**University of Alberta**

# The Validity of the Baltimore Therapeutic Equipment (BTE) Work Simulator in the Measurement of Lifting Endurance

by

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## ABSTRACT

This study investigated the criterion validity of the Baltimore Therapeutic Equipment (BTE) work simulator for measuring lifting endurance. Twenty healthy male volunteers, ages between 18 to 37 years performed repetitive squat lifts of 40 lbs. using actual equipment and the BTE work simulator. Postures, location and frequency of lifts were kept constant. Endurance, oxygen consumption and heart rate were measured and compared. Results indicated that mean values for endurance and steady state physiological responses were significantly different between the real and simulated tasks. Correlation of endurance time between the two tasks was also significant ($r = .706, p < .05$). A regression equation (*predicted R-time = .339 (S-time) + 3.286; r = .706; SE = .991 min*) used to predict endurance performance in real lifting from measurements on the simulator was computed. It is concluded that use of the BTE work simulator tends to overestimate endurance performance in a real situation. Cautions are therefore required for therapists when using the results measured on the simulator directly.

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| | | |
|---|---|---|
| **the BTE work simulator** | - | the Baltimore Therapeutic Equipment work simulator |
| **bpm** | - | beats per minute |
| **GEC** | - | gross energy cost |
| **HR** | - | heart rate |
| **$kcal.min^{-1}$** | - | kilocalories per minute |
| **$L.min^{-1}$** | - | litres per minute |
| **MET** | - | metabolic equivalent |
| **$mL.kg^{-1}.min^{-1}$** | - | millilitres per kilogram per minute |
| **NEC** | - | net energy cost |
| **$O_2$ pulse** | - | oxygen pulse |
| **PAR-Q** | - | Physical Activity Readiness-Questionnaire |
| **pHR** | - | peak heart rate |
| **$p\dot{V}O_2$** | - | peak oxygen uptake |
| **%pHR** | - | percentage of peak heart rate |
| **$\%p\dot{V}O_2$** | - | percentage of peak oxygen uptake |
| **RER** | - | respiratory exchange ratio |
| **RPE** | - | rating of perceived exertion |
| **R-time** | - | endurance time in the real task (in minutes) |
| **S-time** | - | endurance time in the BTE-simulated task (in minutes) |
| **$\dot{V}O_2$** | - | oxygen uptake |
| **$\dot{V}O_{2max}$** | - | maximal oxygen uptake |
| **$\dot{V}_E$** | - | expired ventilation |
| **$\dot{V}_E/\dot{V}O_2$** | - | ventilatory equivalent for oxygen |

# CHAPTER I
# INTRODUCTION

Workplace injuries and occupational illnesses are common across Canada. In 1993, 423,000 work injuries were reported in compensation, a rate of almost four for every thousand workers (The Federal, Provincial and Territorial Advisory Committee on Population Health, 1996). Total costs to the health care system, the insurance companies and the employers are so high that it calls for an objective evaluation of the functional abilities of workers after work-related injuries. This evaluation is used to determine the level of work that a person can perform, predict the ability to return to work, determine areas of concentration for further treatment, document change and provide information for case closure if the person is no longer employable (Lechner, Roth, & Straaton, 1991; Tramposh, 1992). The comprehensive and objective assessment of functional capacity prevents a potentially productive person from losing his working life prematurely and protects the workers' compensation system from considerable abuse (Tramposh, 1992).

Occupational therapists are often asked to provide an evaluation of individual's work performance and employability. Functional capacity evaluations have become increasingly important in the practice of occupational therapy in work rehabilitation. However, different functional capacity evaluations are currently available and in use. They vary in the choice of measuring instruments, length of assessment, determination of end-points for testings, choice of work activities chosen and standards of practice (Lechner et al., 1991; Tramposh, 1992; Gibson & Strong, 1997; King, Tuckwell, & Barrett, 1998). Limited scientific studies have been done on these evaluations to test their reliability and validity. To improve the practice of functional capacity evaluations, more research is required to test their measurement properties, to make sure that the instruments used can meet the acceptable standards and to increase the credibility of their use in the medicolegal environment if required.

With advances in technology, the Baltimore Therapeutic Equipment (BTE) work simulator is one of the commercial devices designed for the evaluation of functional capacity (Bhambhani, Esmail, & Brintnell, 1994). This space efficient equipment allows the therapist to simulate the tasks and motions involved in actual job activities (Curtis & Engalitcheff, 1981). It gives information on a person's ability to perform physical work. Few studies have been done to examine the use of the BTE work simulator in work rehabilitation. However, the therapist's ability to accurately evaluate and predict return to work depends on how well the BTE work simulator can actually simulate real work tasks: the greater the match between the BTE simulated tasks and the real work tasks, the more likely the results can apply to a real job situation. Given the high equipment cost, it is important to know that functional capacity evaluation, as measured by the BTE work simulator, is objective and accurate. The results obtained must precisely reflect a person's ability to perform physical tasks, especially over a period of time and be applicable to a real job situation in order to accurately predict work performance.

The main purpose of this study was therefore to validate the use of the BTE work simulator in measuring endurance during lifting by comparison with the real work task in a laboratory setting.

# CHAPTER II
# LITERATURE REVIEW

## A. Measurement of functional capacity using work simulations

Measurement of functional capacity has evolved as a result of the great difficulty experienced by physicians in translating medical impairment into functional limitation (Abdel-Moty et al., 1993). In the past decade, various functional capacity evaluations have been developed to determine a client's level of function and to assist in decision making for return to work. Despite their wide use and development, a few literature reviews have concluded that the reliability and validity of functional capacity evaluations are not well established (Lechner et al., 1991; Velozo, 1992; Dusik, Menard, Cooke, Fairburn, & Beach, 1993; Hart et al., 1994).

Efforts have been made to improve the psychometric properties of functional capacity evaluations, particularly regarding their predictive validity (Smith, Cunningham, & Weinberg, 1986; Kennedy & Bhambhani, 1991; Dusik et al., 1993; Lechner, Jackson, Roth, & Straaton, 1994). There is no doubt that in order to ensure proper return to work decisions using a functional capacity evaluation, the key issue is the match between the client's functional capacity and the critical demands of the actual job (Menard & Hoens, 1994). To achieve this match, the best way of measurement would be to perform a situational assessment on how the client can function in his real work situation. Unfortunately, due to practical constraints such as limitations of time, manpower and resources and the difficulty in quantifying the measurement in a real work situation, real work testing is not commonly used. Instead, therapists set up a work station by themselves (Smith & Baxter-Petralia, 1992) or use commercially available devices or work samples (Matheson & Niemeyer, 1986) to simulate the real work tasks.

Clarity, objectivity and work relevance are critical in the evaluation of functional capacity using the simulated work tasks (Isernhagen, 1990). The simulated tasks used by therapists must reflect the real workplace and they cannot be assumed as ergonomically optimal for the clients being tested (Menard & Hoens, 1994). To resemble a real work task, characteristics such as the demands for strength, endurance, positioning, postures, motions and energy expenditure etc. must be considered in designing the work simulations.

**B. The Baltimore Therapeutic Equipment work simulator**

As its name implies, the BTE work simulator is a commercially available electromechanical device designed to simulate the basic motions required by the upper extremities in most occupations (Curtis & Engalitcheff, 1981). It is commonly used by occupational therapists in work evaluation and work hardening programs. It consists of four major components (1) an electrically controlled variable resistance device, (2) multiple attachments that can mount to the resistance device in different planes, (3) a control console which allows the adjustment of operational mode and resistance and the display of physical data, and (4) the QUEST software package (Bhambhani et al., 1994).

The BTE work simulator has two modes of operation. The static mode allows therapists to determine their client's maximum isometric strength while the dynamic mode allows the assessment of dynamic power and endurance. Data available at the end of the work simulation for each attachment includes the degree of rotation of the shaft being turned (distance), torque (angular force), elapsed time, amount of resistance and the work and power being performed (Curtis & Engalitcheff, 1981). The manufacturers of the BTE work simulator have reported various uses of these data. They include assessment of muscle performance, lift/push/pull evaluation and testing consistency of effort. It can also be applied in the treatment programs such as work hardening, cardiovascular rehabilitation and muscle strength and endurance training (Operator's manual, 1992 ).

**C. Previous studies related to the BTE work simulator**

In the past few years, several studies have reported on the use of the BTE work simulator in evaluation and treatment in work rehabilitation. These include the establishment of normative data for biomechanical and physiological responses of three simulated tasks, namely, wheel turn, push-pull and overhead reach in healthy men and women (Bhambhani et al., 1994; Esmail, Bhambhani, & Brintnell, 1995), grip and wrist flexion strength (Anderson, Chanoski, Devan, McMahon, & Whelan, 1990), and the metabolic and hemodynamic responses to various simulated activities in cardiac patients (Wilke, Sheldahl, Dougherty, Levandoski, & Tristani, 1993). As well, researchers have examined the reliability and validity on the BTE work simulator. The results of these testings are important because a valid and reliable measurement is essential in predicting a person's return to work ability and to establish direction of treatment program.

Anderson et al. (1990) reported that the test retest reliability for grip strength ($r = .979$) and wrist flexion ($r = .913$) were high. The result is also consistent with the study (ICC = .978) done by Trossman, Suleski and Li (1990). Kennedy and Bhambhani (1991) also demonstrated significant correlations between repeated trials and indicated test-retest reliability of the work simulated tasks at three intensity levels by measuring oxygen uptake and heart rate ( r between .74 and .87 for oxygen consumption and between .59 and .78 for heart rate). However, in a study without human subjects, Coleman et al. (1996) examined the reliability (consistency) of resistance in the manual dynamic mode of twelve BTE work simulators by measuring weight-drop time (5-40 lbs.). They found that regardless of weight levels, the simulators failed to provide a constant resistance as reflected by the weight-drop time variations. A significant variation was found in all recorded weight-drop times ($Pr > F = .0001$) and all simulators exhibited weight-drop times greater than 25% deviation from the mean (Coleman, Renfro, Cetinok, Fess, Shaar, & Dunipace, 1996). It implies that resistance in the manual dynamic mode of the work simulator can vary across different machines.

For validity, the study of Kennedy and Bhambhani (1991) showed that criterion validity was not demonstrated at the heavy intensity level of simulated tasks. The measurement of oxygen uptake and heart rate were significantly different ($p < .05$) between the real and simulated work tasks. Wilke et al. (1993) also reported that in cardiac patients, the metabolic and hemodynamic responses were somewhat lower in the BTE work simulated tasks than the real work tasks. The study results suggested that this discrepancy may be due to the restricted movement patterns of the simulated tasks limited by the BTE work simulator (Kennedy & Bhambhani, 1991; Wilke et al., 1993). Therefore, it gives rise to a question of whether the BTE work simulator can be used in the measurement of endurance. If the BTE simulated tasks appear "less strenuous", then measurement of continuous work performance on the simulator may become different from the actual performance on jobs.

Endurance is defined as "the capacity to continue a physical performance over a period of time" (Nieman, 1990, p.551). It will depend on the pulmonary and cardiac function, the oxygen binding capacity of the blood, the oxygen extraction capabilities and muscle oxygenation (Burnett, 1990). The operator's manual (1992) on the BTE work simulator has reported the use of dynamic mode in measuring endurance of different activities. Although Beck et al. (1989) have studied the relationship of endurance to static and dynamic grip strength as measured by the BTE work simulator, their low correlations ($r = -.49$ to .04 for right hand and -.30 to .15 for left hand) only demonstrated that static and dynamic measures do not yield information on endurance. A comprehensive analysis of hand strength should include endurance measures as well as static and dynamic strength measures. To date, no study is available on the validity of the BTE work simulator in measuring endurance, particularly when it is applied to work assessment.

In order to help a person successfully return to work, evaluation of functional capacity which focuses on the maximum intensity a person can manage on the job is insufficient. The ability to sustain an activity without undue fatigue is also important (Matheson & Niemeyer, 1986; Isernhagen, 1990). A person, who is unable to sustain a given work intensity for a certain period of time as required by the job, may decrease the chance of employability and make him/her more prone to re-injury. It is therefore necessary to apply measurement that closely resembles the actual job in a manner that reflects the intensity, duration and pace of the job.

**D. Physiology underlying endurance performance**

In work rehabilitation, endurance performance can be a critical factor in determining successful return to work when a person's job requires repetitions of work tasks over a period of time. Endurance performance is dependent upon cardiovascular and respiratory systems, muscle metabolism, mechanical efficiency and thermoregulation (Hughson, Green, Phillips, & Shoemaker, 1996). To optimize endurance performance, efficient aerobic transformation of metabolic substrates into mechanical power, with delayed depletion of the glycogen reserves is crucial (Hughson et al., 1996).

Conceptually, endurance performance is opposite to fatigue. Fatigue is defined as "the inability to maintain the expected force and power output" or "a transient loss of work capacity resulting from preceding work regardless of whether or not the current performance is affected" (Maassen, 1996, p.31). It may occur at different sites such as muscles, central nervous system and cardiorespiratory system. Although fatigue is related to us in everyday life, there is no universally acceptable way of measuring it (Hueting & Sarphati, 1966; Grandjean, 1988).

To perform a given workload for a period of time, energy production in the form of adenosine triphosphate (ATP) must meet the energy consumption in the muscles. Any factors which affect the efficiency of the metabolic machinery in the muscle cells will limit one's capacity to perform (Wenger & Reed, 1976). Different muscle fibres display different fatigue properties. Fast-twitch fibres, with a high capacity for anaerobically producing ATP in glycolysis, are fast fatiguable, whereas slow-twitch fibres, with greater aerobic capacity due to the increased number and size of mitochondria and higher levels of enzyme activities, are more resistant to fatigue (Pette, 1996).

Wenger and Reed (1976) have described the metabolic factors associated with muscular fatigue during aerobic and anaerobic work. They proposed that in high intensity, anaerobic types of work where fast-twitch motor units are recruited, the inability to continue work is related to increased lactate production and decreased muscle and blood pH. Other factors including depleted glycogen in fast-twitch motor units, decreased availability of co-factors (NAD+) and decreased inorganic phosphate will also initiate fatigue. In lower intensity, long duration, aerobic types of work where slow-twitch muscle fibres are primarily recruited, the primary limiting factor will be the availability of fuel. Blood glucose is lowered due to the depletion of glycogen reserves. Although fat can be used as an alternative source of fuel, the increased lactate during high intensity will inhibit fat mobilization from the adipose tissues, therefore, stored glycogen reserves are depleted faster. As well, the supply of hydrogen through NADH for oxidative phosphorylation become limited for ATP production. Other factors such as increased muscle temperature, limited oxygen supply and ATP transport form the mitochondria to muscle cells are also related to fatigue.

There are two important physiological factors influencing endurance performance: (1) the maximal capacity to consume oxygen as reflected by maximum aerobic power ($\dot{V}O_{2max}$), (2) the maximal level for steady state exercise or the onset of blood lactate accumulation (OBLA) (McArdle, Katch, & Katch, 1996, p.255). The $\dot{V}O_{2max}$ value quantitatively expresses a person's capacity for aerobic resynthesis of ATP and it is an important factor in determining one's ability to sustain high intensity exercise for longer than 4 or 5 minutes (McArdle et al., 1996). The OBLA identifies the intensity at which lactate begins to accumulate at an exponential rate in blood (Coyle, 1995).

McArdle et al. (1996) pointed out that the OBLA is a more consistent and powerful predictor of performance in aerobic exercise than the $\dot{V}O_{2max}$ because longer duration, high intensity exercise is not performed at the $\dot{V}O_{2max}$. Correlations between performance velocity or power output and the OBLA were high. However, Coyle (1995) observed in a study of Farrell et al. that although performance velocity was most highly correlated to the lactate threshold velocity at a 15 km running race ($r = .97$), $\dot{V}O_{2max}$ was also significantly correlated with the performance velocity ($r = .89$). Therefore, he concluded that measures incorporating lactate threshold could not be interpreted as better than $\dot{V}O_{2max}$ in predicting endurance performance. In his two studies on endurance-trained heart disease patients (low $\dot{V}O_{2max}$ but identical lactate threshold) and competitive cyclists (identical $\dot{V}O_{2max}$ but different lactate threshold), he found that performance was determined primarily by blood lactate threshold instead of the $\dot{V}O_{2max}$ ($r = .90$). Yet, $\dot{V}O_{2max}$ sets the upper limits for prolonged steady state exercise. He further wrote that $\dot{V}O_{2max}$ should be viewed as "a functional ability contributing to performance during prolonged exercise through its influence on lactate threshold" (Coyle, 1995, p.38).

It is generally believed that endurance time at a given intensity level is related to a person's aerobic capacity. Numerous studies have been done over the years to establish acceptable energy expenditure limits as a percentage of $\dot{V}O_{2max}$ for an 8 hour working day that will not cause undue accumulation of fatigue. Most data suggest a range between 21 and 50% of $\dot{V}O_{2max}$ for an 8-hour shift (Legg & Myles, 1985). The current upper limits of work recommended by the National Institute for Occupational Safety and Health (1991) are 50%, 40%, and 33% of $\dot{V}O_{2max}$ for work tasks lasting 1 hour, 1 to 2 hours, and 2 to 8 hours respectively (Waters, Putz-Anderson, Garg, & Fine, 1993).

**E. Fatigue and work**

According to Grandjean (1988), fatigue denotes a loss of efficiency and a decline in any kind of efforts. It is not a single, definite state. It usually becomes less clear as one tries to define it more specifically. Classification of fatigue into different types is partly based on the cause and partly on the way it manifests itself. Different kinds of fatigue are listed below (Grandjean, 1998, p.159):

- muscular fatigue, arising from overstressed muscles
- visual fatigue, arising from overtiring eyes
- general bodily fatigue, due to physical overloading of the entire body
- mental fatigue, cause by overstress of the psychomotor system
- monotony of either occupation or surroundings
- chronic fatigue brought by accumulation of long term effects
- circadian or nyctemeral fatigue, due to the day-night rhythm, and initiating a period of sleep

In a workplace, fatigue is caused by a combination of various factors such as increased temperature, noise, dehydration, tight external pacing, high visual demands and psychological stresses, and the accumulation of lactic acid and depletion of glycogen reserves as related to the intensity and duration of work, etc. The symptoms of fatigue can be both objective and subjective (Grandjean, 1988). Apart from the measurable decreases in quantity and quality of work output, they may also include subjective feelings of weariness and distaste of work, reduced alertness, sluggish and slow reaction, poor perception and unwillingness to work. Individuals working under fatigue are more likely to demonstrate reduced work productivity and increased risk for injury. Therefore, in order to maintain efficiency, rest is needed both at night and during the day while at work to reduce the amount of physical and psychological stresses. As well, more understanding of the job and workplace are necessary in order to assist the workers to work more comfortably and efficiently.

**F. Use of the Borg scale**

The Borg scale (1982) is range of scores from 6 at rest to 20 at peak effort. It gives ratings of perceived exertion (RPE) that can be used to assess exercise tolerance, to prescribe exercise intensity, to determine the effect of a therapeutic intervention, and to guide the time course of a graded exercise test (Noble & Robertson, 1996). Because this 15-graded scale is constructed with careful choice of verbal categories, the perceptual ratings are linear with heart rate and power output (Gamberale, 1985). These relationships form an important basis for its application in both research and clinical settings. Extensive studies have been done to examine the Borg scale. They include the study of its reliability and validity, of the influences by various central, peripheral, psychological and environmental factors, and of its application in exercise testing and prescription for both healthy and clinical populations.

Reliability of the RPE responses to a progressive exercise test and a random test with changed workloads were .80 and .78 respectively (Skinner, Hustler, Bergsteinova, & Buskirk, 1973). Another study which was conducted by Stamford (1976) also indicated an acceptable reliability, correlations were found between .76 and .90 during four tasks (treadmill walking, treadmill running, cycling and stool stepping) with each test a minimum of 48 hours apart.

As sensations arise from the body during physical exercise have physiological origin is central to the application of RPE (Noble & Robertson, 1996), numerous studies have been done to examine the relations of RPE with various physiological factors. For heart rate, correlation coefficients from .80 to .90 were found by Skinner et al. (1973). For percentage of $\dot{V}O_2$ maximum, Burke (1986) demonstrated that significant increases in values were consistent with the significant increases in RPE. Pollock, Jackson and Foster (1986) also reported their previous study that a multiple correlation of .84 was found between the RPE and heart rate, pulmonary ventilation, blood lactate and oxygen uptake. Hence, use of the RPE provides a valid measure to prescribe and monitor an exercise program.

Several studies have been done to examine the change of RPE during prolonged exercise (Cafarelli, Cain, & Stevens, 1977; Wardle & Gloss, 1978; Borg & Johansson, 1986; Ljunggren, Ceci, & Karlsson, 1987). They all showed that perceived exertion changes systematically over time, following a negatively growing power function. Unlike heart rate, the RPE increases continuously over time (without reaching a steady state) and after 15 minutes of exercises, it covaries with the corresponding blood lactate (Ljunggren et al., 1987). The RPE may reflect an accumulating effect of fatigue over time which is not shown by the heart rate (Borg & Johansson, 1986). Myles (1985) also reported that when exercise is of several minutes' duration (>30 sec.) at a constant intensity, RPE increases as fatigue develops. However, what factors (central or peripheral) are contributing to the subjective sensations of fatigue and the perceived exertion remain uncertain (Noble & Robertson, 1996).

Pandolf (1977) pointed out that RPE does not seem to be a function of any single physiological factor. Both local factors arising from the working muscles/joints and central factors originating from the cardiorespiratory system may contribute to the perception of exertion during physical work. In most cases, peripheral factors predominated over central input, especially in work with smaller muscle groups. Central factors may be of greater importance at higher work intensities, longer duration (after 30-180 sec. of exercise) and in work with larger muscle groups when they tend to stress the pulmonary ventilation and circulation in addition to the local strain (Cafarelli et al., 1977; Pandolf, 1978; Pandolf, 1986).

A model was proposed by Weiser and Stamper (1977) which described the interaction between different areas of fatigue and physiological events during exercise. It stated that there are four levels of subjective reporting as related to perceived exertion. At the subordinate level, discrete symptoms are clustered into three sub-groups (cardiopulmonary fatigue, general fatigue and local muscular fatigue) that define fatigue and feelings of exertion. Therefore, differentiated ratings of perceived exertion at this level, requiring special focus on specific areas of fatigue, will represent local and central factors. At the superordinate level, subjective symptoms originated from local working muscles (eg. muscle aches, joint pain), the cardiorespiratory system (eg. heart pounding, shortness of breath) and the central nervous system (eg. feel tired, worn out) are operating in consort with physiological processes to set upper limits of endurance performance. An undifferentiated RPE will therefore reflect the integration of all sensations and physiological events at this level.

Although there is some concern over the influence of psychological factors such as motivation and personality on the RPE during the work tasks, Noble and Robertson (1996) have written that psychological factors are more salient at light and moderate intensities than high intensities. When exercise is of high intensity and longer duration, it is likely that attention is focused on noxious exercise sensations which dominate focal awareness, thus, psychological factors have a lesser effect on the RPE. Burke (1986) also pointed out that the association of RPE with percentage of maximal oxygen consumption and anaerobic threshold has given credibility to the use of the scale despite criticisms on its subjectivity.

### G. Use of upper arm ergometry

In the past, research efforts have been concentrated on lower body. However, as muscles of upper body are involved in many daily tasks at home, at work and in sports, understanding of physiological responses in upper body exercise is becoming important and meaningful (Steinacker, 1996). Recently, more studies have been done to study the physiology of upper body exercises. Based on the review papers written by Sawka (1986), Pendergast (1989), Miles, Cox and Bomze (1989) and Steinacker (1996), the physiological responses to upper body exercises are summarized as followed:

- Peak oxygen uptake is lower in arm work than in leg work (~ 70% of leg work). The smaller muscle mass in arm work has limited peak oxygen uptake by its smaller oxidative capacity, reduced ability to generate tension and reduced blood perfusion to skeletal muscles.
- At the same submaximal power output, greater oxygen uptake and heart rate are elicited by arm work indicated that arm work is less energy efficient. This can be explained by increased energy requirements for torso stabilization, greater isometric exercise component and differences in skeletal muscle recruitment patterns.
- Cardiac output at a given submaximal oxygen uptake are similar for arm work and leg work. However, higher heart rate and lower stroke volume are reported during arm crank exercise. It can be explained by decreased preload due to failure to facilitate venous return and the increased afterload to the heart.
- Blood pressure and total peripheral resistance are higher in arm work because of the smaller vascular cross-sectional area being perfused by the same cardiac output and resulting in greater blood flow. Also, an increased sympathetic response to arm work will cause a greater vasoconstrictor tone. Increased mechanical compression of the vasculature during arm work and increased blood viscosity would also contribute to the rise in total peripheral resistance.
- Lower oxygen extraction ($[a - v]O_2$ difference) during arm work because of the greater blood flow to the non-exercising muscles and the smaller vascular cross-sectional area being perfused.
- Arm work results in higher blood lactate concentration than a comparable level of leg work. Also, the onset of anaerobic metabolism occurs at a lower level of oxygen uptake. It could be explained by the recruitment of more fast-twitch glycolytic fibres in arm work and the delayed adjustment of oxygen uptake leading to an increased oxygen deficit.

- Pulmonary ventilation response are greater at arm work than in legs at a similar power output. It might be related to the lower peak oxygen uptake, greater blood lactate concentration, greater isometric component and greater neurogenic drive.

To study the relationship between peak aerobic power and endurance performance during work activities, it would be more appropriate and task-specific to use upper body exercise. The reasons are first, the physiological responses are different between the arm and leg work, and second, most occupational tasks are involving the upper limbs.

According to Bar-Or and Zwiren (1975), test-retest reliability of using arm test to determine $\dot{V}O_{2max}$ was high with reliability coefficients of .94. When the $\dot{V}O_{2max}$ value of an arm test was compared to a progressive running test on the treadmill, $\dot{V}O_{2max}$ -arm was about two-thirds of the respective leg values ($r = .74$). Therefore, predictability of maximal leg values from arm data or vice versa are only fair. It would be more suitable to use upper arm ergometry to find out the maximal responses when the data are being applied to occupational tasks involving upper limbs.

**H. Summary**

Measurement of functional capacity is imperative in deciding a person's ability to return to work after an injury or illness. Work simulations are often used by occupational therapists in functional capacity evaluations to resemble the demands of a job in order to measure their client's physical tolerance and strength to sustain the work tasks. The availability of the BTE work simulator allows therapists to use these simulations within a confined space.

Various studies have been done to understand the psychometric properties of the BTE work simulator as a measurement device in functional capacity evaluations. However, none has validated its use in the measurement of endurance. As endurance performance is also one of the critical factors in determining a person's work capacity, the utility and usefulness of the BTE work simulator in this aspect requires further exploration. As well, through the use of objective measurement involving physiological and psychophysical approaches, it is hoped that more insights will be gained on the measurement of endurance by the BTE work simulator in the evaluation of worker's performance.

# CHAPTER III
# SPECIFIC GOALS

The first objective of this study was to evaluate the criterion validity of the BTE work simulator in measurement of endurance by: a) comparing the length of time for which subjects can sustain the floor to bench lifting under real and simulated conditions with the same intensity, and b) examining the degree of relationship between these time measurements of endurance. Endurance was defined in this study as the ability to sustain an activity for prolonged periods of time without undue fatigue. If the study demonstrated a significant relationship for endurance time between the real and BTE-simulated tasks, then measurement of endurance by the BTE work simulator might be able to provide an useful estimation of an individual's ability to sustain his/her work in a real job situation and assists in making decisions regarding return to work after injuries or illnesses.

The second objective of this study was to determine whether there were any differences in the energy requirements of the real and simulated lifting tasks by comparing their oxygen consumption ($\dot{V}O_2$) and heart rate (HR). The variables measured were also expressed as a percentage of peak oxygen uptake (%p$\dot{V}O_2$), percentage of peak heart rate (%pHR) and the metabolic equivalent (MET) value of the work tasks. The gross (GEC) and net (NEC) energy expenditure of the work tasks were also calculated.

The third objective was to determine a regression equation which predicts endurance performance on lifting based on the measurement of endurance time by the BTE work simulator. Two other independent variables, namely the body mass index (BMI) and the resting HR, were also used to predict endurance performance in the real task.

# CHAPTER IV
# METHODS

## A. Sampling and design

The study mainly examined the criterion validity of the BTE work simulator in measurement of endurance during work activities. The amount of time for which subjects sustained the BTE simulated tasks and the real work tasks were measured and compared.

A convenience sample of 20 healthy young men, aged between 18 to 40 years, was recruited from students and staff from the University of Alberta to participate in this study (see sample size calculation in Appendix A). Subjects were free from any metabolic and cardiorespiratory disorders and were not taking medication during the time of study. Any subjects with known history of medical or orthopaedic conditions like asthma and low back pain were excluded. Each subject was also required to sign a written consent (see information sheet and consent form in Appendix B and C) and completed a health status questionnaire before participation. The Physical Activity Readiness Questionnaire (Canadian Society for Exercise Physiology, 1994) was used (see Appendix D) in this study. It is a simple and brief medical questionnaire commonly used in Canada to screen for any contraindications to exercise such as chest pain, dizzy spells, bone and joint problems etc. Use of the questionnaire will help to ensure safety of an exercise testing and the beginning of a progressive exercise program (Nieman, 1990).

In this study, only males between the ages of 18 to 40 were included because they represented the population mostly engaged in occupational tasks that involved manual material handling. The literature indicated that aging leads to limitations in occupational performance as a result of progressive decline in oxygen transport, aerobic fitness and muscle strength (Shephard, 1994). There is also a gender difference in that women, in general, have a reduced oxygen carrying capacity and more body fat than men (Nieman, 1990). Since it was not the intent of this study to examine the effect of age and gender on the measurement of endurance, women and older men were excluded. Hence, the results from the study are only applicable to healthy men. Further investigation will be required for application on the injured workers. This study was considered preliminary to test the use of the BTE work simulator in the measurement of endurance during functional capacity evaluations.

**B. Procedures**

Subjects were asked to complete three testing sessions over a two-week period (see graphic presentation of procedures in Appendix E). The sessions were scheduled at least 24 hours apart and they lasted approximately one hour each. In each session, the tests were carried out in a constant environment with room temperature of 20-23 °C because fatigue is more likely at extreme cold or heat (Shephard, 1994). The three sessions were also scheduled at approximately the same time of a day to avoid any diurnal influence.

Data including subject's age, height, body mass and resting HR (in standing position) were collected at the beginning. The age-predicted maximal HR and the BMI ( body mass (kg) ÷ [square of height ($m^2$)] ) (McArdle et al., 1996) were calculated from the data. The resting HR and the BMI were used to predict real lifting performance in subsequent analysis. These two variables were chosen because they are related to the physical fitness of a person and they can be easily determined by the therapists without using any special equipment. For resting HR, given that the resting cardiac output is relatively constant in individuals of similar body size, a slow resting HR implies a good myocardial contractility, therefore, a larger reserve of cardiac function to meet the demands of aerobic exercise (Shephard, 1994). The BMI, derived from body mass and stature, is frequently used as a measure of the normalcy of individual's body weight. In general, an excess body weight is related to a poorer physical fitness. A high BMI is also linked to the increased risk of variable medical conditions such as cardiovascular disease, diabetes and renal problems (McArdle et al., 1996).

Subjects were asked to perform an incremental arm cranking test in the first session to determine their peak oxygen uptake ($p\dot{V}O_2$) and peak heart rate (pHR). They were then asked to perform the work task chosen in this study in subsequent sessions. The order of work tasks to be tested under real or simulated conditions were randomized. A workstation was set up in the laboratory using the actual tools and equipment whenever possible to perform the real work task. The shaft height, head position and the resistance level of the BTE work simulator were adjusted to simulate the real task as much as possible. The postures and positions involved in the real and simulated tasks were kept the same because fatigue is more likely in awkward postures if a substantial effort is needed to maintain the posture. Different postures will influence a person's ability to tolerate a task at a given pace (Shephard, 1994).

*Tasks:*

The occupational task selected was lifting. This task was chosen because it is included in the U.S. Department of Labor's twenty physical demands of work, and safe performance of it requires both physical strength and endurance. Lifting is one of the work tasks commonly used by vocational counsellors and rehabilitation therapists to classify jobs (Lechner et al., 1991). A load of 40 lbs. was used in this study. The load was classified as heavy workload according to the Employment and Rehabilitation Institute of California's version of the Department of Labour's system (Matheson, Ogden, Violette, & Schulz, 1985). A heavy workload was chosen because it put a demand on the physical abilities of the subjects. Otherwise, the endurance time measured might be affected by the feeling of fatigue due to boredom and low arousal of the work tasks.

Under the real condition, subjects were asked to bilaterally lift and lower a plastic crate (13 x 13 x 13 inches) weighing 40 lbs. through a vertical distance of 30 inches between the floor and a bench. For the simulated condition, attachment # 191 of the BTE work simulator was used. The simulator head was positioned appropriately and the shaft height was adjusted such that the subjects lifted through the same vertical distance (same origin and destination) as the real task. A small desk with the same height as the bench and a plastic crate on its top was used as a reference point. The resistance level of the BTE work simulator was adjusted to the torque setting (60 inch-lbs.) which simulated the weight of 40 lbs. according to the conversion chart provided in the operator's manual for this particular attachment (Operator's manual, 1992, p.317). The set-up of the real and simulated tasks were reviewed by two experienced ergonomists during pilot testing. The two tasks were modified to ensure that their settings were as close as possible (see Appendix F for illustrations of the real and simulated tasks). Subjects were also instructed to use similar body motions while performing the real and simulated tasks.

*Session 1: (a) Incremental arm cranking test*

In this session, subjects were asked to perform an incremental arm cranking test according to the procedures described by Kennedy and Bhambhani (1991) to determine the $pVO_2$ and the pHR. Before the start of procedures, resting HR for each subject in a standing position was determined using the Polar wireless heart rate monitor (See Appendix G). This type of monitor demonstrates good validity and has been found to agree within one or two heart beats per minute with the EKG readings (Nieman, 1990). The subjects were instructed to turn the cranks of an arm ergometer (See Appendix G) at 50 rpm and zero load for two minutes. Thereafter, the power output was increased by 15W every two minutes until: (a) voluntary exhaustion was attained, (b) the subjects reached their age-predicted maximum heart rate, calculated as 220 - age in years, and (c ) the respiratory exchange ratio (RER) of $\geq$ 1.10 was attained. During the tests, HR was monitored by the Polar wireless monitor, and the $VO_2$ was recorded by an automated metabolic cart (See Appendix G) which was calibrated with precision gases (15.98% $O_2$, 3.99% $CO_2$). The pneumotach in the metabolic cart was calibrated by injecting a known volume of air from a syringe (0.89 L) through the mixing chamber, as recommended by the manufacturer. Subjects were connected to the instrument through a mouth piece and breathing hose in order to monitor the expired gases. Continuous data including oxygen uptake, carbon dioxide production, ventilation volume, respiratory exchange ratio were computed by the machine every 20 seconds. The highest $\dot{V}O_2$ attained during the test was the $p\dot{V}O_2$ for each subject. The pHR was also recorded at this point.

*(b) Task familiarization*

After the incremental arm cranking test, subjects were allowed a few minutes rest.

They were then allowed to familiarize themselves with the equipment and the work tasks for a brief period of time. The subjects were asked to perform the real and simulated lifting tasks for approximately one minute. This procedure helped to eliminate any intra-individual differences in measurement as a result of anxiety and unknown factors. While the subjects were familiarizing themselves with the work tasks, they were also asked to select a work pace that they felt most comfortable lifting without becoming unusually tired. The following instruction was given: "*Imagine you are continuously working at a job. Now try to find a suitable pace for yourself such that you can work comfortably for a long time without getting too tired.*" For each subject, the number of repetitions per minute was counted and used in subsequent sessions.

*Sessions 2 and 3: Real and simulated work tasks*

In the next two sessions, subjects were asked to perform the floor to bench lifting under the real or simulated conditions in random order. To quantify endurance, the time for which subjects lifted repetitively at the pre-determined self-selected pace was measured until their ratings of perceived exertion (RPE) increased by two units. The work pace selected was held constant throughout the tests in both the real and simulated tasks. A limit on the pausing time (< 30 sec.) was also set when the subjects felt tired and wanted to slow down their pace.

External motivation from the rater was controlled by using the same instructions for all the tasks during the tests. Subjects were given the following instruction: " *Imagine that you are working at a job, lift the load at a pace you selected previously for as long as you can. We will time the duration for which you can sustain the task without a rest.*"

In this study, the criterion used to define fatigue was an increase in the RPE over time. The RPE was recorded at rest and at the end of every minute using the Borg scale (Borg, 1982) (See Appendix H). After the RPE increased by two units when compared to the fourth minute value (steady state conditions), the work task was discontinued. The fourth minute RPE value on the Borg scale was used as a reference point because it would take a few minutes for the integration of central and peripheral inputs that arise from the body movement to give a more accurate undifferentiated RPE (Birk & Birk, 1987). The length of time for which subjects sustained each task after an increase in two RPE units (when compared to the reference value) was recorded in minutes and seconds using a stopwatch.

To ensure proper administration and accurate ratings of perceived exertion, it was vital for the subjects to understand the concept of perceived exertion and the range of sensations that corresponds to the Borg scale (Birk & Birk, 1987; Noble & Robertson, 1996). Subjects were shown a copy of the Borg scale during tests. The following instructions which were modified from Morgan (1981) and Noble and Robertson (1996) were used:

> *" When you begin doing your task, try to estimate how hard you feel the work is; that is, rate the degree of perceived exertion you feel. Think of perceived exertion as the total amount of exertion and physical fatigue, combining all sensations and feelings of physical stress, effort and fatigue. When rating how the whole body is feeling while working, don't concern yourself with any one factor such as muscle pain or shortness of breath, simply try to concentrate on your, total, inner feeling of exertion. Try to estimate as honestly and objectively as possible. Don't underestimate or overestimate the degree of exertion you feel. The scale we used here will range from a score 6 to a score 20. You should imagine each number from 6 through 20 represents a category of sensation ordered according to intensity. A rating of 7 means lowest exertion imaginable when you are working while the rating of 19 is reserved for feelings of maximum effort imaginable. As you shall see, there are ratings of 6 and 20 left. Score 6 should be assigned to any feelings of exertion that are less than those experienced while working at extremely low intensity and score 20 should be assigned to any feelings of exertion that are greater than those experienced during the extremely high intensity. When a response is requested, you should provide a number from the*

*scale by nodding your head when we point to that number."*

Questions regarding the use of Borg scale were addressed first before the administration of work tasks.

In order to simulate the real working world where workers are often taking rest breaks between work-times, subjects were asked to repeat the task for one more trial using the same procedures. Each subject was allowed a sufficient rest period so that the HR returned to the resting level (± 5 bpm) before starting the second trial. The work-time for each trial and the resting time were recorded.

During the tests, physiological measurements including HR and $\dot{V}O_2$ were monitored according to the procedures described above. The data were taken at four minutes when a steady state condition was reached. In addition, $\dot{V}O_2$ and HR measured for the real and simulated work tasks were also expressed as a percentage of p$\dot{V}O_2$ and pHR using the peak values obtained in the incremental arm cranking test. The MET value of each task was calculated by dividing the relative $\dot{V}O_2$ (mL.kg$^{-1}$.min$^{-1}$) by 3.5 mL.kg$^{-1}$.min$^{-1}$ to indicate the energy cost of the task as a ratio of the resting energy cost (McArdle et al., 1996). The GEC (kcal.min$^{-1}$) of the work tasks was computed by multiplying the absolute $\dot{V}O_2$ (L.min$^{-1}$) and the thermal equivalents of oxygen (kcal/L$O_2$) using the non-protein respiratory exchange ratio ( McArdle et al., 1996, p.147). The NEC was calculated by subtracting the resting energy cost (while standing) from the GEC during the work tasks.

The test administrator responsible for collecting data in this study was a trained occupational therapist whose professional background and knowledge of activity analysis, work physiology and medical conditions enabled accurate ratings to be made. As this study mainly involved measurement of time and physiological variables, biases that might occur as a result of rater's subjective perception were not expected here. The use of automated electronic devices including arm crank ergometer, metabolic cart and heart rate monitor, has enhanced the precision of measurement of the physiological variables. As well, the definition of endurance and the criterion used to define fatigue were specified to ensure the consistency of time measurements. Thus, the only concern was possible subject bias due to the personal desirability towards anyone of the applied conditions (real or simulated). To decrease this bias, subjects were given a chance to get familiar with the work tasks before the tests, and the order of the work tasks was randomized.

### C. Statistical analysis

Descriptive statistics (means, standard deviations and ranges) for the endurance time and physiological variables were computed. Two-way ANOVAs with repeated measures were used to examine any differences in the means between the two trials and tasks (real and simulated) for the time and physiological variables. Significant 'F' ratios were examined to look at possible main effects and interaction. Because of the number of univariate analyses performed, the issue of significant multiple comparisons which could occur due to chance alone was considered. Therefore, the Bonferroni adjustment was made by dividing the alpha level by the number of comparisons (Ottenbacher, 1991). In order to establish validity, Pearson product-moment correlations were used to study the relationship between the real and simulated tasks for selected variables. Stepwise regression analysis was run to examine the prediction of endurance in the real work task from the endurance measured by the BTE work simulator. In this analysis, average endurance time from the two trials of the real task was entered as dependent variable, while average endurance time of the simulated task, BMI and resting HR were entered as independent variables. Results were considered to be significant at an alpha level of $p<.05$. All statistical analysis were performed using the SPSS computer package.

In this study, the power was set at the minimum acceptable value of .80. Based on the results of a previous study (Kennedy & Bhambhani, 1991), we were interested in finding a minimal correlation between the real and simulated tasks of .65, therefore, a manageable sample size of 20 was required at a significance level of .05.

### D. Ethical considerations

Each subject was informed that this study was being conducted by a graduate student at the University of Alberta. They were provided with an overview of study purposes, the procedures to be undertaken in this study, and the information about any known risks and benefits that they may expect from participation. As this study involved stressing the subject's physical ability to tolerate a work task, a consent was required and signed voluntarily. Questions concerning subject's previous medical conditions such as history of back pain, chest pain etc. were asked before participation. Subjects were also required to complete a Physical Activity Readiness Questionnaire to screen for any risk for exercising. As well, proper body mechanics on lifting were demonstrated to prevent any possible back injury due to poor postures. The test administrator was qualified to perform CPR if complications occurred during exercise. The procedures undertaken in this study were approved by the Human Ethics Review Committee (Panel B) at the University of Alberta. Statements acknowledging that subjects could withdraw from the study at any time without prejudice and guaranteeing their confidentiality were also included in the information sheet.

# CHAPTER V
# RESULTS

## A. Characteristics of subjects

A majority of the subjects came from a similar background being students at the University of Alberta. Twenty percent of the subjects had a sedentary lifestyle, with no regular physical activities per week. The rest were actively involved in sport or physical activities such as jogging, swimming, basketball, karate, golf and weight-training. The duration of exercise participation by subjects varied and it ranged from one to fifteen hours per week. Two subjects were constantly involved in physical activities (> 15 hours) because of their part-time jobs as a nursing assistant and grocery store keeper.

Descriptive statistics for the subjects are reported in Table 1. During the incremental arm cranking tests, sixty percent of the subjects reached an RPE of 18 on the Borg Scale, and the peak RER values of ninety percent of the subjects were greater than 1.10. These observations suggest that subjects had performed at maximal efforts during the tests. However, none of the subjects had reached their age-predicted maximal HR during these tests.

Table 1 : Physical characteristics and peak physiological responses of subjects during arm cranking.

| Variables | Mean | Standard deviation | Minimum | Maximum |
|---|---|---|---|---|
| age (yr.) | 25.4 | 6.1 | 18 | 37 |
| height (m) | 1.73 | .06 | 1.58 | 1.79 |
| weight (kg) | 69.9 | 9.8 | 50.0 | 88.3 |
| BMI ($kgm^{-2}$) | 23.40 | 3.03 | 19.03 | 30.20 |
| resting HR (bpm) | 77.5 | 10.4 | 52 | 90 |
| $p\dot{V}O_2$ ($L.min^{-1}$) | 1.54 | .31 | 1.02 | 2.19 |
| $p\dot{V}O_2$ ($mL.kg^{-1}.min^{-1}$) | 22.2 | 3.9 | 14.5 | 28.2 |
| pHR (bpm) | 171.6 | 12.8 | 152 | 194 |
| peak $\dot{V}_E$ ($L.min^{-1}$) | 71.3 | 17.1 | 45.2 | 115.1 |
| peak $O_2$ pulse (mL/beat) | 9.0 | 1.9 | 5.7 | 13.7 |
| peak RER | 1.25 | .14 | 1.00 | 1.59 |
| peak RPE | 18.1 | 1.5 | 16 | 20 |

**B. Criterion validity of the BTE work simulator in the measurement of endurance**

Comparisons of endurance, RPE and rest-time during real and simulated lifting at trials one and two are shown in Table 2. There were significant differences ($p < .05$) in the endurance performance and perceived exertion between the real and simulated tasks. Yet no significant difference was found between trial one and trial two within the same task. When compared to the simulated task, subjects performed the real task for a shorter duration and they perceived it as being significantly harder. It is also interesting to note that the rest time between the two trials was significantly longer for the real task than for the simulated task.

Table 2 : Comparisons of endurance, RPE and rest-time during real and simulated lifting at trials one and two.

| Variables | Real lifting | | Simulated lifting | |
|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 1 | Trial 2 |
| endurance* min. | 6.34 (1.44) | 5.85 (1.57) | 8.30 (2.46) | 8.26 (3.85) |
| RPE* | 13.30 (2.68) | 13.30 (3.03) | 10.15 (1.98) | 9.90 (1.89) |
| rest-time* min. | 24.15 (14.06) | | 19.30 (8.14) | |

Note: mean (s.d.)
* significant difference between real and simulated lifting for each trial
no significant difference between trials 1 and 2 within the same task

The correlation matrix for endurance between the real and simulated lifting at trials one and two are presented in Table 3. After the endurance time was averaged between trial one and trial two, a significant correlation ($r = .706$, $p < .05$) was found between the real and simulated tasks. This indicated that subjects with longer endurance during the real task were more likely to demonstrate a longer endurance during the simulated task.

Table 3 : Correlation matrix of endurance between the real and simulated lifting during trials one and two.

| | MR-time | MS-time | R-time-1 | R-time-2 | S-time-1 | S-time-2 |
|---|---|---|---|---|---|---|
| MR-time | 1.00 | .706* | .897* | .915* | .571* | .675* |
| MS-time | | 1.00 | .762* | .526* | .838* | .937* |
| R-time-1 | | | 1.00 | .642* | .507* | .799* |
| R-time-2 | | | | 1.00 | .525* | .440 |
| S-time-1 | | | | | 1.00 | .595* |
| S-time-2 | | | | | | 1.00 |

Note: MR-time = average time of trials 1 and 2 in real lifting
MS-time = average time of trials 1 and 2 in simulated lifting
* significant correlation at alpha level = .05

Results of the 2-way ANOVAs repeated measures (tasks by trials) indicated no significant interaction between tasks and trials for any of the variables examined. The F-ratios and P-values are presented in Table 4. The lack of interaction implies that for both real and simulated tasks, the trend observed in the two trials was the same for each task. Examination of the main effects of tasks indicated significant differences for endurance, $\dot{V}O_2$, HR, %p$\dot{V}O_2$, %pHR, MET, GEC and NEC, but not for the RER, $O_2$ pulse and $\dot{V}_E/\dot{V}O_2$. The mean values of steady state physiological responses are presented in Table 5. In general, the mean values were higher during the real task by 6 to 29% when compared to the simulated task. Except the $\dot{V}_E/\dot{V}O_2$ which denotes efficiency of ventilation as related to metabolism, it showed a lower value during the real task by 4%. Examination of the main effects for trials indicated no significant differences for any of these variables, implying that there was no significant difference in the means between trials for the real and simulated tasks.

Table 4 : F-ratios and P-values for time and physiological variables showing the main effects and interaction using the 2-way ANOVAs (tasks by trials).

| Variables | Task | Trial | Task X Trial |
|---|---|---|---|
| endurance | ***21.52*** ***(.000)*** | .80 (.383) | .26 (.615) |
| $\dot{V}O_2$ | ***25.01*** ***(.000)*** | .22 (.645) | 2.12 (.162) |
| HR | ***93.99*** ***(.000)*** | 9.10 (.007) | 5.07 (.036) |
| $\dot{V}_E$ | ***40.38*** ***(.000)*** | .15 (.702) | 4.05 (.059) |
| RER | 10.00 (.005) | 2.12 (.162) | .84 (.371) |
| $O_2$ pulse | 2.21 (.154) | 4.04 (.059) | .57 (.459) |
| $\dot{V}_E/\dot{V}O_2$ | .13 (.727) | .65 (.431) | 3.38 (.082) |
| %p$\dot{V}O_2$ | ***24.57*** ***(.000)*** | .08 (.780) | 2.42 (.137) |
| %pHR | ***93.34*** ***(.000)*** | 9.01 (.007) | 2.88 (.106) |
| MET | ***24.38*** ***(.000)*** | .36 (.554) | 2.46 (.133) |
| GEC | ***30.50*** ***(.000)*** | .63 (.437) | 1.78 (.198) |
| NEC | ***39.9*** ***(.000)*** | .42 (.527) | 2.22 (.153) |

Note: F-ratio (p-value)
bold numbers indicated a significant effect at $p < .05$ level after the Bonferroni adjustment

Table 5 : Comparisons of steady state physiological responses during real and simulated lifting at trials one and two.

| Variables | Real lifting | | Simulated lifting | |
|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 1 | Trial 2 |
| absolute $\dot{V}O_2$* $L.min^{-1}$ | 1.38 (.24) | 1.40 (.20) | 1.07 (.27) | 1.10 (.27) |
| relative$\dot{V}O_2$* $mL.kg^{-1}.min^{-1}$ | 20.0 (3.7) | 20.3 (3.4) | 15.7 (3.1) | 15.2 (2.9) |
| HR* bpm | 138.4 (13.3) | 142.6 (13.2) | 117.5 (11.9) | 118.4 (10.3) |
| $\dot{V}_E$* $L.min^{-1}$ | 43.3 (8.2) | 45.5 (9.3) | 34.6 (5.6) | 33.1 (5.1) |
| $O_2$ pulse | 10.1 (1.9) | 9.9 (1.6) | 9.5 (2.4) | 9.1 (2.6) |
| RER | .97 (.08) | .95 (.12) | .91 (.10) | .88 (.08) |
| %pHR* | 81.0 (8.8) | 83.2 (8.9) | 68.8 (8.3) | 69.5 (7.8) |
| %p$\dot{V}O_2$* | 91.7 (18.8) | 93.7 (20.8) | 73.2 (20.4) | 70.3 (19.5) |
| $\dot{V}_E/\dot{V}O_2$ | 31.7 (6.2) | 32.8 (6.6) | 33.1 (10.8) | 33.3 (10.2) |

Note: mean (s.d.)
* significant difference between real and simulated lifting for each trial
no significant difference between trials 1 and 2 within the same task

Correlation coefficients of oxygen uptake and heart rate between the real and simulated tasks are presented in Table 6. There was a moderate correlation of heart rate between the real and simulated tasks at trial one and trial two. Yet the correlations were lower for absolute oxygen uptake, and almost no correlation was found when the values were adjusted for body weight. As heart rate is linearly related to oxygen uptake (McArdle et al., 1996), the inconsistency in these observations led to a closer examination of the raw data. Upon re-examination, it was found that due to a technical problem with the metabolic cart, the $\dot{V}O_2$ values of two cases were inaccurate because the fractions of oxygen and carbon dioxide in the expired air were outside the physiological range during the real task. After exclusion of these two cases, the correlation coefficients of absolute $\dot{V}O_2$ between the real and simulated lifting at trial one and trial two were .556 and .704 respectively. For relative $\dot{V}O_2$, they were .481 and .601 ( See Appendix M for raw data). The new correlation coefficients demonstrated a significantly modest relationship between the real and simulated tasks. Scatterplots of oxygen uptake and heart rate at trials one and two are shown in figures 1, 2, 3 and 4 respectively to demonstrate these relationships.

Table 6 : Correlation coefficients of oxygen uptake and heart rate between the real and simulated lifting during trials one and two (n = 20).

| Variables | Real - simulated lifting | |
|---|---|---|
| | trial 1 | trial 2 |
| absolute $\dot{V}O_2$ | .316 | .412 |
| relative $\dot{V}O_2$ | .082 | .129 |
| HR | .627* | .600* |

Note: *significant correlation at alpha level = .05

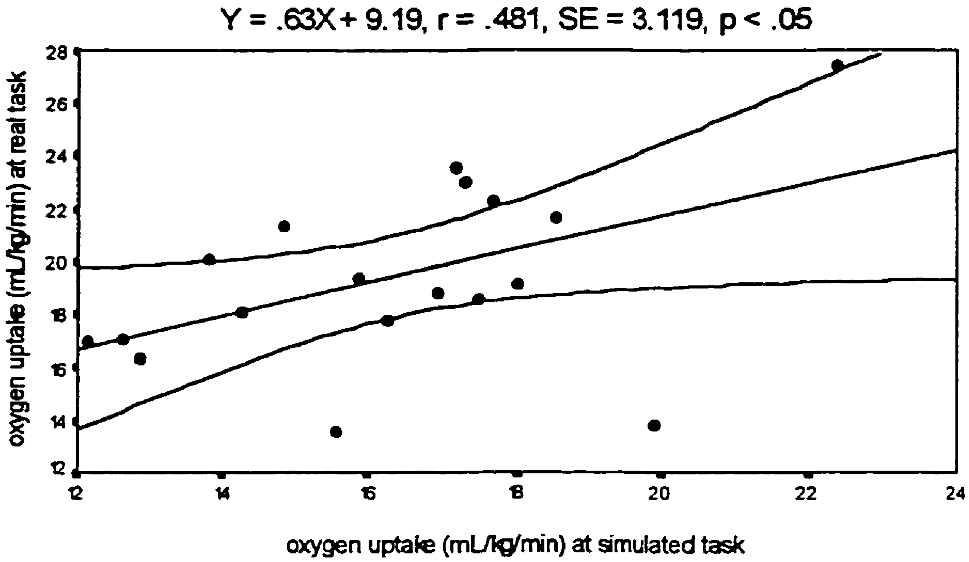


Fig. 1 : Scatterplot showing the relationship of oxygen uptake between the real and simulated lifting during trial one (n = 18).

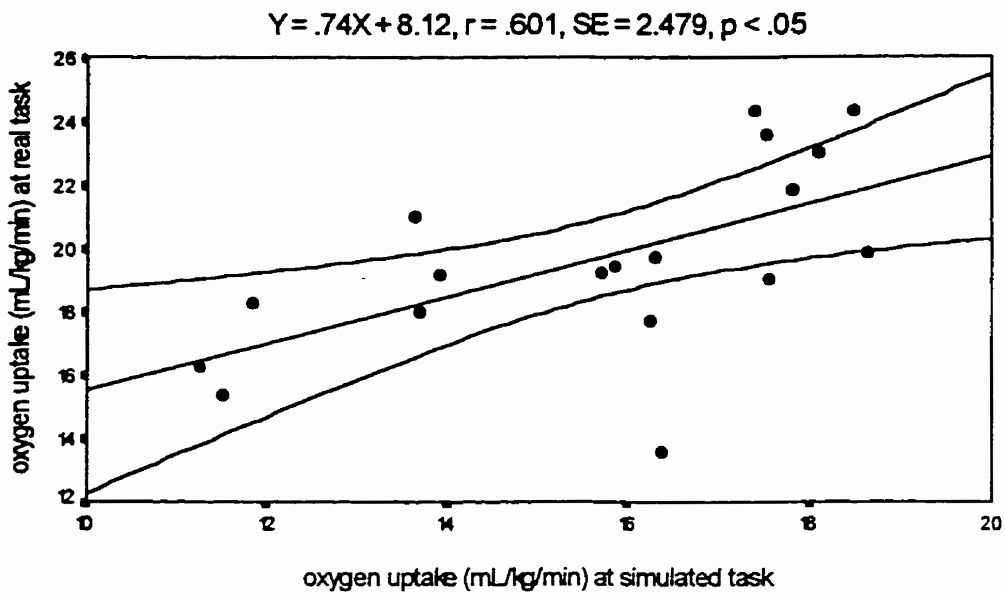


Fig. 2 : Scatterplot showing the relationship of oxygen uptake between the real and simulated lifting during trial two (n = 18).

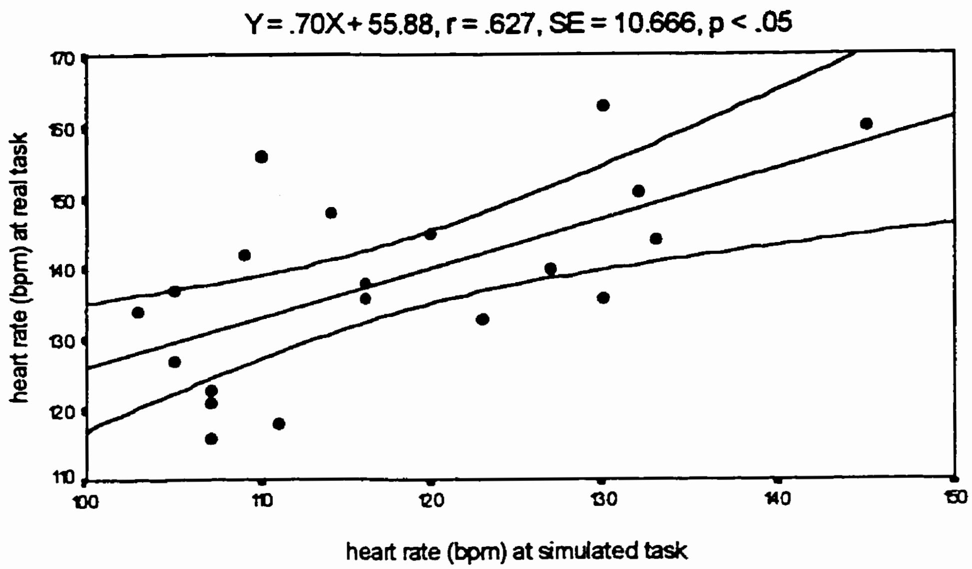


Fig. 3 : Scatterplot showing the relationship of heart rate between the real and simulated lifting during trial one (n = 20).

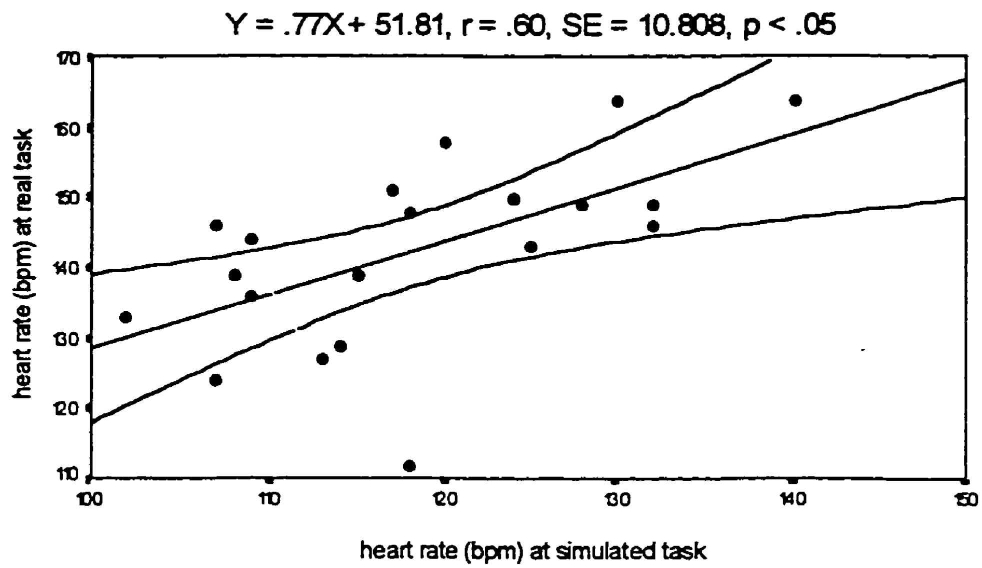


Fig. 4 : Scatterplot showing the relationship of heart rate between the real and simulated lifting during trial two (n = 20).

**C. Energy requirements of the real and simulated lifting**

Comparisons of energy expenditure during the real and simulated lifting at trials one and two are shown in Table 7. The energy expenditure of the real task was significantly higher than the BTE simulated task. However, there was no significant difference between trials one and two within the same task. Boxplots of relative oxygen uptake and net energy expenditure during the real and simulated tasks at trials one and two are presented in Fig. 5 and 6 respectively.

Table 7 : Comparisons of energy expenditure during real and simulated lifting at trials one and two.

| Variables | Real lifting | | Simulated lifting | |
|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 1 | Trial 2 |
| GEC* $kcal.min^{-1}$ | 6.95 (.99) | 6.89 (1.19) | 5.43 (1.36) | 5.21 (1.32) |
| NEC* $kcal.min^{-1}$ | 5.51 (.98) | 5.60 (.82) | 4.12 (1.01) | 3.90 (1.00) |
| MET* | 5.72 (1.06) | 5.80 (.97) | 4.52 (.93) | 4.33 (.82) |

Note: mean (s.d.)
* significant difference between real and simulated lifting for each trial
no significant difference between trials 1 and 2 within the same task

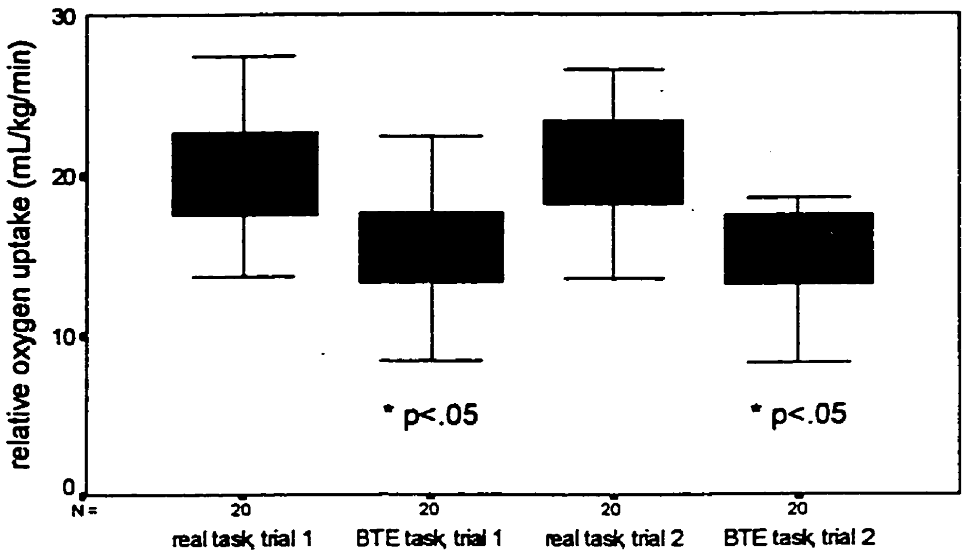


Fig. 5 : Boxplot showing relative oxygen uptake between the real and simulated lifting during trials one and two.

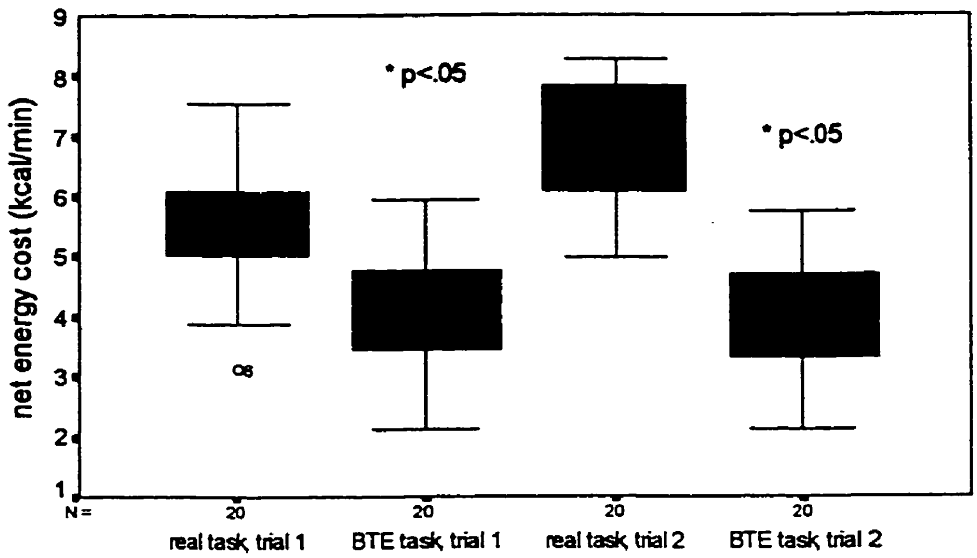


Fig. 6 : Boxplot showing net energy expenditure between the real and simulated lifting during trials one and two.

**D. Prediction of endurance performance in real lifting from measurements on the BTE work simulator**

The relationship of endurance time between the real and simulated tasks is presented in figure 7. Three independent variables (S-time, BMI and resting HR) were entered into the stepwise regression analysis procedure. Only endurance time in the simulated task (S-time) was selected into the regression model to predict endurance performance during the real task (R-time). The regression equation developed is given below (See Appendix L for stepwise output) :

$$\text{predicted R-time} = .339\ (\text{S-time}) + 3.286;\ r = .706;\ SE = .991\ \text{min.}$$

It is evident from this equation that: (a) For one standard deviation increase in S-time, the R-time would increase on average by .706 of a standard deviation, and (b) about 50% of variance in R-time was explained by the S-time, leaving the remaining 50 % unexplained.

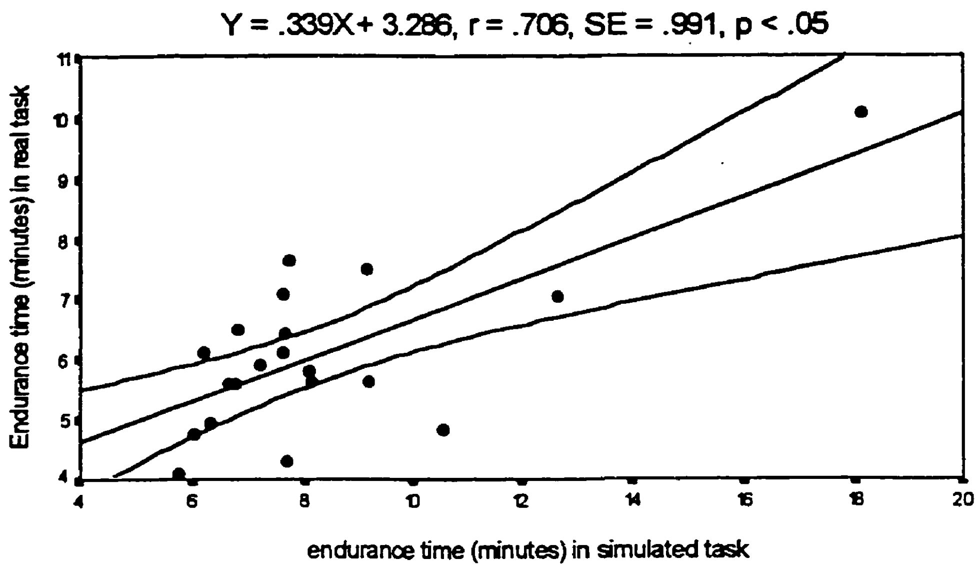


Fig. 7 : Scatterplot showing the relationship of average endurance time between the real and simulated tasks

# CHAPTER VI
# DISCUSSION

## A. Characteristics of subjects

It is obvious that there was a great variation in the peak physiological responses to incremental arm cranking among the subjects who participated in this study. The $pVO_2$ ranged from 14.50 to 28.16 $mL.kg^{-1}.min^{-1}$ and the pHR ranged from 152 to 194 bpm. Comparison of subjects' characteristics with other studies is presented in Table 8. When compared to the male subjects with similar age and background, the mean value of 22.2 $mL.kg^{-1}.min^{-1}$ was below the mean values reported by Kennedy and Bhambhani (1991) and Bhambhani et al. (1994). However, it was still within the range of values from various studies reviewed by Sawka (1986). It is speculated that the lower mean values in this study were either due to the lower physical fitness of the study subjects or the use of the Cybex upper body exerciser. The arm cranking was performed at shoulder level with a greater arm elevation and abduction. Many subjects reported that the termination of arm cranking was due to shoulder and upper arm muscular fatigue rather than the cardiorespiratory stress. For heart rate, the mean peak value obtained in this study was comparable to that reported by Kennedy and Bhambhani (1991) and Bhambhani et al. (1994). It was also within the range of values reported by Sawka (1986). The BMIs of subjects participating in this study ranged from 19.3 to 30.2. The mean value of 23.4 was within the range of lowest health-risk category (BMI: 20 to 25) as reported by McArdle et al.(1996).

Table 8 : Comparisons of peak physiological responses with other studies using arm ergometry in males

| Investigators | present study* | Kennedy and Bhambhani (1991) | Bhambhani et al. (1994) |
|---|---|---|---|
| number of subjects | 20 | 30 | 20 |
| age (years) | 25.4 ± 6.08 (18 - 37) | 28.6 ± 2.80 (19 - 35) | 24.8 ± 5.40 (18 - 39) |
| $p\dot{V}O_2$ ($L.min^{-1}$) | 1.54 ± .31 (1.02 - 2.19) | 2.33 ± .57 (1.17 - 3.4) | 2.38 ± .42 (1.12 - 3.07) |
| $p\dot{V}O_2$ ($mL.kg^{-1}.min^{-1}$) | 22.2 ± 3.86 (14.50 - 28.16) | 31.1 ± 7.0 (17.8 - 47.6) | 31.6 ± 4.7 (23.4 - 41.0) |
| pHR (bpm) | 172 ± 12.83 (152 - 194) | 167 ± 15 (141 - 187) | 184 ± 8.6 (164 - 197) |

Note: Mean ± s.d. ( range)

* The present study used the Cybex upper body exerciser (Model MET 500) while the other two studies used the Monark rehab trainer (Model 881)

**B. Differences between the real and simulated tasks across trials**

Endurance should be considered in functional capacity evaluations if the jobs demand a high degree of repetitive efforts over a continuous period of time. The present study demonstrated that when the BTE work simulator was used in the evaluation of endurance performance during the floor to bench lifting, there was a significant difference in timed measurements between the real and simulated tasks (See table 2). Endurance measured on the BTE work simulator was significantly higher than that of the real task. As well, the RPE at steady state was lower and a shorter recovery time was required between the two trials. Given that both tasks were carried out in a constant environment, using the same postures, location and weight of lifts as well as a controlled work pace, it is postulated that the difference may due to the failure of the BTE work simulator to duplicate metabolic and cardiovascular demands required by the real task.

The above speculation was further substantiated by the differences in the steady state physiological responses during the real and simulated tasks. Oxygen consumption and working heart rate of the real task were significantly higher than that of the simulated task. When these values were expressed as percentages of $p\dot{V}O_2$ and pHR, they were significantly higher during the real task when compared to the simulated task (See tables 4 and 7). During the performance of a work task, especially if it involves moderate to strenuous exertion, physiological changes take place in the body. Measurement of these changes provides indices of the level of stress imposed upon a person (Garg, Rodgers, & Yates, 1992). Therefore, the study results indicated that stresses or demands of the BTE simulated task were lower when compared to the real task.

The lifting and lowering of a load from the floor to bench were a combination of static and dynamic efforts. The demand for oxygen while lifting is most likely due to the dynamic work involved, and a comparatively smaller portion can be attributed to the static work. As the load of 40 lbs. was lifted repetitively up and down for the same vertical distance, it appeared that the lifting and lowering on the BTE work simulator were facilitated by the design of the rope and pulley system. The dynamic effort of the simulated task was most likely lowered, leading to a reduction in oxygen consumption.

Static work is more fatiguing than dynamic work (Garg et al., 1992; Grandjean, 1988). During static effort, blood vessels to the muscular tissues are compressed and the blood flow is reduced at intensities exceeding 15% of the maximum voluntary contraction (Garg et al. 1992). Supply of oxygen and substrates cannot meet the muscular demand resulting in the accumulation of lactic acid and other metabolites. This eventually leads to localized fatigue. Grandjean (1988) reported that under similar conditions, static muscular effort will lead to higher energy consumption, raised heart rate and longer rest periods when compared to dynamic work. Therefore, the reduced amount of static work in the BTE-simulated task could have explained the increased endurance time, lowered perceived exertion, shorter rest period between trials, decreased oxygen consumption and working heart rate and the expense of fewer calories per unit time when compared to the real lifting task.

Another possible explanation for the difference between real and simulated tasks was the subjects somehow found alternative strategies to relieve fatiguing muscles and change their lifting mechanics. Few subjects had mentioned that they found the BTE-simulated task easier because they could use their knees to help their performance. Wheeler, Graves, Miller, O'Connor and MacMillan (1994) pointed out that the weak link in the biomechanical system while lifting is usually related to the lumbar extensor musculature, yet it may not be true for all people. The gluteal muscles, hamstrings, arm and shoulder muscles are also important. When a heavier load is lifted, the lifting mechanics can change to protect the lumbar musculature (Rodgers, 1992; Wheeler et al., 1994). It was therefore possible that the trunk, arm and shoulder muscle strength were critical in determining endurance performance in the real task while in the simulated task, subjects might have developed some ways to minimize muscular efforts because of the set-up of the BTE work simulator.

In this study, a lower rating of perceived exertion was observed in the simulated task when compared to the real task. One possible explanation was due to the difference in "purposefulness" between the two tasks. Purposeful activities refer to tasks that are goal directed and meaningful with focusing attention to an object or outcome (King, 1978). For the simulated task using attachment #191 on the BTE work simulator, the repetitive lifting and lowering actions performed on the resistance head had created a monotonous motion assisted by the rope and pulley design. No purposeful outcome was identified by the subjects and this resulted in lowered perceived exertion. However, it is interesting to note that non-purposeful activity with a lower perceived exertion can lead to boredom. Earlier fatigue may occur because of the low stimulation (Kircher, 1984; Grandjean, 1988). Although the simulated task was relatively non-purposeful in this study, the endurance time obtained was significantly longer than the real task suggesting that earlier fatigue due to boredom did not occur. Therefore, it is speculated that the heavy physical demand of using a workload of 40 lbs. may have reduced the psychological influence on the subjects while performing the tasks.

The results of this study were comparable to those of Kennedy and Bhambhani (1991). They demonstrated that subjects had significantly lower $\dot{V}O_2$ and HR values while performing at the heavy work intensity on the BTE work simulator when compared to the criterion tasks. These differences were explained by the restricted movement patterns of the simulated tasks, which may have minimized extraneous postural adjustments and reduced the overall workload for subjects. These results are also consistent with the findings of Wilke et al. (1993) who concluded that there was a tendency for the BTE work simulator to underestimate the energy requirements of various activities after the study of 14 functional tasks. The authors reasoned that it may due to the stationary location of the worksite, an inability to duplicate the multiple integrated task components on the BTE work simulator and the individual variation in the determination of force level. To enhance duplication, they encouraged factors pertaining to reproduce body positioning, muscular action and work pace of an activity. It should be noted that in the present study, only lifting was examined. Since the postures, location and pace of lifts were controlled such that the simulation was as close as possible, the evidence therefore suggested that in lifting, the differences observed may due to the inherent insufficiency of the BTE work simulator to duplicate the actual work required. It is also possible that a change in lifting mechanics may have occurred within the person while performing the lifts. Caution is therefore required when interpreting the results from the BTE work simulator, especially if performance over time is of concern.

The study results also indicated that in general, there was no significant difference for the endurance performance and physiological responses between trials one and two within the same task. One possible explanation for this is that the subjects were allowed sufficient time to recover from the fatiguing task. This is further supported by the fact that the rest-time was much longer than the time spent in performing the real and simulated tasks (See table 2). As the subjects performed at about 90% and 70% of their arm cranking peak aerobic capacity during the real and simulated tasks respectively, it is thought that fatigue was possible if a rest period was not allowed. This would eventually affect the duration for which the subjects could sustain the tasks. These results imply that therapists who plan to evaluate endurance performance in functional capacity evaluation, the amount of rest being given to the individual during evaluation may influence the performance. Unfortunately, no data is available to date to justify how much rest should be given to allow a safe assessment without losing the validity. On the one hand, it is important to relate the actual job demands such as the continuous performance of a fatiguing task, to the evaluation of worker's capacity. On the other hand, safety is an issue to avoid placing unnecessary harm on clients during the procedures. Sound clinical judgement relying on the therapist's knowledge, experience and observation, as well as the client's feedback are therefore important.

**C. Criterion validity of the BTE work simulator in the measurement of endurance**

The results of this study showed that correlations of endurance time were significant between the real and simulated tasks and between the two trials for each of the tasks (See table 3). The moderate correlations between the two trials ($r = .642$ for real task; $r = .595$ for simulated task) also indicated an acceptable reliability for the measurement. The only exception was the non-significant correlation between the real and simulated task at trial two. This may be explained by the fact that after the first trial, subjects somehow found the BTE-simulated task less heavy than expected and they developed "ways" to make the task less fatiguing. They may have learnt to use the rope and pulley system on the BTE work simulator to help the lifting and lowering. This is also reflected by the lower RPE values in the simulated task at trial two. It should be noted that although a difference was found in endurance time between the real and simulated task, their significant correlation suggested that their time varies in a consistent manner.

As shown by the scatterplot indicating the relationship of average values of endurance between the real and simulated tasks (See figure 7), most subjects performed the repetitive lifts at a constant pace for a duration of 4 to 8 minutes. It is speculated that subjects who had continued for a longer period, might have a greater strength and endurance of the muscle groups used during the lifting tasks. It is also possible that they could have used different strategies to conserve energy during the two types of lifting. The results of this study are therefore only applicable to healthy male with similar characteristics. It is recommended that further research be conducted to examine the relationship between lifting endurance and physiological variables pertinent to lifting in the occupational and clinical settings.

Similar to the endurance time, the correlations of physiological responses were significant between the real and simulated tasks at trials one and two. Once again, these correlations suggested that even though there was a difference between the real and simulated tasks, they vary in a consistent manner. As mentioned before, due to a technical problem with the metabolic cart, two sets of data were excluded in the calculation of correlation for oxygen uptake. Since only the time variable, resting HR and BMI were used in the prediction of endurance performance in real task, it is expected that this technical problem would not affect the regression model discussed in the next section. Besides, correlation of endurance between the real and simulated tasks was the highest ($r = .706$) among the three variables: endurance, $\dot{V}O_2$ and HR.

**D. Prediction of endurance performance in real lifting from measurements on the BTE work simulator**

Ideally, functional capacity evaluations conducted in the workplace should produce valid information about worker's performance, yet it is not often feasible because of both practical and safety concerns. The prediction equation developed in this study allows therapists to estimate endurance performance for healthy males in real lifting (R-time) based on measurement by the BTE work simulator (S-time). Although the equation can only be applied to the specific lifting task (symmetrical, squat lifts from the floor to bench for a vertical distance of 30 inches, box bilaterally handled) used in this study, it is still a common functional activity in the work settings. The $r^2$ value of .499 indicated that about 50 % of variance in R-time was explained by the S-time. The remaining 50 % of variance may be explained by other factors such as age, motivation, change in lifting mechanics, perceived exertion, fear of injury, cardiovascular fitness, muscle strength and previous training or experiences.

The most likely reason for the modest correlation was that the data of the subjects were quite homogenous. Examination of the scatterplot (see figure 7) revealed that with the exception of two subjects, the remaining data points were within a fairly narrow range. Had there been greater variability in these data, the correlation between the real and simulated endurance time would have been stronger, thereby resulting in a better prediction. In addition, the criterion used to define fatigue as an increased RPE by 2 units may have influenced the correlation. It is thought that if subjects were allowed to lift to the point of "very very hard" work (ie. a rating of 19) on the Borg scale, the difference in physiological demands between the real and simulated tasks might become more prominent as the lifting duration increased. A greater variability of subject's endurance performance would result, thereby leading to a higher correlation.

Due to the narrow age range of study subjects, age was not considered initially as an independent variable for the prediction of endurance in real task. Yet it was found that age was somewhat related to the R-time ( $r = .385$, $p = .094$). Therefore, it is speculated that if a wider age range was used in the study, age might become the next independent variable entering the regression model to predict lifting performance in a real task. Further research is necessary to investigate this hypothesis.

One consideration when using this prediction equation is that both real and simulated tasks were carried out at a constant pace throughout the study. It may be different in the occupational settings if self-pacing of work is allowed. Under such conditions, workers can slow down to relieve the fatiguing muscles or the cardiorespiratory stress. The energy requirement of the tasks may reduce leading to a lower perceived exertion. Therefore, workers are able to work longer in the tasks. As such, it is recommended that therapists should assess the job demands before using this equation. If self-pacing of work is allowed, there is a possibility that the prediction will underestimate the actual endurance performance in the real job environment.

Finally, the study results indicated that use of the BTE work simulator for evaluation purpose may run the risk of overestimating endurance performance. Although a prediction equation was developed to adjust for the difference between the real and simulated tasks, its application is still quite restricted. Therefore, caution is required by therapists if using the results measured on the simulator alone. Additional measures relating to the job requirements may still be required. The BTE work simulator appears to be more appropriate for training use such as in work hardening and in cardiovascular rehabilitation. It provides a method of simulating various work activities within a protective environment. However, failure of the BTE work simulator to duplicate the physical and cardiovascular demands questions its validity as an evaluative device.

### E. Study limitations

The results of this study suggested that the nature and design of the BTE work simulator may have caused the differences between real and simulated lifting. A prediction equation was therefore developed to objectively estimate actual endurance based on measurement by the BTE work simulator. As mentioned before, this equation is only applicable to healthy male subjects with similar characteristics. It is also limited to individuals who are co-operative, motivated and willing to exert themselves. Besides, it applies only to the specific lifting task used in this study. As functional capacities demand more than the ability to lift longer or heavier loads, performance measurement relevant to the job demands should also be included. No one assessment can provide all the answers concerning work injury and return to work (King et al., 1998).

Another limitation is that the definition of real task in this study referred only to the use of actual equipment. The entire procedures were carried out in a laboratory setting. In the real world where the actual tasks are performed, external factors such as temperature, humidity, dimension of tools handled, set-up of a workplace and job stress etc. may vary and influence the work performance. Job analysis is therefore strongly recommended to increase understanding of job requirements and should be used in the final return-to-work decision making. It is also important to note that since differences were already found in the present study, a larger difference between the real and simulated tasks was expected if the procedures were repeated in the actual work settings.

Although this study developed a prediction equation to improve the use of the BTE work simulator in measurement of endurance during lifting, it is still far from being able to project performance to an 8-hour working day. More work has to be done to relate endurance performance in the BTE work simulator to the ability for an 8-hour work shift. It would be desirable if the endurance performance over a workday can be inferred from measures on the BTE work simulator using a shorter time but higher exercise intensity.

# CHAPTER VII
# CONCLUSION

Given the high equipment cost and the need to develop an objective and accurate measurement, validity testing is essential for the BTE work simulator to show that it is useful and precise in functional capacity evaluations. On the basis of the results of this study, it was concluded that:

1. Measurement of endurance by the BTE work simulator was significantly higher than the actual performance in real lifting.
2. Significant differences were also found in the steady state physiological responses between the real and simulated tasks. Caution is therefore required when using the results to decide worker's capacities.
3. Endurance time during the real lifting task could be predicted by the equation : *predicted R-time = .339 (S-time) + 3.286; r = .706; SE = .991 min.* Yet this equation is limited to the specific lifting task used in the present study and applied only to subjects with similar characteristics.
4. Correlation between the real and simulated tasks for HR were .627 and .600 during trials one and two respectively. For absolute $\dot{V}O_2$, they were .556 and .704. For relative $\dot{V}O_2$, they were .481 and .601.

Further research is needed to see if the results can be used on different populations such as older workers, female or persons with injuries. Simulations of other occupational tasks using different attachments should also be studied. Use of the BTE work simulator allows a safer evaluation of functional capacity within a clinical setting, however, there is still a great deal of work to be done to establish its validity.

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## Appendix A

## Sample size calculation

This sample size calculation was based on the study conducted by Kennedy and Bhambhani (1991) in which they determined the criterion validity between the real and simulated work tasks at three different intensities by physiological measures. Correlation for oxygen consumption and HR between the criterion and simulated tasks at heavy intensity were found to be .68 to .90 in their study. Therefore, we expected a minimal correlation of .65 between the real and simulated tasks. Formula used in this calculation were taken from the text written by Cohen and Cohen (1983, p.117).

$$f^2 = \frac{R^2}{1 - R^2} = \frac{(.65)^2}{1 - (.65)^2} = .732$$

where $R$ = minimal correlation expected
$f^2$ = population effect size

Substituting $f^2$ and the L value in the following formula:

$$n = \frac{L}{f^2} + k + 1 = \frac{10.90}{.732} + 3 + 1 = 18.89$$

where $n$ = number of cases necessary
$f^2$ = population effect size
$k$ = number of independent variables

At alpha level = .05, power = .80 and k = 3, the L value is 10.90 from the appropriate table (Cohen & Cohen, 1983, p.527). Therefore, the necessary number of cases required in the study was 19 subjects. A sample size of 20 subjects was used.

Reference:

Cohen, J., & Cohen, P.(1983). Applied multiple regression/correlation analysis for the behavioural sciences ( 2nd ed., pp.116-118). Hillsdale NJ : Lawrence Erlbaum Associates, Publishers.

## Appendix B

## Information sheet

**Title:**

The validity of the Baltimore Therapeutic Equipment (BTE) work simulator in measurement of endurance during work activities.

**Investigators:**

Dr. Y. Bhambhani, Principal Investigator, Professor, Department of Occupational Therapy, University of Alberta, phone no.: (403) 492-7248.
Winnie Ting, Co-Investigator, Graduate Student, Department of Occupational Therapy, University of Alberta, phone no.: (403) 492-0404.
(This study will be part of the Masters of Science degree requirements for Winnie Ting, who is a graduate student in the Department of Occupational Therapy.)

**Background:**

The BTE work simulator is an instrument designed to test arm and shoulder motions commonly involved in many jobs. It can be used to measure how much work a person can do and helps in selecting proper treatment programs. For the BTE work simulator to be used by therapists, it is important that its accuracy in copying real work tasks be proven. So far, there are only a few studies available to examine this aspect.

**Purpose:**

The study will look at the accuracy of the BTE work simulator in testing how long a healthy person can work on a job task. We will compare the time in which you can lift a load of 40 lbs. from the floor to a bench under two conditions: (a) using the BTE work simulator, and (b) using a plastic crate weighing 40 lbs. Your oxygen use and heart rate will also be compared to see if there is any difference between the tasks.

**Procedures:**

You will be asked to complete three testing sessions over a two-week period. Each session will last approximately one hour.

Data including your age, height, weight and current activity status will be asked at the beginning of session one. Then, you will perform an arm test to measure how well your heart, lungs and muscles are working. In this session, you will cycle with your arms while you are sitting. The test will start at a very light workload and will be slowly increased every two minutes until you are totally tired. During the test, you will be connected to an instrument through a mouth piece and breathing hose so that we can measure the amount of oxygen you are using. An elastic strap will also be placed directly over your chest to measure your heart rate. *If at any time during the test, you feel uncomfortable, you can stop the test immediately.*

After completing the arm test, you will be asked to lift 40 lbs.of load on the BTE work simulator and from the floor to a bench so that you get familiar with these two tasks. A lifting task is selected because it is one of the 20 tasks used by the U.S. Department of Labour for vocational evaluation. A load of 40 lbs is used because it is classified as "heavy" for many jobs. To avoid any potential injury to your back, we will show you proper body mechanics used in lifting. And throughout the next two sessions, correction on body mechanics will be made if necessary.

In sessions two and three, you will perform a lifting task under the real or simulated condition as described earlier. You are asked to work at a comfortable pace without becoming unusually tired. During the tasks, we will ask you how hard you are feeling on a scale ranging from 6 to 20 every minute. When the score increases by two units after the fourth minute value, we will stop the test. We will also measure your oxygen uptake and heart rate in the same way as we did in session one.

Sufficient rest will be given to you when your heart rate returns to resting level. After that, you will be asked to do the task once again. This will be done to make it looks like a real job when rest break is allowed.

**Benefits/risks:**

Through your participation in this study, you will obtain valuable information on how well your heart, lungs and muscles are working during upper body exercise without any cost. The study results will also help us to understand the usefulness of the BTE work simulator.

During the tests, your breathing, HR and blood pressure will increase and make you feel uncomfortable. These will come back to normal in a few minutes when you stop working. There is also a chance that you may feel dizzy or nauseous during the tests. If this happens, you can stop working immediately. After the tests, you may feel some soreness in your muscle and joints for a few days. This is quite normal if the tasks you are doing are different from what you are used to in everyday life. There is also a small chance that certain abnormal responses (eg. abnormal heart beats, raised blood pressure and chest pain) to the work may occur. To prevent this, you have to complete the Physical Activity Readiness Questionnaire before participation to see if you are fit for exercising.

All the tests will be administered by the graduate student who holds a valid CPR certificate. She will attend to any problems occurred during the tests immediately.

**Confidentiality:**

After the first exercise test, you will be provided with information on how well your heart, lungs and muscles performed. You will also be given a personalized exercise program based on these test results if you request it.

We will make sure that nobody knows about your results in the following way: (1) your name will not be used when entering the information into the computer for the tests. Instead, you will be assigned a code by the investigator for future identification, (2) hard copies of your data and back up copies of computer disks will be stored in the graduate student's office under lock and key, they will be kept for a period of seven years, (3) any publications resulting from this research will not include your name, (4) only the investigators participating in this study will have access to the information.

If any further analysis is conducted with the data, further ethics approval will be obtained first.

**Freedom to withdraw:**

You are free to withdraw consent and discontinue participating in any procedures. You can also choose to withdraw your information from the study database at anytime.

You will be given a copy of this consent form. You may ask any further questions related to the study at anytime at phone no. (403) 492-0404. If you have any concerns about any aspects of this study, you may also contact Dr. Anne Rochet, Associate Dean of Graduate Studies and Research in the Faculty of Rehabilitation Medicine, University of Alberta at (403)492-9674. Dr. Rochet is independent from the study investigators.

## Appendix C
## Consent form

**Title**: The validity of the Baltimore Therapeutic Equipment (BTE) work simulator in measurement of endurance in work activities.

**Principal investigator**: Dr. Y. Bhambhani, Professor, Department of Occupational Therapy, University of Alberta, phone no. (403) 492-7248.

**Co-investigator**: Winnie Ting, graduate student, Department of Occupational Therapy, University of Alberta, phone no. (403) 492-0404.

*Please complete the following:*

Do you understand that you have been asked to be in a research study? Yes No

Have you read and received a copy of the attached Information Sheet? Yes No

Do you understand the benefits and risks involved in taking part in this research study? Yes No

Have you had an opportunity to ask questions and discuss this study? Yes No

Do you understand that you are free to refuse to participate or withdraw from the study at anytime and you do not have to give any reason? Yes No

Has the issue of confidentiality been explained to you? Do you understand who will have access to the information you provided? Yes No

This study is explained to me by: ____________________________

I agree to take part in this study.

______________________________ _______________
Signature of Research Participant Date

______________________________
Printed name

I believed that the person signing this form understands what is involved in the study and voluntarily agrees to participate.

______________________________ __________________
Signature of Investigator Date

# Appendix D

## Physical Activity Readiness Questionnaire (PAR-Q)

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 1994)

# PAR - Q & YOU

**(A Questionnaire for People Aged 15 to 69)**

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

| YES | NO | | |
|---|---|---|---|
| ☐ | ☐ | 1. | Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor? |
| ☐ | ☐ | 2. | Do you feel pain in your chest when you do physical activity? |
| ☐ | ☐ | 3. | In the past month, have you had chest pain when you were not doing physical activity? |
| ☐ | ☐ | 4. | Do you lose your balance because of dizziness or do you ever lose consciousness? |
| ☐ | ☐ | 5. | Do you have a bone or joint problem that could be made worse by a change in your physical activity? |
| ☐ | ☐ | 6. | Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition? |
| ☐ | ☐ | 7. | Do you know of any other reason why you should not do physical activity? |

**If you answered**

### YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

### NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active — begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal — this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively.

**DELAY BECOMING MUCH MORE ACTIVE:**

- if you are not feeling well because of a temporary illness such as a cold or a fever — wait until you feel better; or
- if you are or may be pregnant — talk to your doctor before you start becoming more active.

[illegible]

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

**You are encouraged to copy the PAR-Q but only if you use the entire form**

*NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.*

I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.

NAME ______________________________

SIGNATURE ______________________________ DATE ______________________

SIGNATURE OF PARENT ______________________________ WITNESS ______________________
or GUARDIAN (for participants under the age of majority)

continued on other side...



Supported by: Health Canada Santé Canada

## Appendix E

## Graphic presentation of study procedures

*Session 1: Incremental arm cranking test*

- To determine peak oxygen uptake ($p\dot{V}O_2$) and peak HR (pHR) of each subject
- To familiarize subjects with the equipment and the push/ pull task under real and simulated conditions (after the $p\dot{V}O_2$ and pHR are determined)

*Session 2 : Real or simulated lifting*

- To measure endurance of the real or simulated floor to bench lifts
- To determine energy requirement of the task by monitoring the physiological variables ( $\dot{V}O_2$ and HR)
- The whole procedure will be repeated once

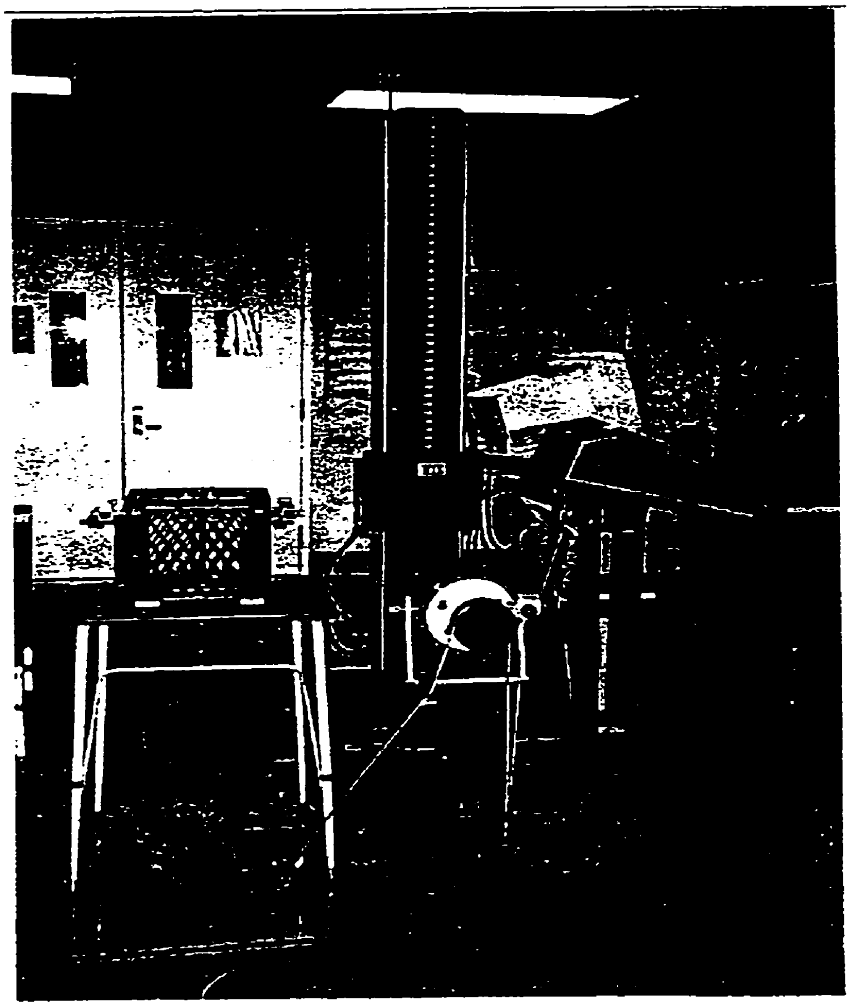
*Session 3 : Real or simulated lifting*

- To measure endurance of the real or simulated floor to bench lifts
- To determine energy requirement of the task by monitoring the physiological variables ( $\dot{V}O_2$ and HR)
- The whole procedure will be repeated once

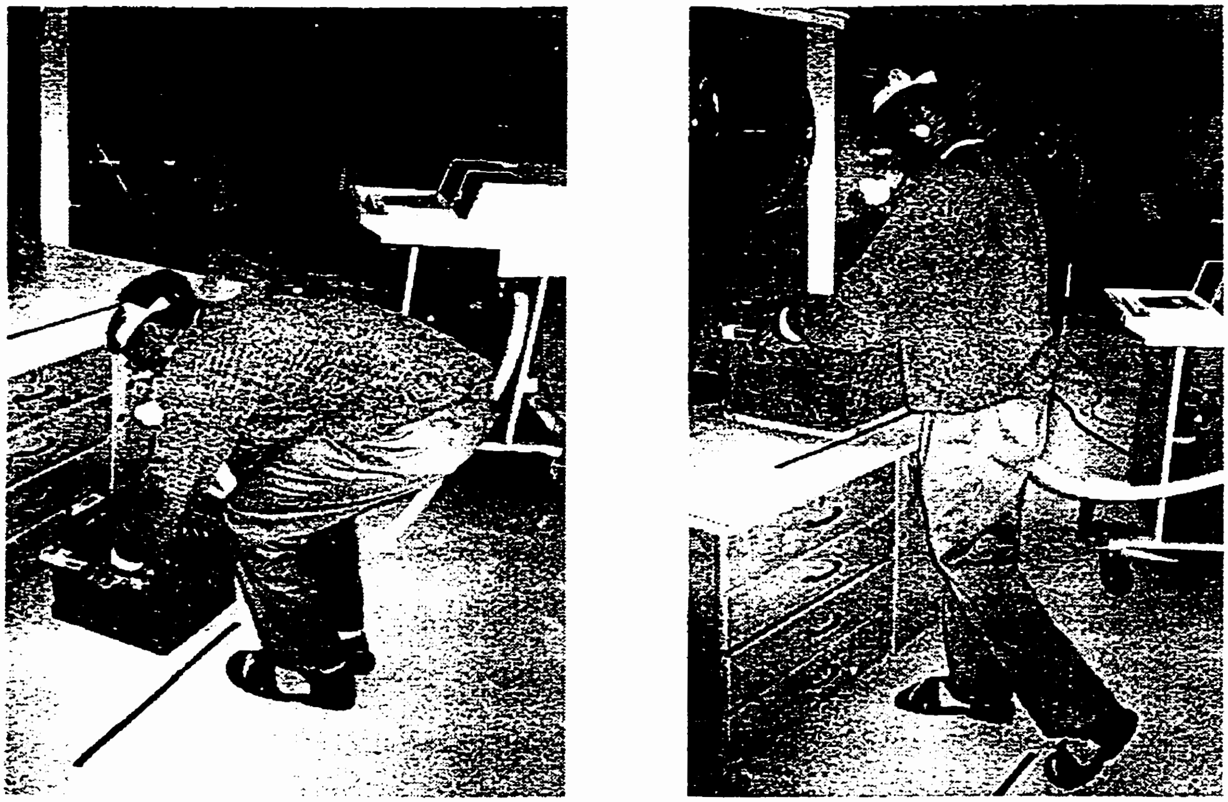
NB.: - Order of the real and simulated lifting was randomized in sessions 2 and 3
- Constant self-selected pace was used in both tasks and trials
- Sufficient rest was allowed between the two trials when the subject's HR returned to a resting level
- Data collection : time, $\dot{V}O_2$, HR

## Appendix F

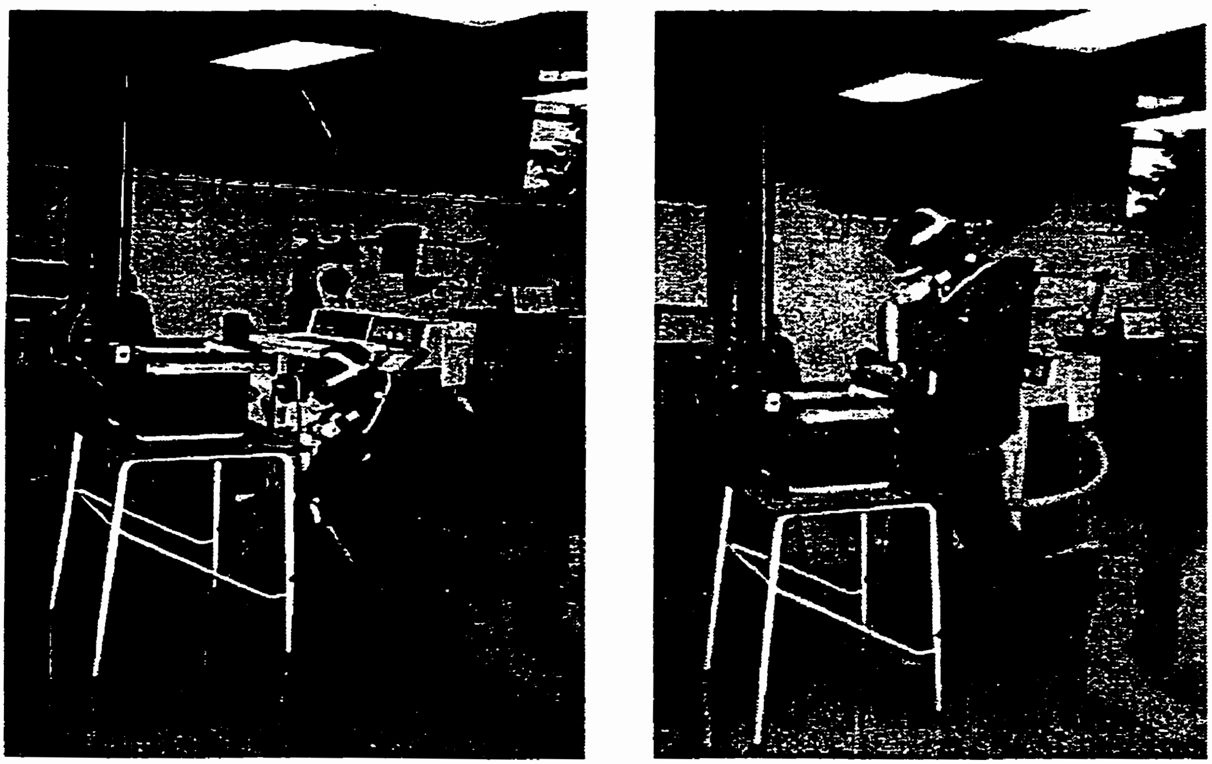
### Illustrations of the real and simulated tasks



The BTE Work Simulator



Lifting with Actual Load (Real task)



Lifting on the BTE Work Simulator (Simulated Task)

## Appendix G

### Manufacturer's specification on equipments used

1. Arm ergometer - Model MET 500, Cybex Upper Body Exerciser, Chattanooga, Tennessee

2. Polar wireless HR monitor - Sport Tester Model 3000, Polar Key, Finland

3. Metabolic measurement cart - MMC, Horizon, Sensormedics, Inc., Anaheim, California

4. Baltimore Therapeutic Equipment (BTE) work simulator - Model W20R, Baltimore Therapeutic Equipment Company, Hanover, Maryland

## Appendix H

## Borg Scale

| | |
|---|---|
| 6 | |
| 7 | Very, very light |
| 8 | |
| 9 | Very light |
| 10 | |
| 11 | Fairly light |
| 12 | |
| 13 | Somewhat hard |
| 14 | |
| 15 | Hard |
| 16 | |
| 17 | Very hard |
| 18 | |
| 19 | Very, very hard |
| 20 | |

Reference:
Borg, G.A.V.(1982). Psychophysical bases of perceived exertion. Medicine and Science in Sports and Exercise, 14, 377-381.

## Appendix I

### Data collection on subject's characteristics

Subject number: _________

◆Age: _____

◆Weight: ______ kg.

◆Height: ______ cm.

◆Age predicted maximal HR: 220 - age = _______ bpm.

◆Resting HR: ________bpm.

◆BMI: Body mass (kg) / height $(m)^2$ = ____________

◆Current status of exercise participation: sedentary , moderately active , active

*Please indicate what kinds of sports or physical activities you are engaging at present.*

______________________________________________________________

*How many hours per week will you spend in physical activities?*

_____________ hours

◆Do you have any medical condition that we should be made aware of (eg. asthma, multiple sclerosis, arthritis?

______________________________________________________________

◆Do you have any back problems or have you had any back injuries?

______________________________________________________________

NB. Sedentary = irregular or no leisure time physical activity
Moderately active = engage in regular but not intense physical activity
Active = engaged in vigorous exercise on a regular basis

# Appendix J

## Data collection

Subject number: ______

Age predicted maximum HR : _______________

**Session 1: Incremental arm cranking test** Date: ______________

resting HR: _________ bpm

peak HR: ________ bpm

peak $\dot{V}O_2$: _________ L/min

**Session 2 and 3: Real or simulated work tasks** Date:___________

| | Real lifting | | Simulated lifting | |
|---|---|---|---|---|
| | Trial one | Trial two | Trial one | Trial two |
| endurance time / min. | | | | |
| HR / bpm | | | | |
| $\dot{V}O_2$ / L/min | | | | |
| $\dot{V}O_2$ / ml/[kg.min] | | | | |

**Data collection (cont'd)**

Lifting: real / simulated Subject no.: ______

| | Trial one | | | Trial two | | |
|---|---|---|---|---|---|---|
| Time (min.) | RPE | $\dot{V}O_2$ | HR | RPE | $\dot{V}O_2$ | HR |
| 0:00 | | | | | | |
| 1:00 | | | | | | |
| 2:00 | | | | | | |
| 3:00 | | | | | | |
| 4:00 * | | | | | | |
| 5:00 | | | | | | |
| 6:00 | | | | | | |
| 7:00 | | | | | | |
| 8:00 | | | | | | |
| 9:00 | | | | | | |
| 10:00 | | | | | | |
| 11:00 | | | | | | |
| 12:00 | | | | | | |
| 13:00 | | | | | | |
| 14:00 | | | | | | |
| 15:00 | | | | | | |
| 16:00 | | | | | | |
| 17:00 | | | | | | |
| 18:00 | | | | | | |
| 20:00 | | | | | | |

Reasons for terminating task:

# Appendix K

## Ethics approval by University of Alberta

University of Alberta
Edmonton
Canada T6G 2G4

Faculty of Rehabilitation Medicine
Rehabilitation Research Centre
3-48 Corbett Hall
Director (403) 492-7856 Telephone (403) 492-2903
Fax (403) 492-1626

*UNIVERSITY OF ALBERTA HEALTH SCIENCES FACULTIES, CAPITAL HEALTH AUTHORITY, AND CARITAS HEALTH GROUP*

### HEALTH RESEARCH ETHICS APPROVAL

**Date:** June 1998

**Name(s) of Principal Investigator(s):** Winne Ting and Dr. Yagesh Bhambhani

**Organization(s):** University of Alberta

**Department:** Graduate Studies; Department of Occupational Therapy

**Project Title:** The Validity of the Baltimore Therapeutic Equipment (BTE) Work Simulator in Measurement of Endurance During Work Activities.

The Health Research Ethics Board has reviewed the protocol for this project and found it to be acceptable within the limitations of human experimentation. The HREB has also reviewed and approved the patient information material and consent form.

The approval for the study as presented is valid for one year. It may be extended following completion of the yearly report form. Any proposed changes to the study must be submitted to the Health Research Ethics Board for approval.

for Dr. Sharon Warren
Chair of the Health Research Ethics Board (B: Health Research)

File number: B-030698-REM

# Appendix L

## Stepwise regression output from SPSS

```
Equation Number 1
     Dependent variable   MRTIME
Block Number   1.              Method:   Stepwise
Criteria       PIN        .0500     POUT .1000
MSTIME    BMI             RESTHR
Variable(s) Entered on Step Number
1..  MSTIME
Multiple R                .70609
R Square                  .49856
     Adjusted R Square    .47070
     Standard Error       .99081

                Analysis of Variance
               DF        Sum of Squares       Mean Square
Regression     1         17.56914             17.56914
Residual       18        17.67054             .98170
F =  17.89671                 Signif F =      .0005


------------------ Variables in the Equation-------------

Variable         B     SE B       Beta              T          Sig T
MSTIME     .339314   .080208    .706089           4.230      .0005
(Constant)3.286068   .700023                      4.694      .0002

------------- Variables not in the Equation -------------
Variable  Beta In    Partial    Min Toler         T          Sig T
BMI        .072783    .096455   .880663           .400       .6945
RESTHR    -.150326   -.196897   .860257          -.828       .4191
End Block Number     1          PIN = .050 Limits reached.
```

## Appendix M

## Raw data of the study

| | age | weight | height | resthr | bmi | expart | hrspw | pk_o2pul | peakrer |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 21 | 64.00 | 1.77 | 70 | 20.43 | active | 4.0 | 9.48 | 1.49 |
| 2 | 35 | 55.00 | 1.70 | 90 | 19.03 | active | 16.0 | 5.73 | 1.59 |
| 3 | 24 | 63.60 | 1.68 | 80 | 22.53 | modact | 1.5 | 8.51 | 1.00 |
| 4 | 19 | 71.50 | 1.72 | 86 | 24.15 | modact | 1.0 | 9.57 | 1.28 |
| 5 | 18 | 66.80 | 1.68 | 80 | 23.67 | modact | 15.0 | 10.23 | 1.25 |
| 6 | 19 | 66.40 | 1.78 | 76 | 21.08 | sed | 7.0 | 7.97 | 1.29 |
| 7 | 24 | 80.23 | 1.75 | 82 | 26.20 | active | 14.0 | 10.66 | 1.17 |
| 8 | 22 | 69.32 | 1.78 | 84 | 21.88 | modact | 5.0 | 7.44 | 1.31 |
| 9 | 35 | 87.27 | 1.70 | 85 | 30.20 | modact | 8.0 | 8.32 | 1.05 |
| 10 | 24 | 68.86 | 1.67 | 83 | 24.69 | modact | 40.0 | 10.53 | 1.20 |
| 11 | 37 | 67.73 | 1.76 | 88 | 21.87 | sed | .0 | 7.05 | 1.34 |
| 12 | 31 | 78.18 | 1.79 | 55 | 24.40 | modact | 3.5 | 13.69 | 1.23 |
| 13 | 35 | 83.18 | 1.69 | 71 | 29.12 | active | 40.0 | 10.55 | 1.11 |
| 14 | 20 | 62.05 | 1.65 | 83 | 22.79 | sed | .0 | 7.15 | 1.13 |
| 15 | 21 | 63.64 | 1.72 | 52 | 21.51 | act | 4.0 | 8.13 | 1.23 |
| 16 | 26 | 88.30 | 1.77 | 68 | 28.18 | sed | .0 | 10.14 | 1.22 |
| 17 | 26 | 50.00 | 1.58 | 80 | 20.03 | modact | 2.0 | 7.24 | 1.25 |
| 18 | 21 | 68.18 | 1.78 | 83 | 21.52 | modact | 7.0 | 8.33 | 1.32 |
| 19 | 22 | 73.70 | 1.78 | 85 | 23.26 | act | 5.0 | 11.78 | 1.18 |
| 20 | 28 | 69.00 | 1.79 | 68 | 21.53 | act | 7.0 | 8.07 | 1.34 |

| | peakrpe | peakve | peakhr | pk_vo2 | pk_vo2_r | rtime1 | rtime2 | stime1 | stime2 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 19 | 115.10 | 190 | 1.802 | 28.16 | 4.83 | 3.83 | 8.20 | 7.15 |
| 2 | 16 | 80.10 | 177 | 1.015 | 18.45 | 10.03 | 10.10 | 16.10 | 20.08 |
| 3 | 17 | 60.40 | 156 | 1.328 | 20.88 | 6.05 | 5.27 | 9.05 | 7.17 |
| 4 | 20 | 96.90 | 181 | 1.732 | 24.22 | 6.05 | 3.62 | 12.03 | 9.12 |
| 5 | 20 | 65.50 | 171 | 1.750 | 26.20 | 6.33 | 5.33 | 8.08 | 8.05 |
| 6 | 19 | 63.60 | 154 | 1.228 | 18.49 | 4.18 | 4.03 | 5.42 | 6.05 |
| 7 | 20 | 60.80 | 178 | 1.897 | 23.64 | 6.07 | 6.83 | 8.10 | 7.15 |
| 8 | 16 | 81.10 | 194 | 1.444 | 20.83 | 7.00 | 8.06 | 11.13 | 7.10 |
| 9 | 20 | 45.20 | 152 | 1.265 | 14.50 | 4.98 | 4.55 | 6.03 | 6.05 |
| 10 | 18 | 64.50 | 158 | 1.664 | 24.16 | 5.08 | 6.12 | 10.17 | 8.17 |
| 11 | 18 | 54.30 | 172 | 1.212 | 17.89 | 6.15 | 6.10 | 7.16 | 5.20 |
| 12 | 19 | 88.20 | 160 | 2.191 | 28.03 | 7.12 | 8.17 | 7.13 | 8.28 |
| 13 | 17 | 60.50 | 157 | 1.657 | 19.92 | 6.13 | 6.10 | 8.10 | 7.06 |
| 14 | 19 | 62.70 | 170 | 1.215 | 18.82 | 5.13 | 4.78 | 7.31 | 5.33 |
| 15 | 17 | 72.70 | 178 | 1.448 | 22.75 | 5.15 | 6.05 | 6.18 | 7.32 |
| 16 | 19 | 98.30 | 183 | 1.856 | 21.02 | 7.05 | 6.00 | 7.10 | 6.48 |
| 17 | 17 | 64.70 | 193 | 1.398 | 27.96 | 6.12 | 5.70 | 7.25 | 7.12 |
| 18 | 16 | 62.50 | 170 | 1.416 | 20.77 | 9.06 | 5.08 | 7.23 | 18.08 |
| 19 | 18 | 68.90 | 167 | 1.968 | 26.67 | 8.13 | 6.10 | 7.10 | 8.06 |
| 20 | 16 | 60.20 | 170 | 1.372 | 19.88 | 6.12 | 5.13 | 7.15 | 6.10 |

| | rhr1 | rhr2 | shr1 | shr2 | rvo1 | rvo2 | svo1 | svo2 | rvo1_r |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 163 | 164 | 130 | 130 | 1.761 | 1.565 | 1.435 | 1.185 | 27.45 |
| 2 | 133 | 129 | 123 | 114 | 1.001 | 1.011 | .786 | .651 | 18.15 |
| 3 | 134 | 146 | 103 | 107 | 1.281 | 1.224 | .879 | .889 | 20.12 |
| 4 | 136 | 139 | 116 | 115 | 1.338 | 1.416 | 1.254 | 1.166 | 18.65 |
| 5 | 137 | 144 | 105 | 109 | 1.582 | 1.582 | 1.149 | 1.174 | 23.63 |
| 6 | 140 | 149 | 127 | 128 | .920 | 1.535 | 1.324 | 1.204 | 13.90 |
| 7 | 138 | 148 | 116 | 118 | 1.374 | 1.240 | 1.013 | .926 | 17.10 |
| 8 | 136 | 143 | 130 | 125 | 1.485 | 1.466 | 1.031 | .945 | 21.36 |
| 9 | 144 | 146 | 133 | 132 | 1.678 | 1.668 | 1.576 | 1.536 | 19.20 |
| 10 | 121 | 124 | 107 | 107 | 1.497 | 1.513 | 1.275 | 1.227 | 21.70 |
| 11 | 145 | 150 | 120 | 124 | 1.562 | 1.656 | 1.174 | 1.185 | 23.03 |
| 12 | 116 | 127 | 107 | 113 | 1.285 | 1.414 | 1.006 | 1.072 | 16.43 |
| 13 | 142 | 139 | 109 | 108 | 1.135 | 1.134 | 1.298 | 1.364 | 13.63 |
| 14 | 151 | 149 | 132 | 132 | 1.209 | 1.214 | .986 | .985 | 19.43 |
| 15 | 127 | 136 | 105 | 109 | 1.201 | 1.229 | 1.079 | 1.001 | 18.83 |
| 16 | 123 | 133 | 107 | 102 | 1.573 | 1.566 | 1.434 | 1.435 | 17.81 |
| 17 | 148 | 151 | 114 | 117 | 1.296 | 1.332 | .629 | .644 | 25.92 |
| 18 | 160 | 164 | 145 | 140 | 1.664 | 1.692 | .578 | .565 | 24.40 |
| 19 | 118 | 112 | 111 | 118 | 1.647 | 1.467 | 1.301 | 1.372 | 22.34 |
| 20 | 156 | 158 | 110 | 120 | 1.173 | 1.126 | .839 | .776 | 17.00 |

| | rvo2_r | svo1_r | svo2_r | rpphr1 | rpphr2 | spphr1 | spphr2 | rppvo1 |
|---|---|---|---|---|---|---|---|---|
| 1 | 24.40 | 22.35 | 18.48 | 85.79 | 86.31 | 68.42 | 68.42 | 97.72 |
| 2 | 18.33 | 14.25 | 11.83 | 75.14 | 72.88 | 69.50 | 64.41 | 98.62 |
| 3 | 19.23 | 13.80 | 13.92 | 85.90 | 92.17 | 66.00 | 66.94 | 96.46 |
| 4 | 19.75 | 17.50 | 16.30 | 75.14 | 76.80 | 64.09 | 67.32 | 77.25 |
| 5 | 23.63 | 17.18 | 17.55 | 80.12 | 80.12 | 61.40 | 63.74 | 90.40 |
| 6 | 23.05 | 19.90 | 18.10 | 90.91 | 96.75 | 82.47 | 83.12 | 74.92 |
| 7 | 15.40 | 12.63 | 11.50 | 77.53 | 83.15 | 65.17 | 66.29 | 72.43 |
| 8 | 21.10 | 14.83 | 13.63 | 70.10 | 73.71 | 67.01 | 64.43 | 102.84 |
| 9 | 19.08 | 18.00 | 17.56 | 94.75 | 96.05 | 87.50 | 86.64 | 132.65 |
| 10 | 21.93 | 18.52 | 17.82 | 76.58 | 78.48 | 67.72 | 67.72 | 89.96 |
| 11 | 24.36 | 17.30 | 17.43 | 84.30 | 87.21 | 69.77 | 72.09 | 128.88 |
| 12 | 18.05 | 12.85 | 13.68 | 72.50 | 79.38 | 66.88 | 70.63 | 58.65 |
| 13 | 13.60 | 15.56 | 16.38 | 90.45 | 88.54 | 69.43 | 68.79 | 68.50 |
| 14 | 19.50 | 15.85 | 15.86 | 88.82 | 87.65 | 77.65 | 77.65 | 99.51 |
| 15 | 19.28 | 16.93 | 15.70 | 71.35 | 76.40 | 58.99 | 61.24 | 82.94 |
| 16 | 17.74 | 16.24 | 16.25 | 67.21 | 72.68 | 58.47 | 55.74 | 84.75 |
| 17 | 26.64 | 12.58 | 12.88 | 76.68 | 78.24 | 59.07 | 60.62 | 92.70 |
| 18 | 24.82 | 8.48 | 8.28 | 94.12 | 96.47 | 85.29 | 82.35 | 117.51 |
| 19 | 19.90 | 17.66 | 18.62 | 70.66 | 67.07 | 66.47 | 70.66 | 83.69 |
| 20 | 16.32 | 12.15 | 11.25 | 91.76 | 92.94 | 64.71 | 70.59 | 85.50 |

| | rppvo2 | sppvo1 | sppvo2 | rmet1 | rmet2 | smet1 | smet2 | mrtime |
|---|---|---|---|---|---|---|---|---|
| 1 | 86.85 | 79.63 | 65.76 | 7.84 | 6.97 | 6.39 | 5.28 | 4.33 |
| 2 | 99.61 | 77.44 | 64.14 | 5.19 | 5.24 | 4.07 | 3.38 | 10.07 |
| 3 | 93.60 | 66.19 | 68.59 | 5.75 | 5.49 | 3.94 | 3.98 | 5.66 |
| 4 | 81.76 | 72.40 | 64.09 | 5.33 | 5.64 | 5.00 | 4.66 | 4.84 |
| 5 | 90.40 | 65.66 | 67.09 | 6.75 | 6.75 | 4.91 | 5.01 | 5.83 |
| 6 | 125.00 | 107.82 | 98.05 | 3.97 | 6.59 | 5.69 | 5.17 | 4.11 |
| 7 | 65.37 | 53.40 | 48.81 | 4.89 | 4.40 | 3.61 | 3.29 | 6.45 |
| 8 | 101.52 | 71.40 | 65.44 | 6.11 | 6.03 | 4.24 | 3.89 | 7.53 |
| 9 | 131.86 | 124.58 | 121.42 | 5.49 | 5.45 | 5.14 | 5.02 | 4.77 |
| 10 | 90.93 | 77.74 | 73.74 | 6.20 | 6.26 | 5.78 | 5.09 | 5.64 |
| 11 | 136.63 | 96.86 | 97.77 | 6.58 | 6.96 | 4.94 | 4.97 | 6.13 |
| 12 | 64.54 | 45.92 | 48.92 | 4.69 | 5.16 | 3.67 | 3.91 | 7.65 |
| 13 | 68.44 | 78.33 | 82.32 | 3.89 | 3.89 | 4.45 | 4.68 | 6.12 |
| 14 | 99.92 | 81.15 | 81.07 | 5.55 | 5.57 | 4.53 | 4.54 | 4.96 |
| 15 | 84.88 | 74.52 | 69.13 | 5.38 | 5.51 | 4.84 | 4.49 | 5.60 |
| 16 | 84.38 | 77.26 | 77.32 | 5.09 | 5.07 | 4.64 | 4.64 | 6.53 |
| 17 | 94.56 | 44.90 | 46.06 | 7.41 | 7.61 | 3.59 | 3.69 | 5.91 |
| 18 | 119.49 | 40.82 | 39.90 | 6.97 | 7.09 | 2.42 | 2.37 | 7.07 |
| 19 | 74.54 | 66.11 | 69.72 | 6.38 | 5.69 | 5.04 | 5.32 | 7.12 |
| 20 | 82.07 | 61.15 | 56.56 | 4.86 | 4.66 | 3.47 | 3.21 | 5.63 |

| | mstime | rrest | srest | rve1 | rve2 | sve1 | sve2 | rrer1 |
|---|---|---|---|---|---|---|---|---|
| 1 | 7.68 | 25.00 | 28.53 | 63.15 | 76.05 | 43.73 | 40.10 | 1.06 |
| 2 | 18.09 | 38.25 | 33.63 | 46.53 | 44.43 | 39.53 | 31.00 | 1.02 |
| 3 | 8.11 | 18.68 | 9.62 | 51.35 | 48.90 | 30.28 | 31.68 | 1.09 |
| 4 | 10.58 | 11.35 | 26.00 | 43.05 | 51.55 | 30.86 | 31.40 | .90 |
| 5 | 8.07 | 15.00 | 9.16 | 48.72 | 44.93 | 29.68 | 30.18 | 1.03 |
| 6 | 5.74 | 28.83 | 18.87 | 26.18 | 56.53 | 43.68 | 40.90 | 1.06 |
| 7 | 7.63 | 16.10 | 14.20 | 42.80 | 41.23 | 34.45 | 32.83 | .93 |
| 8 | 9.12 | 21.58 | 20.68 | 48.75 | 48.76 | 37.53 | 36.40 | .95 |
| 9 | 6.04 | 32.05 | 30.61 | 48.65 | 47.03 | 47.20 | 42.03 | .97 |
| 10 | 9.17 | 12.03 | 14.15 | 40.40 | 43.08 | 31.33 | 27.73 | .93 |
| 11 | 6.18 | 38.77 | 22.23 | 44.08 | 45.93 | 31.73 | 29.95 | 1.00 |
| 12 | 7.71 | 17.77 | 11.13 | 38.63 | 40.00 | 30.95 | 30.53 | .85 |
| 13 | 7.58 | 52.80 | 23.42 | 38.90 | 38.28 | 32.08 | 34.38 | .94 |
| 14 | 6.32 | 32.88 | 32.28 | 49.65 | 46.23 | 32.75 | 31.53 | 1.05 |
| 15 | 6.75 | 9.52 | 11.61 | 32.48 | 34.50 | 29.25 | 24.68 | .87 |
| 16 | 6.79 | 10.38 | 9.05 | 43.48 | 40.76 | 33.70 | 33.20 | .98 |
| 17 | 7.19 | 19.35 | 11.73 | 29.70 | 31.75 | 30.53 | 30.28 | .87 |
| 18 | 12.66 | 30.15 | 25.43 | 45.25 | 49.68 | 37.23 | 38.18 | .90 |
| 19 | 7.58 | 12.87 | 14.33 | 38.05 | 38.25 | 39.63 | 40.13 | .87 |
| 20 | 6.63 | 39.65 | 19.35 | 45.65 | 42.65 | 26.75 | 24.50 | 1.04 |

| | rrer2 | srer1 | srer2 | r_o2pul1 | r_o2pul2 | s_o2pul1 | s_o2pul2 | r_gec1 |
|---|---|---|---|---|---|---|---|---|
| 1 | 1.34 | 1.00 | 1.06 | 10.80 | 9.54 | 11.04 | 9.12 | 8.887 |
| 2 | .93 | 1.22 | .94 | 7.53 | 7.84 | 6.39 | 5.71 | 5.052 |
| 3 | 1.04 | .87 | .93 | 9.58 | 8.38 | 8.53 | 8.31 | 6.465 |
| 4 | .95 | .81 | .90 | 9.84 | 10.19 | 10.81 | 10.14 | 6.588 |
| 5 | .96 | .83 | .85 | 11.55 | 10.99 | 10.94 | 10.77 | 7.984 |
| 6 | 1.13 | 1.02 | .98 | 6.57 | 10.30 | 10.43 | 9.41 | 4.640 |
| 7 | .94 | .93 | .95 | 9.96 | 8.38 | 8.73 | 7.85 | 6.816 |
| 8 | .93 | .94 | .97 | 10.92 | 10.25 | 7.93 | 7.56 | 7.400 |
| 9 | .93 | 1.02 | .87 | 11.65 | 11.42 | 11.85 | 11.64 | 8.407 |
| 10 | .93 | .83 | .76 | 12.37 | 12.20 | 11.92 | 11.47 | 7.427 |
| 11 | .91 | .89 | .82 | 10.77 | 11.04 | 9.78 | 9.56 | 7.883 |
| 12 | .82 | .84 | .83 | 11.08 | 11.13 | 9.40 | 9.49 | 6.248 |
| 13 | .94 | .92 | .82 | 7.99 | 8.16 | 11.90 | 12.63 | 5.644 |
| 14 | .97 | .94 | .89 | 8.01 | 8.15 | 7.47 | 7.46 | 6.101 |
| 15 | .87 | .83 | .78 | 9.46 | 9.04 | 10.28 | 9.18 | 5.869 |
| 16 | .92 | .78 | .79 | 12.79 | 11.77 | 13.40 | 14.07 | 7.900 |
| 17 | .84 | .93 | .87 | 8.76 | 8.82 | 5.52 | 5.50 | 6.334 |
| 18 | .88 | .82 | .82 | 10.40 | 10.32 | 3.99 | 4.04 | 8.194 |
| 19 | .83 | .97 | .95 | 13.96 | 13.10 | 11.72 | 11.63 | 8.049 |
| 20 | .99 | .84 | .83 | 7.51 | 7.13 | 7.63 | 6.47 | 5.920 |

| | r_gec2 | s_gec1 | s_gec2 | r_nec1 | r_nec2 | s_nec1 |
|---|---|---|---|---|---|---|
| 1 | 7.899 | 7.242 | 5.981 | 7.557 | 6.776 | 5.958 |
| 2 | 5.015 | 3.967 | 3.240 | 3.872 | 3.869 | 3.256 |
| 3 | 6.178 | 4.296 | 4.410 | 5.405 | 5.148 | 3.468 |
| 4 | 7.059 | 6.036 | 5.740 | 5.416 | 5.510 | 4.543 |
| 5 | 7.907 | 5.559 | 5.708 | 5.607 | 6.297 | 4.249 |
| 6 | 7.747 | 6.682 | 6.046 | 3.149 | 6.010 | 4.940 |
| 7 | 6.167 | 5.025 | 4.616 | 5.501 | 4.793 | 3.652 |
| 8 | 7.273 | 5.127 | 4.734 | 6.353 | 6.146 | 3.870 |
| 9 | 8.275 | 7.954 | 7.506 | 5.928 | 6.219 | 5.901 |
| 10 | 7.506 | 6.168 | 5.828 | 5.649 | 5.391 | 4.561 |
| 11 | 8.174 | 5.766 | 5.718 | 6.213 | 6.929 | 4.582 |
| 12 | 6.823 | 4.879 | 5.186 | 5.060 | 5.609 | 3.487 |
| 13 | 5.639 | 6.422 | 6.581 | 4.925 | 5.155 | 4.967 |
| 14 | 6.082 | 4.903 | 4.837 | 5.002 | 5.163 | 3.705 |
| 15 | 6.006 | 5.220 | 4.781 | 5.206 | 5.133 | 4.046 |
| 16 | 7.749 | 6.849 | 6.871 | 5.851 | 5.740 | 4.962 |
| 17 | 6.460 | 3.120 | 3.147 | 5.515 | 5.234 | 2.410 |
| 18 | 8.289 | 2.789 | 2.726 | 6.936 | 7.127 | 2.137 |
| 19 | 7.097 | 6.518 | 6.839 | 6.291 | 5.022 | 4.635 |
| 20 | 5.669 | 4.069 | 3.754 | 4.729 | 4.646 | 3.087 |

| | s_nec2 | rrpe1 | rrpe2 | srpe1 | srpe2 |
|---|---|---|---|---|---|
| 1 | 4.588 | 16 | 18 | 11 | 10 |
| 2 | 2.574 | 8 | 7 | 7 | 7 |
| 3 | 3.481 | 12 | 10 | 9 | 8 |
| 4 | 4.322 | 11 | 10 | 8 | 8 |
| 5 | 4.135 | 13 | 13 | 11 | 13 |
| 6 | 4.400 | 14 | 14 | 12 | 11 |
| 7 | 3.373 | 14 | 13 | 14 | 12 |
| 8 | 3.775 | 10 | 10 | 9 | 8 |
| 9 | 5.777 | 17 | 18 | 14 | 14 |
| 10 | 3.809 | 15 | 16 | 9 | 9 |
| 11 | 4.830 | 12 | 13 | 12 | 11 |
| 12 | 3.969 | 14 | 14 | 9 | 9 |
| 13 | 4.898 | 11 | 12 | 9 | 10 |
| 14 | 3.327 | 16 | 17 | 12 | 10 |
| 15 | 3.710 | 12 | 13 | 9 | 10 |
| 16 | 4.858 | 9 | 10 | 8 | 8 |
| 17 | 2.301 | 15 | 16 | 12 | 12 |
| 18 | 2.123 | 17 | 15 | 9 | 8 |
| 19 | 5.189 | 13 | 11 | 9 | 9 |
| 20 | 2.582 | 17 | 16 | 10 | 11 |