and fatigue prevention. A limited amount of research exists that deals with the prediction of optimal rest periods during manual repetitive lifting tasks as related to factors associated with increased risk of low back disorder. The main objective of this study was to determine rest periods based on activity heart rate during a repetitive lifting task where freestyle lifting technique was utilized. We found that on average, the heart rate took between 1.19 to 2.92 minutes to recover. To address the secondary objective, a mathematical model for the rest period based on frequency, duration, weight, and the interaction between frequency and duration of the lift was developed to predict the rest times.

7.1 Hypotheses Testing

At the onset of this study, a set of seven hypotheses were asserted for each dependent variable.

Hypothesis 1 to 3:

The first three hypotheses tested the differences of the average response values (HRR and Borg) among two levels of each independent factor (duration, frequency and weight of the lift). Based on the results of mixed model ANOVA for the HRR (Table 5.2-5.3), we do not observe a significant p-value for factor duration (p-value>0.1), therefore we fail to reject hypothesis three meaning that we do not have enough evidence to conclude there is a significant difference in average values for recovery time within two levels of duration. Based on the p-values of frequency

and weight (both p-values<0.1) we reject hypotheses one and two and conclude that the average recovery time within both levels of weight and frequency are significantly different.

By referring to the results of mixed model analysis for Borg (Table 5.7), for the main effects of duration and frequency of the lift, no significant effect is observed between different levels of those main factors (p-values>0.1), as a result we fail to reject hypotheses 1 and 3 for reported Borg-rating, meaning that for frequency and duration as fixed factors, there was no significant difference in the average recovery time within the two level of each factor. On the other hand, based on the p-value of weight (p-values <0.1), we reject hypothesis 2 meaning that there is a significant difference between each level of weight for the reported Borg-rating. In other words, the weight of the lift was the only factor that significantly affected how participants felt about fatigue.

Hypothesis 4 to 7:

The last four hypotheses tested the differences of the average response values (HRR and Borg) among all possible interactions among independent factor (duration, frequency and weight of the lift). Based on the results of mixed model ANOVA for the HRR (Table 5.2-5.3), we observe insignificant p-values for the interaction between duration and weight (p-value>0.1), the interaction between weight and frequency (p-value>0.1), and also for the three-way interaction of the study (p-value>0.1). Therefore, we do not have enough evidence to reject hypotheses 5-7. On the other hand, we observe a significant p-value (p-value<0.1) for hypothesis 4 (the interaction between frequency and duration) at 90% significance level. As a result, we reject hypothesis four meaning that the interaction between the frequency and duration significantly affected the heart rate recovery time.

Based on the results of mixed model ANOVA for Borg (Table 5.7), no significant p-value is observed for the interaction effects, meaning that all two-way interactions and the single three-way interaction of the study had no significant effect on the perceived level of exertion.

7.2 Summary of Research and Conclusions

In order to achieve the objective of this research, a series of lifting experiments were conducted. The methodology included recording operator-related variables (static strength measures, activity level, and BMI) before the experiment and monitoring the heart during a freestyle repetitive manual lifting task. The response variables were the heart rate recovery time (which was the duration needed for the heart rate to reach a steady state after a lifting task) and subjective Borg scale. The independent variables (task-variables) were weight of the lift (10 and 20 kg), the frequency of the lift (6 and 9 lifts per minute), and the duration of the lift (5 and 10 minutes). As a result of independent variables interaction (each at two level), a total of 8 treatments was obtained. Twenty-four male participants between the ages of 20 and 37 were selected for the experiment. The experimental lifting task consisted of each participant performing a single treatment by lifting a load from knuckle level (77.8 cm in height) to the shoulder level (147.6 cm in height) by the use of a lifting platform.

The results of the experiment were analyzed using mixed model analysis of variance technique. Where the overall effects of independent variables or their interactions were found to be significant at the 10% level, a separate analysis of variance was conducted by including the significant factors. Further, for obtaining the recovery equation factorial regression analysis followed by a multiple linear regression were used. The following conclusions can be made as a result of these analyses:

1. Among main factors, frequency and weight of the lift increased the time needed for heart rate to recover after a lifting task, while their effects were also significant. On the other hand, duration of the lift negatively impacted the recovery time; however, its effect was insignificant. The only interaction effect that significantly affected the recovery time was the interaction between frequency and duration of the lift.
2. The load weight was the only factor that had a significant effect on the self-reported Borg rating and led to a 20% increase in fatigue rating when weight was doubled.
3. None of the confounding factors of the study (BMI, static strength, PA-R, grip strength) had a significant effect on the recovery time.

7.3 Areas of Application

The results of this study may be used by government agencies and industry in job design and employment placement to establish guidelines for manual material handling tasks. Based on the results of this study, in manual material handling tasks requiring repetitive lifting, proper rest breaks should be allocated with respect to the weight and frequency of the lift. The rest equation will provide a suggested minimum amount of rest based on the task intensity.

CHAPTER 8: LIMITATIONS AND RECOMMENDATIONS FOR FUTURE STUDIES

- One of the major limitations of this study was the relatively small sample size. In future studies, a larger sample size which is more representative of the general population may be used to support the findings with a higher accuracy. For instance, choosing the test participants based on a large array of BMI can be suggested (e.g. based on 50^{th}, 75^{th}, and 90^{th} percentile of U.S. adult population BMI).
- Each independent factor of this study had only two levels, if we had used three or more levels for each factor (e.g. frequencies of 2,6, 5, and 9), we could conduct post hoc analysis and determine which level of a certain factor was most significant compared to other levels.
- In addition, having only two levels for each factor reduced the predictability power of our lifting equations. The equations can not be extrapolated beyond their power. For example, the model is based on lifting durations of 5 and 10 minutes, that being said inserting a duration of 30 minutes into the equation would not yield accurate results for the heart rate recovery time. As a result, future studies may incorporate more levels of each factor so that the rest equation yields a more accurate output.
- This study investigated the effects of three task factors on the recovery time. Future studies may incorporate more factors such as lifting height, lifting angle, and the box size. Adding more factors will add to the value of the study.
- This experiment intended to capture recovery time in a single-component task of lifting. Knowing that multiple-component tasks are more in the workplace, future studies may investigate the heart rate recovery time in multiple component tasks (e.g. lifting followed by pushing).

- Only one physiological response (heart rate recovery time) was studied. Future studies may incorporate more response variables such as VO_2 consumption or EMG. In addition, the current study did not investigate gender effect. Adding a gender variable in the future can be suggested.
- Lastly, a major limitation was using college students instead of actual workers. The results might have been more realistic if a random sample of experienced workers were selected and studied. Most of the limitations discussed will require more time and resources, but they are of value to consider.

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Appendix A: LSU Institutional Review Board (IRB) Application Forms

ACTION ON PROTOCOL APPROVAL REQUEST

LSU
Institutional Review Board
Dr. Dennis Landin, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu | lsu.edu/irb

TO: Fereydoun Aghazadeh
Mechanical and Industrial Engineering

FROM: Dennis Landin
Chair, Institutional Review Board

DATE: December 12, 2016

RE: **IRB#** 3664

TITLE: Development of a Mathematical Model to Predict Work-Rest ratio for Manual Lifting Tasks

New Protocol/Modification/Continuation: Modification

Brief Modification Description: Increase number of participants to 30.

Review type: Full ____ Expedited _X_ **Review date:** 12/12/2016

Risk Factor: Minimal _X_ Uncertain ______ Greater Than Minimal______

Approved _X_ **Disapproved** ______

Approval Date: 12/12/2016 **Approval Expiration Date:** 12/8/2017

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 15

LSU Proposal Number (if applicable):

Protocol Matches Scope of Work in Grant proposal: (if applicable)

By: Dennis Landin, Chairman DLandin

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. **SPECIAL NOTE: Make sure you use bcc when emailing more than one recipient.**

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb*

Appendix B: Informed Consent Form

1. Study Title

Effect of Task Variables on Heart Rate Recovery Time in a Simple Lifting Task

2. Performance Site

Louisiana State University and Agricultural and Mechanical College
Human Factors Engineering Lab
Patrick F Taylor Hall
Department of Mechanical and Industrial Engineering
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3. Contacts

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4. Purpose of the study

The purpose of this study is to develop a mathematical model for predicting rest periods for lifting tasks.

5. Participants

The participants will be all male, college-age students (20-37). Each participant must be free from back pain and any musculoskeletal disorders. Additionally, any potential participant that answers 'yes' to any of the following questions will be excluded:

Has your doctor ever said you have heart trouble?
Do you frequently have pains in your heart or chest?
Do you often feel faint or have spells of severe dizziness?
Has your doctor ever said your blood pressure was too high?
Has your doctor ever told you that you have a bone or joint problem, arthritis that has been aggravated or might be made worse by exercise?

Is there a good physical reason not mentioned here why you should not follow an activity program even if you wanted to?
Have you ever had back pain, particularly lower back pain, or spinal/disk surgery?

6. Number of participants

Twenty-Four

7. Study Procedures

Each participant, after passing a screening questionnaire (discussed in item #5 above) will be instructed on what this research entails. The height, weight, age, grip and static strength test will be recorded for each participant. The participant will be informed that he should perform one lifting exercise, and that if the participant decides not to participate in any part of the exercise, he can resign at any time. The investigator will work with the participants to schedule an appropriate time to meet at the lab.

Each participant will install a heart rate monitor upon entering the test area. A short warmup exercise will be performed in which the participant will walk on the treadmill with the speed of 3 miles per hour for five minutes. Once the warmup exercise is complete, the participant will rest for at least 15 minutes before starting the task. Later on, the participant will begin a specified lifting routine (for example, lift a 10 kg. load for 10 minutes at 6 lifts per minute). Upon completion of the lifting experiment, the participant will be asked to rate the level of difficulty of the exercise on a scale from 1 to 10 and is guided to sit down and rest for 10 minutes while his heart rate is being monitored.

8. Benefits

There will not be any direct health, monetary or mental benefits to the individual participant. However, it is possible this study may be of benefit to the greater population/industry in that a viable formula could be produced to inform industry of when workers should take breaks in order to avoid fatigue, and thereby musculoskeletal injuries.

9. Risks/Discomforts

This proposal is a continuation of IRB #3664. The possible risks of participating in the study are muscle fatigue and muscle soreness. Due to the fact that the period of this experiment is relatively short and the amount of the lifting task will be fixed, risks of performing the study will be minimum. In addition, the correct way to lift a box will be demonstrated during the preparation session in order to prevent muscle strains, and monitored during each lifting task by the experimenter who has taken industrial engineering Ergonomics, Safety Engineering, and Occupational Biomechanics courses and is knowledgeable about correct and safe manual materials lifting methods.

Furthermore, all of the participants who do not meet the physical requirements and answer "YES" to the health-screening questionnaire will be excluded.

10. Right to Refuse

At any time during the course of this experiment, each participant may choose not to participate, especially if he feels discomfort with any part of the procedure.

11. Privacy

The identity of each test participant will remain confidential unless disclosure by law is required. All data will be stored in a secure location or password-protected computer. Only first names (and if needed) last initials will be used for each participant. The screening form for any participant that is rejected will be shredded.

17. Withdrawal

The only consequence of a participant withdrawing from the experiment will be that no bonus point will be given to the participant. The participant's data will be destroyed, and another participant will be recruited.

18. Removal

There are two conditions under which a participant could be removed from the study. First, if the participant proves unreliable with regard to tardiness or absence. Second, if the participant exhibits any medical signs (pain while lifting, shortness of breath), the participant will be asked if medical assistance is needed, and will be removed from the study.

Signature

The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about participants' rights or other concerns, I can contact Dennis Landin, Chairman, LSU Institutional Review Board, (225) 578-8692, irb@lsu.edu, www.lsu.edu/irb . I agree to participate in the study described above and acknowledge the researchers' obligation to provide me with a copy of this consent form if signed by me.

Participant Signature: ____

Date:________________

Appendix C: Borg Scale Form

Borg-Scale and Time Form for Dynamic Strength Project

Name: ___________________ Gender: ________
Age: ____ Weight (lb): ____ Height: ____

How would you rate the physical intensity of each method using the Borg-scale (below)? Look at the verbal expressions first and then choose the corresponding number. For instance, if your perceived exertion is "difficult," then you would put a rating of 5 in the table below, and if your perceived exertion is "very light," then you would put a rating of 1. Base your ratings solely on how you personally perceive it to be, without considering the thoughts of others.

Borg CR10 Ratings of Perceived Exertion

Rating	Definition
0	Nothing at all
0.5	Very, very easy
1	Very easy
2	Easy
3	Moderate
4	Somewhat hard
5	Hard
6	
7	Very hard
8	
9	Very, very hard
10	Impossible

Appendix D: Physical Activity Rating (PA-R)

This questionnaire tool is for categorizing a person's level of physical activity. Your PAR score is a value between 0 and 7. Select the number that best describes your overall level of physical activity for the previous 6 months:

Points	Sub Category	General Category
0 points	Avoids walking or exercise (for example, always uses elevators, drives whenever possible instead of walking).	Does not participate regularly in programed recreation, sport, or physical activity.
1 points	Walks for pleasure, routinely uses stairs, occasionally exercises sufficiently to cause heavy breathing or perspiration.	
2 points	10–60 minutes per week	Participates regularly in recreation or work requiring modest physical activity (such as golf, horseback riding, calisthenics, gymnastics, table tennis, bowling, weight lifting, or yard work).
3 points	Over 1 hour per week	
4 points	Runs less than 1 mile per week or spends less than 30 minutes per week in comparable physical activity	Participates regularly in heavy physical exercise (such as running or jogging, swimming, cycling, rowing, skipping rope, running in place) or engages in vigorous aerobic type activity (such as tennis, basketball, or handball).
5 points	Runs 1–5 miles per week or spends 30–60 minutes per week in comparable physical activity.	
6 points	Runs 5–10 miles per week or spends 1–3 hours per week in comparable physical activity.	
7 points	Runs more than 10 miles per week or spends more than 3 hours per week in comparable physical activity.	

Appendix E: Demographic Data

ID	Knuckle Height (cm)	Shoulder Height (cm)	Height (cm)	Weight (kg)	Age
1	73.5	147.6	178.5	80.5	22
2	75.8	147	177.5	87.5	21
3	77.6	147	176.4	83	20
4	88.5	155	193	100.9	22
5	77	138	169	90.6	22
6	77	153	184	92.5	21
7	72.5	137.5	170	56.6	22
8	76.5	143	173	70.45	21
9	75.5	141.4	171.5	70.3	24
10	81	146	178	74.8	21
11	77.5	150.4	176.4	62	21
12	72	146	173	62	37
13	80.5	148.6	179.5	78.8	21
14	87	160.6	188.5	96	22
15	78	150.5	182.5	100	23
16	72	139.5	170.8	77.4	22
17	80	146.9	180.3	85	21
18	78.5	147.5	179.9	83	24
19	73.5	145.6	178.2	74.6	23
20	75.2	151.4	180.7	86.1	22
21	82.8	156.2	184.2	75.5	22
22	77.5	152	175	88	21
23	78.6	148.8	177.9	68	22
24	78	142.5	172.5	61.2	23

Appendix F: Raw Data for Reponses

ID	Day	Weight	Frequency	Duration	Treatment	Recovery time(min)	Borg
1	1	10	9	10	6	3	7
2	1	20	9	5	4	2.42	7
3	1	10	6	10	5	1.08	5
4	1	20	9	10	8	2.25	8
5	1	10	6	5	1	2.25	3
6	1	20	6	10	7	1.25	3
7	1	10	9	5	2	1.5	6
8	1	20	6	5	3	1	7
9	2	20	9	5	4	2.63	7
10	2	10	6	5	1	1.5	7
11	2	10	9	5	2	1.5	7
12	2	10	6	10	5	1.5	6
13	2	20	6	10	7	2	10
14	2	20	9	10	8	3	6
15	2	20	6	5	3	3	8
16	2	10	9	10	6	1.5	5
17	3	20	9	5	4	3.5	6
18	3	10	9	10	6	3	7
19	3	20	9	10	8	3.5	7
20	3	20	6	10	7	2.5	8
21	3	10	6	10	5	1	6
22	3	10	9	5	2	2	7
23	3	20	6	5	3	3	8
24	3	10	6	5	1	2	5

Appendix G: Data for Confounding Factors

ID	BMI	PA-R	Grip Strength (kg)	Static Strength(kg)
1	25.27	3	35.5	29.2
2	27.77	2	49.6	21.2
3	26.67	4	53.2	26.5
4	27.09	5	74.6	29.3
5	31.72	4	44.7	33.4
6	27.32	4	45.9	42.2
7	19.58	3	35.2	26.6
8	23.54	3	37.4	26.8
9	23.9	3	48.8	22.4
10	23.61	6	47.4	31.3
11	19.92	2	41.9	31.5
12	20.72	2	46.3	22.5
13	24.46	6	45.8	14.7
14	27.02	6	47.7	36.4
15	30.02	3	54.3	31.6
16	26.53	6	39.6	24.3
17	26.15	6	39.4	27.2
18	25.65	6	50.7	21.6
19	23.49	4	42.3	28.3
20	26.37	5	32.3	13.9
21	22.25	4	52.1	32.8
22	28.73	5	48.6	23.3
23	21.49	5	32.9	28.3
24	20.57	3	33	15.1

Appendix H: Stepwise Regression

```
Welcome to Minitab, press F1 for help.
```

Results for: Sheet1

Factorial Regression: Recovery time versus Weight, Freq, Dur

Backward Elimination of Terms

Candidate terms: Weight, Freq, Dur, Weight*Freq, Weight*Dur, Freq*Dur, Weight*Freq*Dur

	Step 1		Step 2		Step 3		Step 4	
	Coef	P	Coef	P	Coef	P	Coef	P
Constant	2.162		2.162		2.162		2.162	
Weight	0.343	0.022	0.343	0.021	0.343	0.018	0.343	0.016
Freq	0.322	0.030	0.322	0.029	0.322	0.025	0.322	0.022
Dur	-0.030	0.827	-0.030	0.827	-0.030	0.823	-0.030	0.819
Weight*Freq	0.058	0.676	0.057	0.676				
Weight*Dur	-0.057	0.676	-0.057	0.676	-0.057	0.668		
Freq*Dur	0.255	0.077	0.255	0.076	0.255	0.069	0.255	0.063
Weight*Freq*Dur	-0.134	0.335						
S		0.661835		0.661568		0.646347		0.632419
R-sq		51.60%		48.62%		48.07%		47.52%
R-sq(adj)		30.42%		30.48%		33.64%		36.47%
R-sq(pred)		0.00%		0.00%		7.68%		16.26%
Mallows' Cp		8.00		6.99		5.17		3.35

α to remove = 0.1

VITA

Milad Amini was born in Shiraz, Iran. Shiraz is a southern city which is well renowned for its poetry, flowers, and wine. He grew up in Shiraz and received a Bachelor of Science degree in Industrial Engineering from Azad University of Shiraz in 2012. He moved to the United States in 2013 and joined the Industrial Engineering Program at Louisiana State University in the Fall of 2015. At LSU he worked as a graduate teaching assistant in the department of Industrial Engineering and was in charge of Ergonomics and Occupational Biomechanics lab.