Heart Rate Response to Short Duration Exercise

by

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A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfilment of the Requirements
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DEFINITIONS

Cardiac output (CO): Cardiac output is the total volume of blood pumped by the ventricle per minute. CO is equal to the product of stroke volume (mL - millilitres) and heart rate (bpm - beats per minute).

End-Diastolic Volume (EDV): EDV is total volume at the end of the diastole in the ventricle.

End-Systolic Volume (ESV): ESV is the remaining volume of blood at the end of the systole after contraction.

Exercise compliance: Exercise compliance is the level of adherence to a prescribed course of exercise.

Fick Equation: The Fick equation is VO_2=CO x a-vO_2 where CO is cardiac output (L/min), a-vO_2 is the arteriovenous O_2 difference. CO is equal to product of stroke volume (mL) and heart rate (bpm).

Heart Period (HP): The time (ms) between successive heartbeats.

Heart Rate (HR): Heart rate corresponds to the number of QRS complexes or contractions of the ventricles per minute. Heart rate is the inverse of heart period.

Heart Rate Profile: a continuous record of heart rate during an extended period of time. A heart rate profile can be recorded for an exercise session (training or competition), during sleep or during work or play.

Heart Rate Variability (HRV): Heart rate variability represents beat-to-beat (R to R interval) variability in heart rate.

Load: Load during free weight exercise corresponds to the resultant joint moments (Nm) created about each of the involved joints at each instant during the exercise or motion. The resultant joint moment represents the NET rotational tendency of the forces of all the tissues spanning a joint (normally the muscle forces).

Long duration exercise: long duration exercise is known as the continuous bout of exercise for more than 2 minutes. See short duration exercise.

Parasympathetic drive: The parasympathetic drive is a response of the autonomic nervous system that results in a depressant effect, predominating on the heart as a vagal tone through the vagus nerve.

Peak Heart Rate (peak HR): The maximum value of heart rate during an episode of exercise that could correspond to a set of resistance exercise.

Repetitions: A repetition corresponds to one complete cycle of exercise. The total number of repetitions corresponds to the number of complete cycles.

RR interval: RR interval is a measure of the length of one cardiac cycle from start of ventricular contraction to the start of the next ventricular contraction. This interval is commonly used as a measure heart rate.

Resistance to blood flow: the factors that affect resistance to blood flow are expressed individually in Poiseuille's Law such as Flow, by $(P_1\text{-}P_2)\ r^4/8vL$, where v is viscosity of blood, L is length of vessel, P is pressure, and r is blood vessel radius.

Resistance training audit: Resistance training audit is known as the method of determining and examining the accuracy in complying with a prescribed resistance-training session. See exercise compliance.

Resistance training compliance: Resistance training compliance is known as following a prescribed course of resistance training in a session (exercises, sets, repetitions, weight, posture, rest, etc.). See exercise compliance.

1RM: 1RM is an abbreviation for one repetition maximum. 1RM corresponds to the maximum load, usually represented by weight (N or lb) or mass (kg), which can be lifted one time during an exercise without compensatory or accessory motion. 10RM is the maximum load that can be lifted 10 times successfully without compensatory or accessory motion.

Sets: A set is comprised of a number of repetitions that are performed continuously.

Short duration exercise: short duration exercise is known as the continuous bout of exercise for no more than 2 minutes.

Steady state: steady state is considered to be the condition where oxygen uptake remains relatively stable during an aerobic session of exercise; steady state is usually reached after 2 minutes of constant workload exercise.

Stroke Volume (SV): stroke volume is the volume (mL) of blood that is ejected during systole.

Sympathetic drive: The sympathetic drive is a response of the autonomic nervous system that predominates during times of physical or emotional stress.

Vascular compliance: is the tendency of blood vessel volume to increase as the blood pressure increases. The more easily the vessel wall stretches, the greater is its compliance.

Weight: Weight is defined as the product of mass (kg) and gravity (-9.8 m/s^2). Weight is expressed as a Newton (N), where 1 N = 1 kgm/s^2. Weight is a common method of estimating load during resistance exercise.

ABSTRACT

Exercise intensity relates primarily to the load imposed on the musculoskeletal system, which in turn exerts an effect on the cardiovascular system. Heart rate (HR) during aerobic exercise has been employed in cardiovascular training programs since it represents a safe and non-invasive method to monitor exercise intensity. PURPOSE: The purpose of this study was to systematically investigate heart rate response during short duration resistance exercise to provide a basis for its use in "non-aerobic" exercise. The three objectives were: 1) to determine the relationship between peak HR and weight lifted during resistance training exercise over a large range of weights, 2) to determine the relationship between peak HR and the number of repetitions through a range of weights normally used in resistance training exercise, and 3) to determine if HR profiles can be used to measure set duration during resistance training exercise. METHODS: A total of 31 participants were included in this study. In one protocol, the participants performed multiple sets with increasing weight per set for an upper body and lower body exercise. In the second protocol, the participants performed multiple sets with a fixed weight with an increase in the number of repetitions per set for a upper body and lower body exercise. RESULTS: <u>Peak HR versus Weight:</u> The participants performed a dumbbell row (N=10) or squat (N=6) exercise. Correlation between peak HR and weight for the upper body (dumbbell) exercise ranged from 0.854 to 0.990 ($p < 0.001$). For the lower body exercise (squat) the correlation ranged from 0.866 to 0.990 ($p < 0.001$). <u>Peak HR versus Repetitions:</u> participants performed this protocol using dumbbell row (N=10) or squat (N=5) exercise. Correlations ranging from 0.849 to 0.964 ($p < 0.001$) were recorded for the upper body exercise. For the lower body exercise the r-values ranged from 0.951 to 0.988 ($p < 0.001$). <u>HR estimated set duration versus actual set duration:</u> A strong linear correlation was observed ($r = 0.951$, $p < 0.001$) for estimated vs. actual HR set durations performing dumbbell rows ($r = 0.962$, $p < 0.001$ for lower body exercise). CONCLUSIONS: It was concluded that i) there is a strong linear relationship between peak HR and weight lifted during resistance training exercise over a large range of weights, ii) there is a strong linear relationship between peak HR and the number of repetitions through a range of weights normally used in resistance training exercise, iii) There is a strong correlation between estimated and actual set duration on HR profiles during resistance training exercise. These findings establish the use of HR as a tool for investigation and monitoring of resistance training exercise in research and applied settings.

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INTRODUCTION

Heart rate (HR) response during aerobic exercise has been well documented and characterized in the literature (cf. Physiology of Sport and Exercise, 2d ed., 1999, Exercise Physiology, 4^{th} ed., 1996). It is well known that there is a linear relationship between HR and exercise intensity during steady state, aerobic exercise. Exercise intensity is one of the four common factors used in aerobic exercise prescription to induce physiological adaptations. Exercise intensity primarily relates to the load imposed on the musculoskeletal system but it exerts an effect on the cardiovascular system that can be monitored and/or expressed in both absolute (e.g. Watts) and relative terms (e.g. percentage of functional capacity using HR or estimated energy expenditure VO_2). It is possible to modulate HR response during aerobic exercise by varying: i) the duration of the exercise session (Guidelines For Exercise Testing And Prescription) 4^{th} ed., 1991), ii) the environmental conditions during exercise (Physiology of Sport and Exercise, Part IV, 2d ed., 1999), and iii) other parameters such as the mode or type of exercise, the frequency of subject's participation, the subject's posture while performing a session of exercise, and the fitness level of the subject.

HR during aerobic exercise has been employed in cardiovascular training programs as a method to monitor and make adjustments to the desired exercise intensity based upon the well-established linear relationship between HR and exercise intensity or workload. However, there is a lack of knowledge related to HR response during resistance training exercise or during the initial non-steady state component of aerobic exercise. Resistance training is a short duration conditioning method that is designed to progressively load the neuromusculoskeletal system promoting adaptation of this system. In Physiology of Sport and Exercise, 2d ed., 1994, p.275, it is stated that "During a single bout of exercise, the human body is quite adept at adjusting its cardiovascular and respiratory functioning to adequately meet the heightened demands of active muscles".

There are three types of energy systems used during exercise: immediate, short term, and long term. The performance of brief short duration and high intensity exercise (e.g., 100-yard dash) uses the high-energy phosphates or phosphagens, the short-term energy for strenuous exercise that continues beyond a brief period of time (e.g., resistance training exercise) uses the lactic acid system, (anaerobic glycolysis), and the long-term energy for vigorous exercise proceeding beyond several minutes of duration (e.g. jogging) uses the aerobic system. During resistance training a cardiovascular response is required to provide the active muscles with a continuous stream of nutrients and oxygen due to a partial dependence on oxidative metabolism during exercise: (Human Physiology and Mechanism of Disease, 5th ed., 1992, p.136-141), and for clearance of metabolic by-products: Zweifach (as cited in Exercise Physiology, 4th ed., 1996, p.293) through the circulation from the site of energy metabolism.

Oxygenated blood is delivered to the working muscles during resistance training. This delivery is dependent upon cardiac output (CO) which, in turn, is dependent upon heart rate (HR) and stroke volume (SV). The HR response to short duration exercise, e.g. resistance exercise, has not been well elucidated. This response is important to characterize because it may be trainable and could be used in the specification and assessment of resistance exercise for optimal response of the neuromuscular system.

There are two studies (Roach D, Haennel R, Koshman ML, Sheldon R. (1999) and Galvez JM, Alonso JP, Sangrador LA, Navarro G. (2000)) that examined HR response to short duration exercise, but they have some limitations such as a small range of weights and overly simplistic protocols to address the response of HR to short duration exercise. Roach et al. (1999) studied the origins of heart rate variability and established a relationship of HR burst morphology to work duration and load. It was found that burst morphology was generally independent of the exercise load or duration that induces it. There was a nearly discrete heart response to the initiation of exercise from rest, and a transient hypotension and sinus tachycardia that accompanied large muscle activation. The very small range of weights and exercise durations used limited this study, as well as the use of zero load (no external resistance from the bike) in the analysis. There was evidence in their data of a relationship between number of revolutions and heart period (HP). The ANOVA post hoc analysis indicated 1-revolution values to be significantly different from both 3- and 5-revolutions values, which the authors did not address.

Galvez et al. (2000) investigated the effect of muscle mass and the level of force on HR during short duration exercise. They found that peak HR increased with both the intensity of isometric contraction and the amount of muscle mass involved. Multiple regression analysis of the relationship between peak HR and percentage of maximum force, type of the contraction, resting HR, and duration and magnitude of force of the contraction showed that peak HR increased by a mean of 30.1 beats/min from 20 to 50% of maximum voluntary contraction (MVC) (95% confidence interval 18.7-41.5), and by a mean of 20.7 beats/min from handgrip to wheel-turn contractions (95% confidence interval 13.0-28.4). Both basal heart rate and contraction duration had a significant effect on peak HR. They reported the absence of a linear relationship between the intensity of the isometric contraction and peak HR, however only two load conditions were used, and a "zero" load in the supine position was inappropriately defined.

To date, only two studies have been performed to examine HR response during short duration exercise. Both of these studies failed to characterize the HR responses to weight and repetitions but methodological flaws may have contributed to these findings. The purpose of this study was to systematically investigate HR response during short duration, resistance exercise.

Relevance

Resistance training exercise is associated with performance enhancement in sport, at work, in rehabilitation and for general health. Establishing the relationship between HR and short duration exercise is essential if HR monitoring is to be used as a method to modify and monitor compliance with resistance training programs.

Increasing our understanding of this relationship may assist in exercise prescription and may provide means to monitor exercise intensity. Nevertheless, investigations on the use of HR profiles (continuous recording of HR during exercise) for resistance training have yet to be performed. Moreover, the effects of short duration exercise parameters (i.e.

weight, number of repetitions, number of sets, muscle mass, set duration, rest time, and inter-set interval) on HR profiles during resistance training exercise have not been systematically evaluated. Determining the effects of different exercise parameters on HR is important to enhance knowledge in exercise science, and has immediate implications for therapeutic exercise.

Objectives

1. To determine the relationship between peak HR per set and weight lifted per set over a range of weights normally used during resistance training for both upper and lower body exercise.
2. To determine the relationship between peak HR per set and the number of repetitions performed per set through a range of repetitions normally used in resistance exercise for upper and lower body exercise.
3. To determine if heart rate profiles (continuous heart rate recording) can be used to measure set duration, as a measure of work time during resistance training.

Hypotheses

First Objective

Ho: There is no linear relationship between weight lifted and peak heart rate.

H_1: There is a linear relationship between weight lifted and peak HR.

Second Objective

Ho: There is no linear relationship between repetitions and peak HR.

H_1: There is a linear relationship between repetitions and peak HR.

Third Objective

Ho: There is no correlation between estimated and actual HR set duration.

H_1: There is a strong correlation between HR estimated and actual HR set duration.

REVIEW OF LITERATURE

The review of literature is separated into three sections. The first section reviews the studies that are directly related to the topic of this thesis. The second section provides an overview of the general exercise parameters associated with resistance training. The third section provides an overview of the general factors that influence heart rate.

Section 1 – Heart rate response to short duration exercise.

There is a paucity of studies examining HR response during short-duration exercise. There have been two recent studies that have begun to examine HR response to short-duration exercise during dynamic and/or isometric exercise. These two studies will be reviewed.

Roach and colleagues (1999), from The University of Calgary tried to develop a lexicon of heart period (HP) changes, where each lexicon would have a specific physiological basis. In order to do this, they hypothesized two possible reasons for the origins of the burst that appears at the beginning of the exercise. One possible reason is that it is a tachycardic reflex induced by a skeletal muscle contraction. A second possible explanation is that it is a baroreceptor-mediated response due to a transient hypotension related to decreased peripheral resistance during muscle contraction. In this study they investigated the relationship between workload and/or duration and HP burst morphology. In their first protocol they varied repetitions (revolutions) and in the second protocol they varied load. Ten participants who performed the exercise on a stationary bicycle with a pedalling rate set to 60 revolutions per minute (rpm) took part in the study. In the first protocol, the participants performed 1, 3, and 5 revolutions on the stationary cycle against no additional external loading, which they termed 0 Watts load. In the second protocol, the participants performed 5 cycle revolutions but against three different external loads: 25, 50, and 75 Watts. They observed that the burst duration did depend on workload duration (revolutions), but there were no significant differences in measures of burst duration, shape, or HP. There was a nearly discrete HR response to the initiation of exercise from rest, and a transient hypotension and sinus tachycardia that accompanied large muscle activation. They used Analysis of Variance (ANOVA) and post hoc significance tests (Fisher's protected least significant difference tests) to show that there were no significant differences in measures of burst magnitude, HP or shape based upon the work duration (i.e. the number of revolutions - 1, 3, 5 revolutions). However, two of the time parameters of the HP (burst duration and tachycardia duration) showed a significant relationship to work load duration. The HP burst duration and the duration of tachycardia showed p values of 0.033 and 0.0066, respectively to work load duration. This is relevant because it indicates that HR may be related to work load. It is important to note that there was evidence in their data of a relationship between number of revolutions (repetitions) and HP (inverse of HR), the ANOVA post hoc analysis indicated 1-revolution values to be significantly different from both 3- and 5- revolutions values, which the authors did not address. Figure 1 shows the effect of the number of revolutions performed on the HP. These researchers did not observe a relationship between HP and workload (See Figure 2 below). However, in this study they employed a very small range of loads. Further, they inappropriately used a "zero load" condition in the analysis. A zero load condition only refers to the fact that there was no additional load provided externally by the bike. Ignoring the zero load condition, close inspection of the data shown in Figure 2 shows a nearly linear decrease in heart period with increasing load.

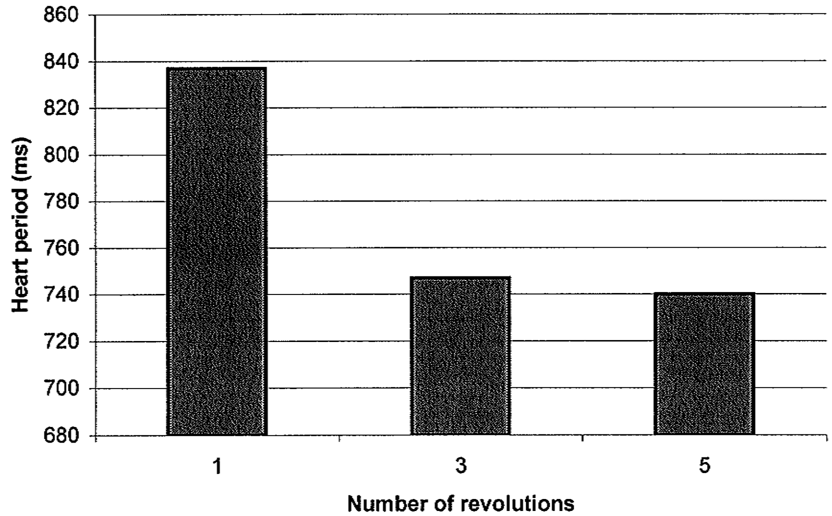


Figure 1. Heart period during the first 30 s after initiating a bout of exercise with different number of revolutions per exercise session (1, 3, 5 revolutions). Adapted from Roach et al. (1999).

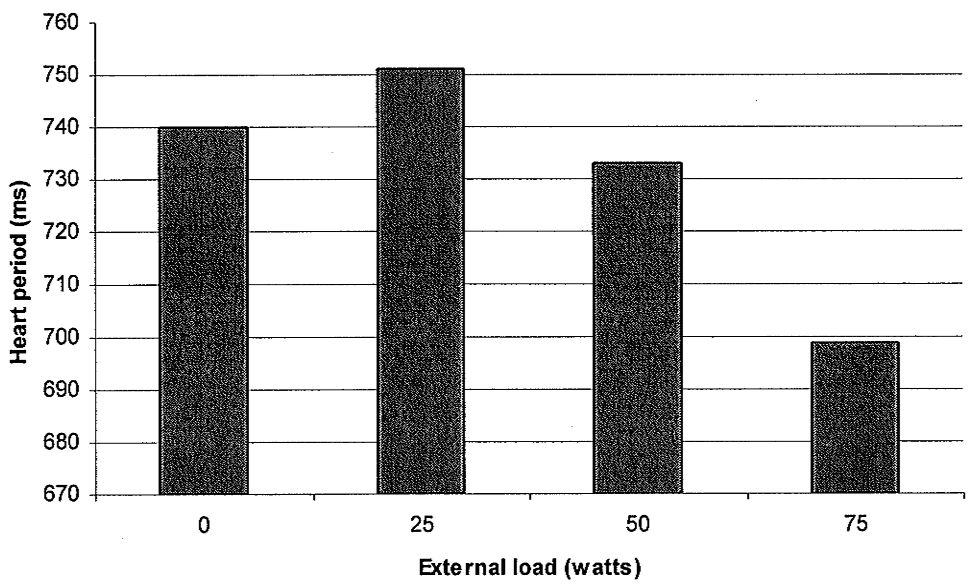


Figure 2. Heart period during the first 30 s after initiation of a bout of cycle exercise at different external loads (0, 25, 50, 75 W). Adapted from Roach et al. (1999).

Galvez and colleagues (2000) investigated the relationship between HR and muscle mass, as well as HR and the level of force (load). In this study they recorded heart rate during isometric contraction of one muscle group sustained to exhaustion at two different force levels. They used two tasks to examine the effect of muscle mass on heart rate; task 1 was a one-handed handgrip task and task two was a two-handed wheel grip task. After determining the maximal force during these tasks, they required the participants to perform isometric contractions at 20% and 50% of the maximal force for each of the tasks (See Figure 3 below). They found that peak HR increased with both the intensity of isometric contraction and the amount of muscle mass involved (See Figure 4 below). Multiple regression analysis of the relationship between maximum HR and percentage of maximum force, type of the contraction, basal heart rate, duration and force of the contraction showed that maximum HR increased by a mean of 30.1 beats/min from 20 to 50% of MVC (95% confidence interval 18.7-41.5), and a mean of 20.7 beats/min from handgrip to wheel-turn contractions (95% confidence interval 13.0-28.4). Both resting heart rate and contraction duration had a significant effect on maximum HR. The model was statistically significant ($p<0.0001$) and explained more than one-third of the relationship of the independent variables to maximum HR (adjusted $r^2=0.36$). They reported the absence of a linear relationship between the intensity of the isometric contraction and peak HR, however they only used two actual load conditions, and used a supine resting condition to inappropriately identify "zero" load in the regression.

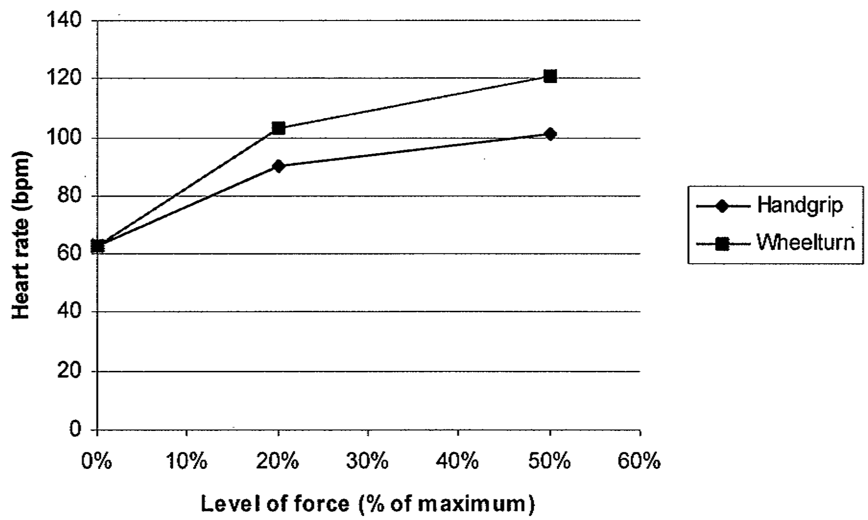


Figure 3. Relationship between maximum HR and the level of isometric contraction for handgrip and wheel-turn trials at 20 and 50% of maximal contraction. Adapted from Galvez et al. (2000).

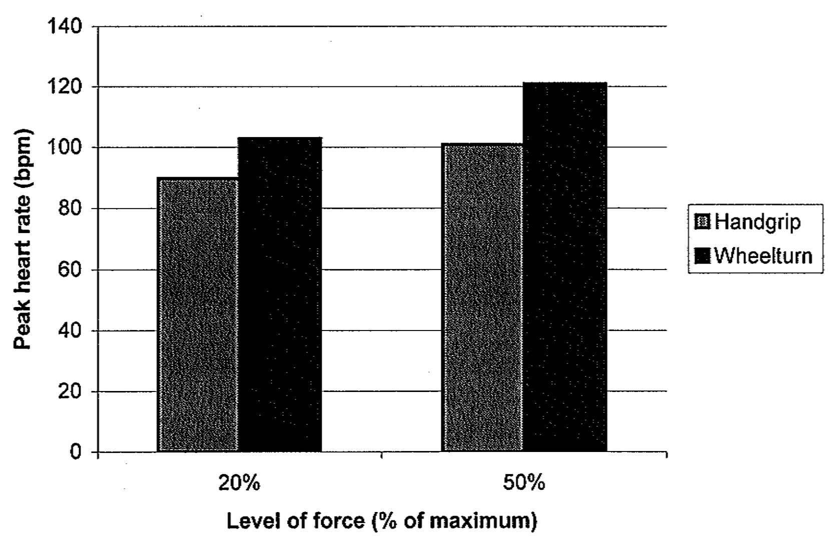


Figure 4. Comparison between level of force in handgrip and wheel turn at 20% and 50%, and peak HR. Adapted from Galvez et al. (2000).

Summary

Two studies have examined the relationship between HR and short duration exercise. In both of the studies, the range of loads and range of repetitions employed was very small. As well, in both studies inappropriate zero load conditions were used which would have limited the ability to fully detect relationships between HR and short duration exercise parameters (weight, repetitions, muscle mass). Further study is required to systematically examine the relationship between HR and short duration exercise parameters.

Section II - Resistance Training Parameters

Resistance training provides an effective method for improving neuromuscular strength and endurance. It uses a systematic loading program principle that exerts an exercise intensity specific effect in the neuromuscular and cardiovascular system during short periods of time. This exercise intensity dictates the specific physiological and metabolic changes in the body during exercise training.

In addition to affecting strength and endurance, resistance exercise also builds body mass, lowers blood pressure, reduces body fat levels, and may prevent the development of low back pain syndrome. For many years, strength gains were assumed to result directly from increases in muscle size; however, it is now known that muscle hypertrophy is only one aspect of increased strength from resistance training. An increased muscle mass has been found to correlate with an increased basal metabolic rate indicating that muscle mass is a major component of daily energy expenditure. Training strategies result in changes to muscle mass which complement aerobic exercise. As such, resistance training seems to result in a decrease in cardiac demands during daily activities like carrying groceries or lifting moderate-to-heavy objects, while simultaneously increasing the endurance capacity to sustain these sub maximal efforts. In order to understand how HR is affected during resistance training exercise, it is important to identify the key resistance training parameters, which may affect HR:

a. Weight

b. Repetitions
c. Sets
d. Rest Time
    i. Time between sets
    ii. Time between exercises
e. Range of motion
f. Type and sequence of contractions (isometric, concentric, eccentric)
g. Number of Segments – Single segment vs. multi-segmental motion
h. Upper Limb versus Lower Limb Resistance Exercise

Section III - HR responses to aerobic exercise.

The cardiovascular system provides an adaptable regulation of HR and an effective distribution of blood in the vascular circuit while it maintains blood pressure (BP) in response to the body's metabolic and physiological needs. The proportional increase discharge of the SNS, the increase in the arterial pressure and the increase in the CO are the essential effects required of the circulatory system to supply the blood flow required during exercise. The factors that determine the above mentioned effects are the neural control (NC), CO, SV, and HR, as follows:

A. NEURAL CONTROL (NC)

The HR is determined primarily by autonomic influences either on the sinoatrial (S-A) node, or the atrioventricular node (A-V) node, or the bundle system. The S-A node is normally the pacemaker of the heart, because it has the fastest spontaneous rate of depolarization in normal adults.

The heart is innervated by both divisions (parasympathetic (PNS) and sympathetic nervous systems (SNS) of the autonomic nervous system through the cardiac plexuses, which can modify the rate, as well as the strength of the beat. The parasympathetic supply comes from the vagus nerves while the sympathetic supply comes from the branches originating in the first four thoracic spinal root levels. The SNS controls heart action in emergency or exercise situations up to 230 bpm.

During exercise, there is a need for greater blood flow and for acceleration of HR through neural control of the pacemaker tissue however, neural tissue stimulation is not required to initiate a change in the pacemaker tissue activity resulting in a change in heartbeat. Norepinephrine not only depolarises the SA node membrane, producing more frequent action potentials and more rapid HR, but also increases the force of heartbeat and causes dilatation of the coronary arteries.

B. CARDIAC OUTPUT (CO)

An increase in CO is necessary during exercise to deliver adequate blood supply to exercising muscles and maintain flow to vital organs. The two determinants of cardiac output are HR (beats per minute) and SV (volume of blood pumped per beat or stroke). The average CO at rest is 4900 mL/min or approximately 5 L/min for both trained and untrained individuals. In trained individuals blood is circulated with the proportionally larger SV of 100 mL/beat at a diminished HR of 50 beats per minute. During exercise the CO can increase to 20 to 25 litres per minute, and CO would be as high as 40 litres per minute in trained athletes during heavy exercise. In trained athletes, the SV is nearly maximal at rest and increases only slightly during exercise. CO is associated with the aerobic capacity. An increase in maximum CO results in a proportionate increase in the capacity to circulate oxygen: with a CO of 16 L, 3200 mL of oxygen is circulated each minute (16 L x 200 mL O2/L). A low aerobic capacity is closely associated with a low maximum CO, whereas the ability to generate a percentage of 5-6 L VO2 max is always accompanied by a 30 L to 40 L CO. The CO increases linearly with O_2 uptake through the major portion of the work range.

C. STROKE VOLUME (SV)

Under normal conditions SV is about 70 mL per beat. In normal conditions, the SV can be influenced by both an intrinsic and an extrinsic control. The intrinsic control is related to the extent of venous return, and the extrinsic control is related to factors originating outside the heart (e.g. SNS control). The intrinsic control can be defined as the heart's inherent ability to vary the SV; it depends on the length-tension relationship of cardiac muscle, which is similar to that of skeletal muscle with the difference being that the heart does not have any bony attachment. For cardiac muscle, the main determinant of stroke volume is the degree of diastolic filling. Therefore, according to the length-tension curve, the more the heart is stretched with blood (venous return), the stronger the contraction resulting in a greater SV (Frank-Starling Law). Under normal circumstances the cardiac muscle does not get stretched beyond its optimal length to the point that contractile strength diminishes with further stretching.

The extrinsic control leads to a more complete ejection that is regulated by the cardiac sympathetic stimulation and catecholamines. The increased contractility is due to the increased Ca^{2+} influx triggered by norepinephrine and epinephrine that allows the myocardial fibers to generate more force through greater cross bridge cycling. Strobel et al. (1994) showed that increments in plasma noradrenaline-sulphate concentrations increases with exercise intensity and duration regardless of the pattern of power output. For trained people, large amounts of blood flow fill the ventricles during diastole; their end-diastolic volumes (EDV) can become as great as 150 to 180 mL in the normal heart, with a decreased end-systolic volume (ESV) that allow trained people to have a more effective stroke volume and higher range to increase HR from resting HR in response to exercise.

D. HEART RATE (HR)

In order to look at HR compliance it is important to know the normal parameters for adults at rest. The average resting HR is 70 beats per minute for normal sedentary adults, and around 50 beats per minute for trained adults. This rhythm is established by the influence of parasympathetic action on the SA node. When the SA node reaches a threshold, an action potential is initiated and spreads throughout the heart, inducing the heart to contract or have a "heartbeat". The heart muscle has a relatively long period of depolarisation of approximately 0.20 to 0.30 s. The time required for the heart to be able to contract again is called refractory period and provides sufficient time for ventricular filling between beats. Endurance training shortens the heart rate recovery period.

Factors that control HR during exercise

During aerobic exercise it is believed that there are three mechanisms that control HR response; 1) the feed-forward central command system, 2) the feedback peripheral input system, and 3) the local effects in the muscles acting directly on the vessels. However, the mechanisms that control HR response have not been well elucidated for resistance training exercise.

1) The feed-forward central command controls neural impulses originating in the brain's higher somatomotor centre located bilaterally in the reticular substance of the medulla, and in the lower third of the pons. It activates central neuronal motor systems such as the vasomotor centre. The vasomotor centre has important areas within it: C-1 or vasoconstrictor area, A-1 or vasodilator area, and A-2 or sensory area or Nucleus Tractus Solitarious (NTS).

2) The feedback mechanism, referred to as the exercise pressor reflex or the muscle chemoreflex, controls cardiovascular motor outflow by transmitting mechanical and metabolic signals generated by contracting skeletal muscle to the brain stem. The afferents from mechanoreceptors and chemoreceptors provide a rapid feedback necessary to modify either parasympathetic or sympathetic outflow. This mechanism is not well established, however, it is believed that input from the mechanoreceptors that are located in the left ventricle, right atrium, and large veins with the input from baroreceptors located in the aortic arch and the carotid sinus,

modify sympathetic outflow from vasomotor center and respond to changes in arterial BP. During exercise, BP gradually increases due to the increasing demands of CO, so there is arterial vessel stretching that in turn activates the baroreceptors until the point that brings about a slowing of the reflex and a compensatory dilatation of the peripheral vasculature. The local increase in blood flow, during muscle contraction is probably caused by several different factors operating at the same time.

3) During exercise, blood flow increases rapidly as previously unused capillaries are opened. There is a local decrease in tissue's oxygen supply and few increases in temperature, carbon dioxide, acidity, adenosine, and ions such as magnesium and potassium as well as the production of nitric oxide by the vascular endothelium of blood vessels. Blood flow increase is achieved via a potent local stimulus for vasodilatation in skeletal and cardiac muscle. The dilatation of pre-capillary sphincters is brought about by the action of increased local blood pressure by the intrinsic neural control, and by local metabolic factors. Radegran and Saltin (1998) studied muscle blood flow at the onset of dynamic exercise in humans. It was concluded that the elevation in blood flow with the first duty cycle (s) is due to the muscle mechanical factor, but vasodilators initiate a more potent amplification with the second to fourth contraction. Zhao et al. (1997) studied the effects of exercise training on coronary vasodilatation following activation of the Bezold-Jarish reflex in conscious dogs (vagally mediated coronary vasodilatation). They believed that the mechanism responsible for the enhanced coronary vasodilatation was most likely due to the increased release of nitric oxide from the endothelial cells. This hormonal response releases large quantities of epinephrine and a small quantity of norepinephrine into the blood. These bring about a generalized constrictor response in blood vessels except for those of the heart and skeletal muscles. This is because the demands in working muscle during exercise have to be met. In Exercise Physiology, 4th ed., 1996, p.303, it is stated, that in skeletal muscle, the

level of blood flow actually increases from 20 to 84% during maximal "big muscle" exercise (e.g. running).

i. Duration- Exercise Intensity

During aerobic exercise, HR increases linearly with workload (Watts) (See Figure 5 below) and VO_2 (oxygen uptake). At low levels of aerobic exercise and at a constant work rate, HR will reach steady state within several minutes (after 2 minutes) and will maintain this steady state condition as long as the metabolic demands during the exercise require this oxygen uptake stabilization. As workload increases, the time necessary for the HR to reach steady state will progressively lengthen. During resistance training, exercise intensity is dependant upon the load (estimated by weight), the number of repetitions, inter-repetition and inter-set rest time and the individual's fitness level. Because of the short set durations (typically less than 2 minutes) of resistance training exercise, steady state may not be achieved and has not been established in the literature thus far, it is important to examine if steady state can be achieved under other conditions than the one's illustrated to date in the literature. Therefore, monitoring set duration, rest time, and exercise intensity, will permit examination of the effect of these variables on HR response.

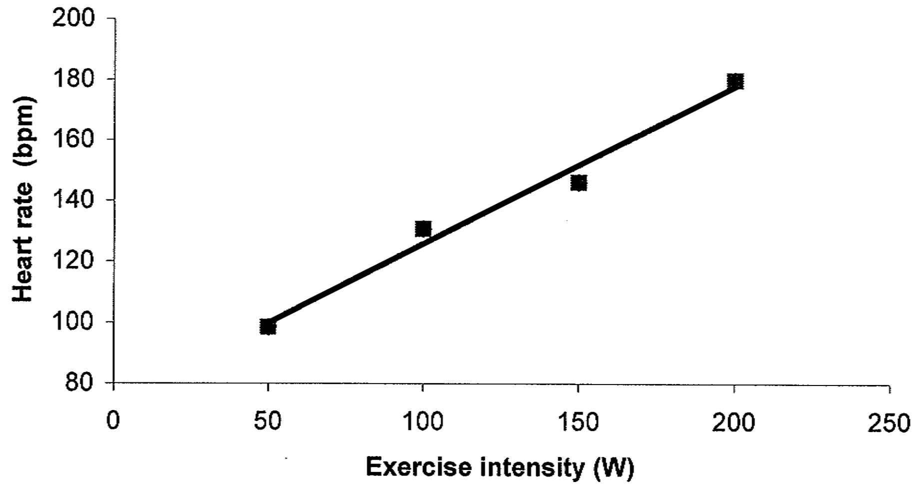


Figure 5. Heart rate obtained from at least three sub-maximal exercise intensities may be extrapolated to the age predicted maximal heart rate. A vertical line to the intensity scale estimates maximal exercise intensity. Adapted from ACSM's Guidelines for Exercise Testing. (1991) p.42

ii. Type of Exercise

During muscle contraction, the peripheral arterial system is mechanically compressed which causes a sustained reduction in muscle perfusion and a large increase in peripheral resistance that is directly proportional to the percentage of the maximum force capacity exerted by an individual (Exercise Physiology, 4th ed., 1996, p.276.) Consequently, sympathetic nervous system activity, CO, and mean arterial pressure increase dramatically in an attempt to restore peripheral muscle blood flow during exercise. The magnitude of this response is directly related to the exercise intensity and the size of the muscle mass involved. Investigations seem to indicate that exercise requiring a large muscle mass and greater relative strain elicits the greatest BP response. This response is due to a greater stimulation of the cardiovascular center by the active areas of the motor cortex and a large peripheral feedback to this center from the contracting muscle mass. However, for short duration exercise, the mechanism has not been well defined yet.

iii. Posture

The HR increases when your body shifts from a reclining to a standing position (See Figure 6 below), because SV immediately drops by venous pooling and gravity reduces the volume of blood returning to the heart due to venous compliance. HR increases when changing to upright position from sitting or supine in order to maintain the CO. In Exercise Physiology, 4^{th} ed., p.301, it is stated, "Once in graded upright exercise, progressive increases in SV occur through the combined effect of an enhanced diastolic filling (muscular pumping) and a more complete emptying during systole". There is a great systolic ejection despite the increased resistance to blood flow provided by the total peripheral resistance (TPR) to the after-load (ESV); due to the heart's ability to contain a functional residual volume of blood and with or without an increase of the end-diastolic volume (EDV) (at rest in the upright position, approximately 40% of the total end-diastolic blood volume remains in the left ventricle after a beat), an enhanced myocardial contractile force (stroke power) is stimulated by the action of catecholamines during exercise. Therefore, stroke power is augmented in order to facilitate the systolic emptying of the heart.

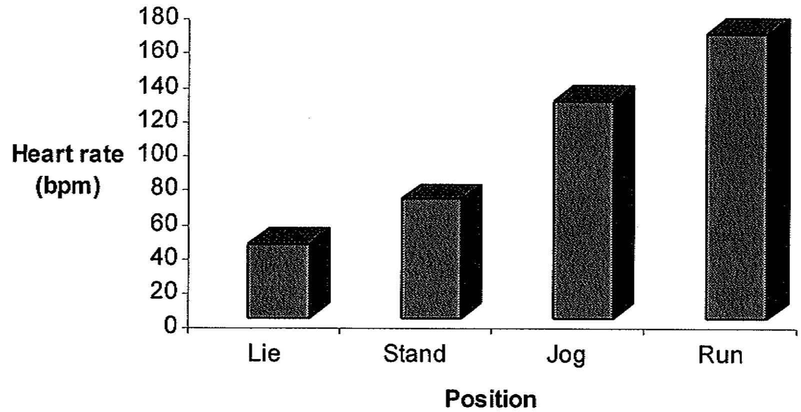


Figure 6. Changes in heart rate with changes in posture and the level of exercise (jogging at 8 km/h and running at 12 km/h). Adapted from Wilmore and Costill (1999) p.229.

iv. Thermal

At rest, only 15-20% of the resting CO goes to muscle, but during exhaustive exercise the muscles receive 80% to 85% of the CO, by reducing blood flow in kidneys, liver, stomach, and intestines. As the body starts to overheat, as a direct result of exercise or because of high environmental temperatures, more blood is redirected to the skin to conduct heat away from the internal body to its periphery, where the heat is transferred to the environment and core body temperature can be maintained within a safe range. The more blood that flows to the skin, the less that is available for the muscles; this is called cardiovascular drift. Cardiovascular drift corresponds to a progressive increase in HR with constant workload due to thermal demands. With prolonged aerobic exercise in a hot environment, at a constant rate of work, there is a gradual decrease in SV, and an increase in HR in order to maintain CO reasonably constant (See Figure 7 below). Dr. Edward Coyle and colleagues (1974), cited by Physiology of Sport and Exercise, 2d ed., 1999, p.232, were able to greatly attenuate cardiovascular drift by maintaining participants in a fully hydrated state. CO remains reasonably constant throughout a 30-minutes exercise bout in a 20 to 36°C environment through an increase in HR. Therefore, exercise-time duration increases HR in a proportional relationship. Fink and co-workers (1991) cited by Physiology of Sport and Exercise, 2d ed., 1999, p.322) demonstrated that exercise in the heat increases oxygen uptake, increasing muscle use of glycogen, as well as to increase production of lactate. Increased heat production and respiration demand more energy, which requires a higher oxygen uptake. During resistance training exercise, the mechanism of heat dissipation vs. exercise intensity is not well established.

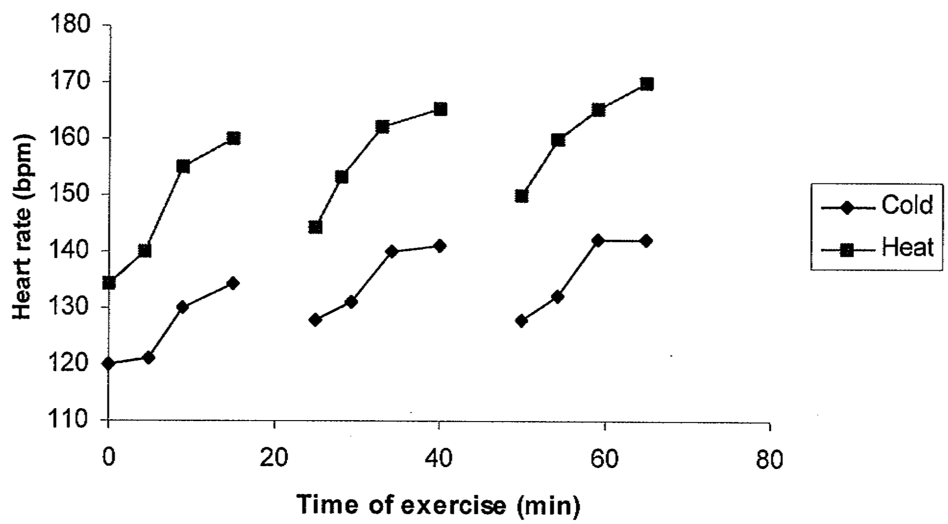


Figure 7. Heart rate responses during exercise (cycling) in hot (40°C, 15% Humidity) and cold (9° C, 55% humidity). Adapted from Wilmore and Costill (1999) p.322.

v. Age

HR response to maximum dynamic exercise depends on numerous factors that have been previously stated, including age and fitness level. Balady G, Fletcher GF, Froelicher VF, Hartley H, Haskell W, Pollock M. (1995) stated that "it appears a reduction in HR averages 5 to 7 beats per minute per decade and is primarily related to neural influences". Both young and older persons exhibit a linear relationship between HR and oxygen uptake, but the younger person has higher HR values (See Figure 8).

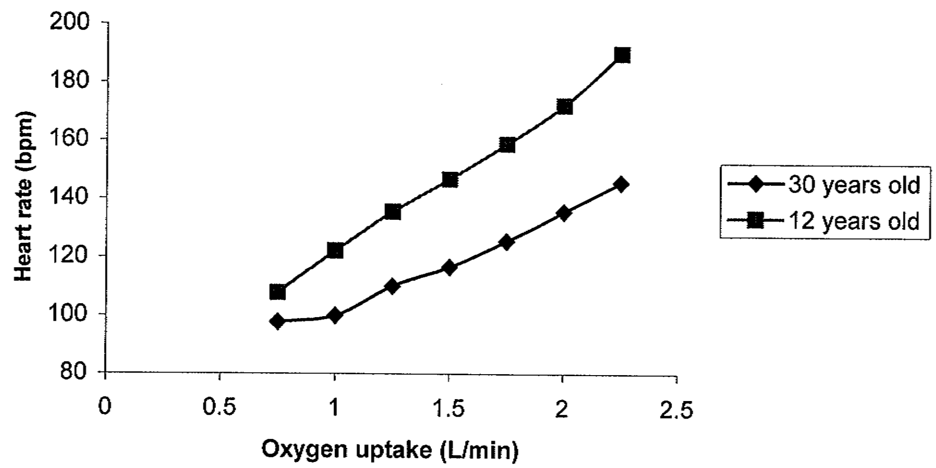


Figure 8. Sub-maximal heart rate versus oxygen uptake in a 12 year-old boy and a fully mature man. Adapted from Wilmore and Costill (1999) p.528.

vi. Sex

SV and CO for women usually average approximately 25% below values for men. This gender difference is essentially due to the smaller body size of the average women. Both teenage and adult females, need a 5 to 10% larger CO, which is most likely due to the 10% lower concentration of hemoglobin in women compared with men. Women's hearts beat faster than men's during exercise (Exercise Physiology, 4th ed., p.305)

vii. Training level

During light and moderate intensity exercise, oxygen deficit in the trained and untrained person is comparable. For the endurance-trained person, however, the steady rate is reached more rapidly and with smaller oxygen deficit compared to someone who is untrained (Exercise Physiology, 4th ed., 1996, p.126). Endurance training shortens the HR recovery period; therefore, a more-fit person recovers faster after a standardized rate of work than a less-fit person (Exercise Physiology, 4th ed., 1996, p.126). In a trained-person, the increase in CO is made at the expense of HR since SV remains almost at its maximum level both during exercise and in normal conditions (See Figure 9). Those with better physical endurance capacity will have lower steady-state HR at a given rate of work than those who are less fit (Physiology of Sport and Exercise, 2d ed., 1999, p.224).

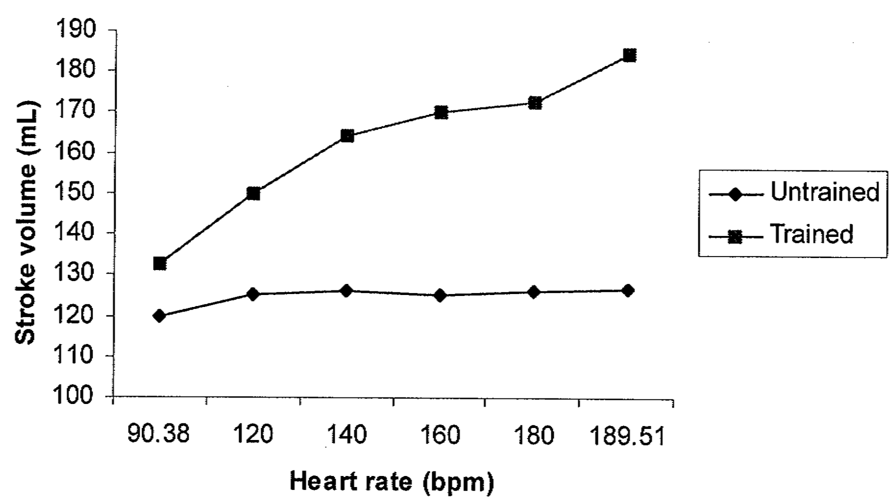


Figure 9. Increases in SV with increasing heart rate and exercise intensity in trained cyclist and untrained participants. Adapted from Wilmore and Costill (1999) p.226.

viii. Steady State

When dynamic aerobic exercise starts, oxygen uptake by the lungs rapidly increases. After the second minute when the rate of work is held constant at sub-maximal levels of exercise, HR increases fairly rapidly until it reaches a plateau corresponding to steady state metabolism. During steady state, oxygen uptake remains relatively stable at each intensity of exercise and HR, CO, BP, and pulmonary ventilation are maintained at reasonably constant levels required to meet the circulatory demands due to a specific rate of work (Physiology of Sport and Exercise, 2d ed., 1999 p.224).
During short duration sets of exercise, studies have not been done to see if it is possible to reach steady state HR. Steady state is normally achieved after two or more consecutive minutes of work, and resistance exercise normally has set durations for not more that one and a half minutes depending upon number of repetitions and pace during the exercise.

ix. Valsalva Maneuver

A person is said to perform the Valsalva maneuver when exhalation is attempted against a closed glottis (which prevents the air from escaping). This maneuver or a modified or partial form is commonly performed during lifting heavy weights. It results in an increase in the intra-thoracic and intra-abdominal pressures and pushes backwards the vertebral column making it more stable and protected against injuries. This compression of the thoracic veins however, causes a fall in venous return, which consequently decreases the SV, and arterial BP. Nevertheless, in order to maintain the CO levels required during exercise, there is a requirement to increase HR. When the glottis is finally opened and the air is exhaled, the CO returns to normal but the total peripheral resistance is still elevated, causing a rise in BP. The BP is then brought back to normal by the baroreceptor reflex, which causes a slowing of the HR or negative feedback baroreceptor reflex (Accepted bibliography Physiology of Sport and Exercise, 2d ed., p.262, Exercise Physiology, 4th ed., p.221, Neuromechanical Basis of Kinesiology, 2d ed., p.57).

x. Stage of exercise

During initial stages of exercise in aerobic exercise, increased CO is caused by increase in both HR and SV. Once exercise begins, HR and oxygen consumption do not increase instantaneously to a steady rate. Oxygen uptakes rise in an exponential fashion (See Figure 10 below) and after some minutes, depending on the exercise intensity, a plateau is reached and the oxygen uptake remains relatively stable for the duration of the exercise (steady state or steady rate). This represents a balance between the required energy by the working muscles and ATP production via aerobic metabolism. The lack in oxygen at the beginning of the exercise is called oxygen deficit. When the level of exercise exceeds 40% to 60% of the individual's capacity, SV has either plateaued or begun to increase at a much slower pace, thus, further increases in CO are largely the result of increases in HR during short period exercise.

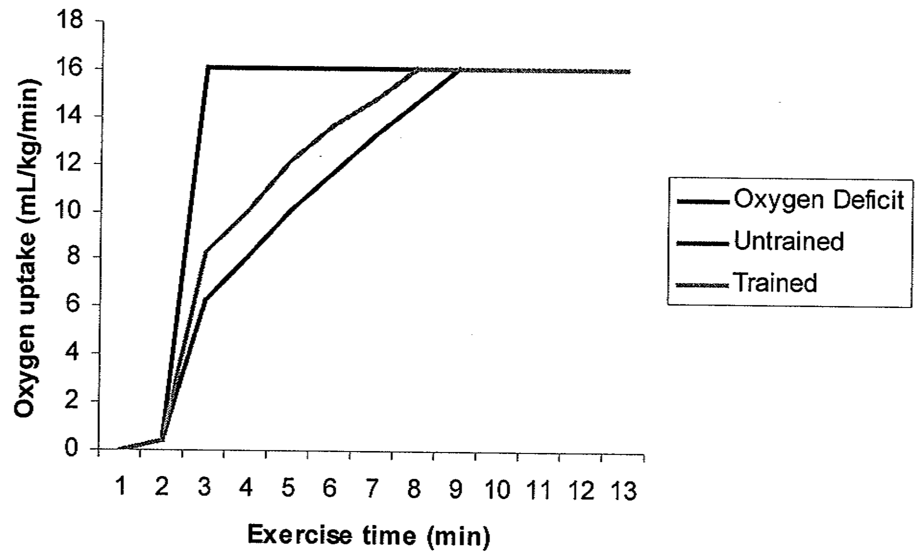


Figure 10. Time course of oxygen uptake during a continuous jog at a relatively slow pace for endurance-trained and untrained individual who exercise at the same steady-rate VO_2. Adapted from McArdle, Katch, and Katch (1996) p.125

xi. Exercise Level-Recovery Time

The specific metabolic and physiological processes resulting from each effort level determine the variation in recovery from light, moderate, and strenuous exercise. The amount of oxygen the body consumes is directly proportional to the energy expended during physical activity. At rest, the human body uses approximately 3.5 ml of oxygen per kilogram of body weight per minute (1 MET). During light aerobic exercise, when the oxygen deficit is small and the steady-rate oxygen uptake is reached rapidly, the recovery oxygen uptake is also small as recovery proceeds quickly. With moderate to heavy aerobic exercise a person takes longer to reach a steady rate, thus, the oxygen deficit is considerably larger compared to light exercise therefore it takes longer to return to the resting level during recovery. Anaerobic energy transfer is large, blood lactate accumulates, and considerably more time is needed for complete recovery. When the energy demands are exceeded, the maximal or peak oxygen uptake and the true oxygen deficit are difficult to determine (Exercise Physiology, Section 2, 4th ed., 1996).

xii. Lower versus Upper Limb Exercise

There are differences in the oxygen uptake levels between exercises performed at the same submaximal intensity level (See Figure 11 below). This could have a differential impact on the HR response required for upper versus lower limb exercise. This might be due to an upper body physiological inefficiency caused by the lack of exposure of the upper body to repetitive tasks compared with the lower limbs that do repetitive tasks during normally daily activities i.e., walking and/or standing. The upper body may be less efficient in recruiting muscle tissue in order to perform a task at the same submaximal exercise intensity than the lower body. In Exercise Physiology, 4th ed., 1996 p. 308, it is stated that "greater metabolic and physiologic strain accompanies a standard submaximal exercise load with the arms" and that is the reason why exercise prescriptions based on running and bicycling cannot be applied to arm exercise and viceversa.

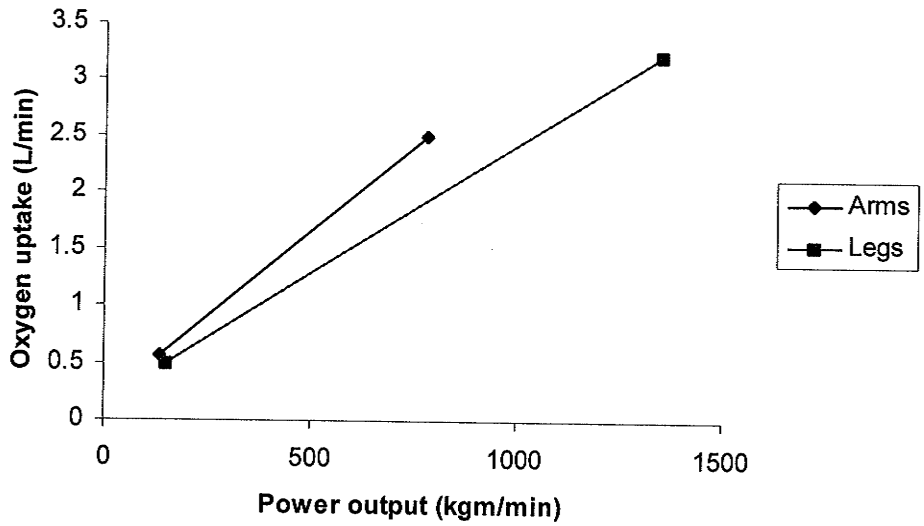


Figure 11. Arm exercise requires a greater oxygen uptake compared to leg exercise at any sub-maximal power output throughout the comparison range. Adapted from McArdle, Katch, and Katch (1996) p.307.

METHODOLOGY

There were two protocols established to address the three objectives of the study. Protocol 1 was established to investigate the relationship between the peak HR achieved during each set of exercise with variation in the weight lifted for each set. Protocol 2 was established to investigate the relationship between the peak HR achieved during each set of exercise with variation in the number of repetitions per set. The second protocol was also used to determine if HR profiles could be used to accurately assess the duration of each set of exercise. Further, for each protocol the relationships were evaluated for both an upper body exercise (dumbbell row) and a lower body exercise (squat).

Participants

For the two protocols the inclusion criteria allowed for male and females participants with ages ranging from 18 to 45 years. This is based on the normal age range for healthy individuals according to ACSM's guidelines for exercise testing and prescription (2000). A total number of 31 participants were included in the study for all protocols. Sixteen participants performed protocol 1, of which 10 performed dumbbell row and 6 performed squat exercises. Fifteen participants performed protocol 2, of which 10 performed dumbbell row and 5 performed squat exercises.

Power analysis

In order to establish the minimum sample size for adequate power of the study, alpha and beta values were required to predict the possibility of type I and type II errors in the study. The Alpha value was selected as 0.05, which means there is a 5% chance of making a Type I error that accepts H1, when there is no real evidence of a relationship between variables. A lower Beta value was selected to guard against Type II errors. The Beta used in the power calculation was 0.05 or power of 0.95, in order to have only 5% risk of missing an effect of a Type II error that rejects H1, when there is a real relationship between the variables. A 95% power of detecting a (relative effect) difference of 10 bpm or greater was desirable. Regression analysis for HR vs. weight and HR vs. number of repetitions for each subject was performed (MS Excel 2000) and the true standard deviation of the results was near 8 bpm (with testing at the usual .05 level). Therefore, for each objective 1 and 2, a minimal sample size of 8.29 in total was required. 16 participants for objective 1, and 15 for objective 2 were included to allow for missing or corrupt data and participant attrition. 35 participants were recruited, but the data from 4 participants were excluded due to their lack of compliance during the session.

Power Index=1.96(0.05α,two-tailed) + 1.64 (0.05 β, one-tailed)

σ Standard deviation of the differences (estimated =8)

μ True mean difference or relative effect (estimated = 10)

Power Index PI=3.60

Sample size $n=(PI\times\sigma/\mu)^2$

$n=(3.60\times8/10)^2=8.29$

Inclusion Criteria

The inclusion criteria were developed to select participants that were physically active and healthy. Participants were selected based upon their level of participation in resistance training exercise (See Appendix A and B for questionnaires).

- Male and female participants aged 18-45.
- Healthy, defined as not having had any type of medical problems within the last 12-month period.
- Participants should have had regular participation 1-4 times a week in resistance training for the last three months.

Exclusion Criteria

Participants were excluded from the study if they reported YES to any of the standard questions of the PAR-Q (see Appendix A), and any one of the questions (questions 7 to 11) in the supplemental questionnaire (see Appendix B),

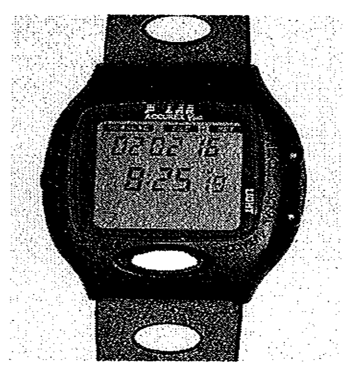
- Participant smoked.
- Reported a history of high blood pressure.
- Any medical or orthopaedic conditions, which might alter the ability of the person to perform the study, based upon the participants self-report.
- Known history of cardiovascular diseases or electrical arrhythmias.
- Pregnant or breast-feeding females.
- Known consumption of substances/stimulants in the past 24 hours.
- An inability to understand and follow instructions.

Recruitment and Informed Consent

Participants were recruited by word of mouth and posters at the Bannatyne campus and the Fort Garry campus of the University of Manitoba. All participants were required to complete an informed consent after reading the participant information and having the opportunity to ask questions related to the study prior to participation in study. Each protocol had a separate participant information consent form (See Appendix C).

Instrumentation

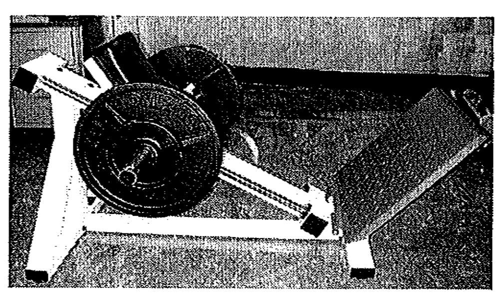
Heart Rate Monitors



A telemetry Polar Accurex Plus (Polar Inc., USA) heart rate monitor (HRM) (inset picture shown to right) was utilized for the study. The HRM consists of three parts: 1) chest transmitter with electrodes, 2) elastic strap, and 3) wrist receiver. The chest transmitter detects the electrical activity of the heart (QRS complexes), and the signal is transmitted via radio waves to the wrist receiver where the signal is processed and the time interval between successive R-R intervals of the QRS complex is determined. The wrist receiver can store up to a maximum of 4008 total records. The HRM can store HR data at 5, 15 and 60-second intervals, as well as record the R-R intervals. The HR is sampled by the watch receiver at the end of these time sampling intervals and is not an average of the time interval (5, 15 or 60 second). The HRM uses the last RR interval of the sample to calculate the heart period (HP). As HP is the inverse measure of the HR (1/HR), the HR (bpm) can be transformed from HP (ms) by dividing by 1000 and multiplying by sixty. All HR data can be downloaded to a PC using a special interface (Polar Interface, Polar Inc, USA) for future analysis. The HR data files are stored in text format, which can be imported to a spreadsheet program (Excel, Microsoft Inc.) or other analysis software. Each file contains the date and time that the HR recording commenced, as well as temporal markers that can be recorded by pressing a 'mark' button on the wrist receiver. The mark button (shown in white on the inset picture of the watch receiver) is depressed to record time-stamps.

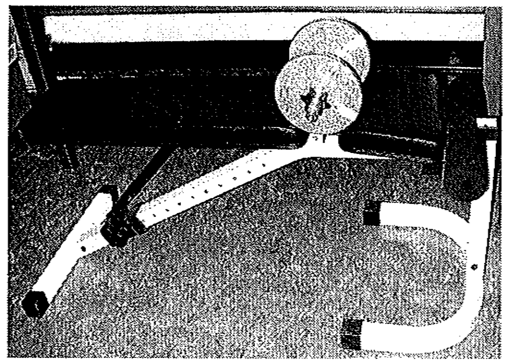
The accuracy of HRM systems has been evaluated by a number of researchers, as follows: Strath et al. (2000), Laukkanen and Virtanen (1998), Kinnunen and Heikkila (1997), Lewis (1992), Wacjciechowski et al. (1991), Godsen et al. (1991), Seaward et al. (1990), Macfarlene et al. (1989), Treiber et al. (1989), Leger and Thivierge (1988), Karvonen, (1984). All have recognized the Polar HR monitors as an accurate tool for HR monitoring. These systems have shown suitable accuracy with correlation coefficients (r) between HR (from different HRM) and ECG tracings, in the ranges of 0.93 to 1.00, with SEE of 0.65 to 1.1-4.4 beats/min.

Hack Squat Device



A hack squat machine (inset picture shown to right) was used to perform the lower body (LB) exercise. This device consists of a backrest, which rides along linear bearings to permit the participant to perform a constrained squat motion. The sliding mechanism has a lock/unlock lever mechanism that allows the participant to lock the squat sit in a resting position at the beginning and end of a set. The bar has a rapid lock/unlock mechanism that permits the addition of plate weights of various values (0.5 kg to 20 kg). The use of the device constrains the motion primarily to one plane, and permits the range of motion to be controlled by simple visual methods.

Dumbbell and Flat Bench



A star lock dumbbell and a flat bench (inset picture shown to right) were used for the subject to perform the upper body (UB) dumbbell row exercise. The star lock dumbbell has a rapid lock/unlock mechanism to permit plate weights to be added to the dumbbell (approximately 0.25 kg to 5 kg). The participant performed the dumbbell row in a bent-over position with one hand and one leg on the flat bench.

Experimental Design

Two experimental protocols were designed to address each objective. Each protocol has a common measurement technique of monitoring HR. Beyond this common element each protocol is described separately.

General Procedure

All participants were given uniform instructions about the procedures involved in the study and a general overview/familiarization of the equipment used in the measurement of HR during the resistance training exercise session. The participants were assessed using the PAR-Q and supplemental questionnaire to ensure that the inclusion and exclusion criteria were met. The heart rate monitoring equipment was attached to the participant.

The general exercise instructions were to 1) maintain the same pace during the session with the aid of an electronic metronome, 2) breath out during concentric contraction of the prime movers and breath in during eccentric contraction, 3) perform the exercise in controlled manner, 4) perform the exercise over the same range of motion per repetitions, and 5) press the red 'mark' at the beginning and end of each set. Each session lasted approximately 50 minutes in duration.

Objective Dependent Protocols

Protocol 1: Peak HR versus Weight

In this protocol, participants performed one of two exercises, either a dumbbell row (n=10) or squat (n=6). The weight lifted by the participants was progressively increased for each consecutive set. The subjects performed 10 repetitions per set with rest times between sets of 3 minutes in duration. A longer rest time was provided depending upon the HR after the completion of the 3-minute rest interval. The investigator attempted to permit the HR to return to pre-exercise baseline prior to commencing the next set. If proper form was not maintained during the completion of each set, the exercise was terminated.

Peak HR versus Weight Protocol

1. Subject screening and informed consent.
2. Familiarization with equipment and protocol.
3. Attachment of HR monitor.
4. Rest one-minute prior to exercise in the position assumed during the exercise without performing any exertion.
5. Perform the exercise (10 repetitions) with a low weight.
6. Increase weight with every set.
7. Rest between sets of 3 minutes:
    a. Remain in the same position after finishing for 1 min.
    b. Stand up and stand still for 1 min.

c. Return and remain to the same initial position for 1 min.

Upon completion of the experiment the heart rate data was downloaded to the computer. The weight used for each set was entered into a spreadsheet and combined with the heart rate data. The HR data was visually examined for errors (dropouts due to poor transmission between wrist receiver and chest transmitter). The peak HR was determined for each set based upon the markers stored in each file. The peak HR and weight data were combined into a spreadsheet. Linear regression was performed between the peak HR recorded per set and the weight per set.

Protocol 2: Peak HR versus Repetitions

As in protocol 1, participants performed one of two exercises, either a dumbbell row (n=10) or a squat (n=5). In this protocol, participants performed an increasing number of repetitions from 1 up to 25 depending upon their own capacity, using a fixed weight with a three-minute rest between sets. If the HR did not come back to the baseline, the rest time was extended until the HR approached the initial or baseline HR. The fixed weight was determined according to the participant's body mass, the participation level, and the weight the subject normally used during routine training. The exercise was performed to a maximum of 25 repetitions per set, depending upon fatigue and the amount of accessory and compensatory motion performed in each set. If proper form was not maintained during the completion of each set, the exercise was terminated.

<u>Peak HR versus Repetitions Protocol</u>

1. Subject screening and informed consent.
2. Familiarization with equipment and protocol
3. Attachment of HR monitor
4. Determination of weight for exercise.
5. Rest for one-minute prior to exercise in the position assumed during the exercise without performing any exertion.

6. Start with one repetition and increase one repetition for each set.
7. Rest between sets of 3 minutes:
    a. Remain in the same position after finishing for 1 min.
    b. Stand up and stand still for 1 min.
    c. Return and remain to the same initial position for 1 min.

Upon completion of the experiment the heart rate data was downloaded to the computer. The number of repetitions performed for each set was entered into a spreadsheet along with the weight used. This data was combined with the heart rate data into one spreadsheet file. The HR data was visually examined for errors (dropouts due to poor transmission between wrist receiver and chest transmitter). The peak HR was determined for each set based upon the markers stored in each file. The peak HR and repetition data were combined into a spreadsheet. Linear regression was performed between the peak HR recorded per set and the number of repetitions per set

Set Duration Protocol

This protocol was included with the peak HR versus repetitions protocol because it was recognized that there would be a systematic variation in the duration of each set due to a fixed increment in the number of repetitions per set. Further, since the HR monitors can be used as a stopwatch with a marker function (resolution of 0.1 s), there was an opportunity to obtain an accurate measure of set duration. The start and end of each set was marked by pressing the 'Marker' button on the stopwatch (wrist receiver which is part of the HR monitor). The set duration measured from the HR profile of the exercise session could be compared to the actual set duration measured by a stopwatch. The start and stop of each set was determined from the HR profile by visually identifying the onset of HR elevation (start) and the end was assessed as the peak HR (See Figure 12 below). For this study, the HR monitor recorded heart rate data on 5 second time intervals but the stopwatch recorded the set duration to a resolution of 0.1 s. Figure 13 illustrates the impact of a 5 s HR recording interval in comparison to the actual instantaneous HR profile measured during one set of exercise consisting of 25 repetitions. It is apparent that the effect of 5 s recording does not have any substantial impact on the estimation of set duration.

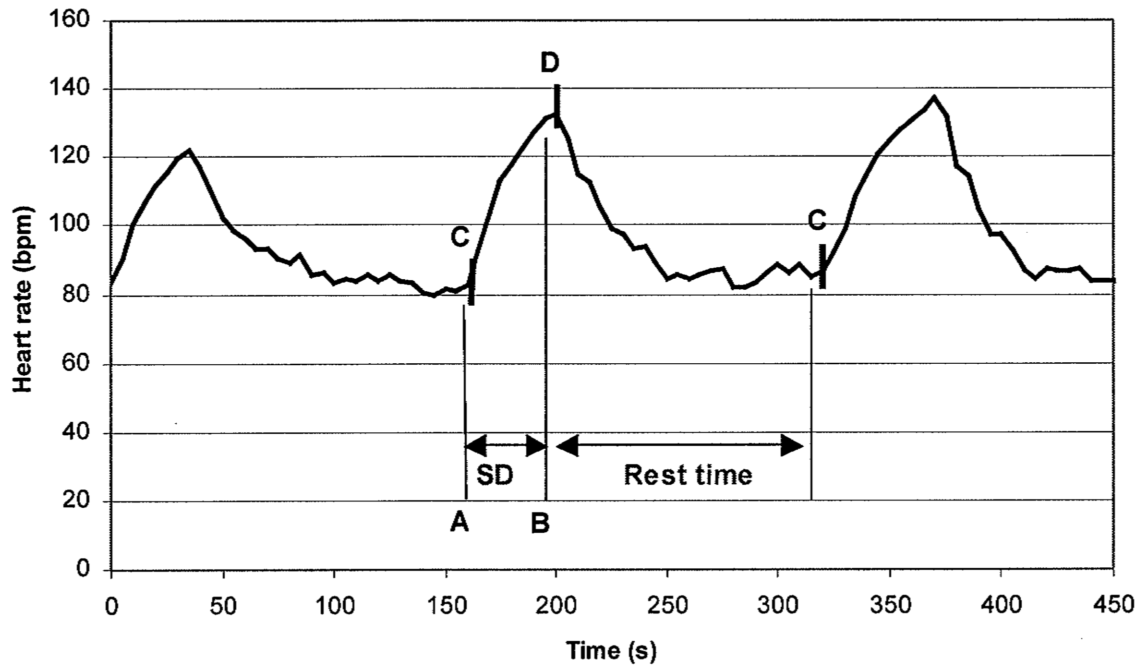


Figure 12. Actual versus estimated set duration (SD). Three sets of exercise are shown. The thin black lines indicate the estimated set duration determined by HR profile (A- start, B- end). The thick tick marks indicate the start and stop of the actual set duration determined by the stopwatch (C – start, D- end). The rest time can be estimated from the end of one set to the start of the subsequent set.

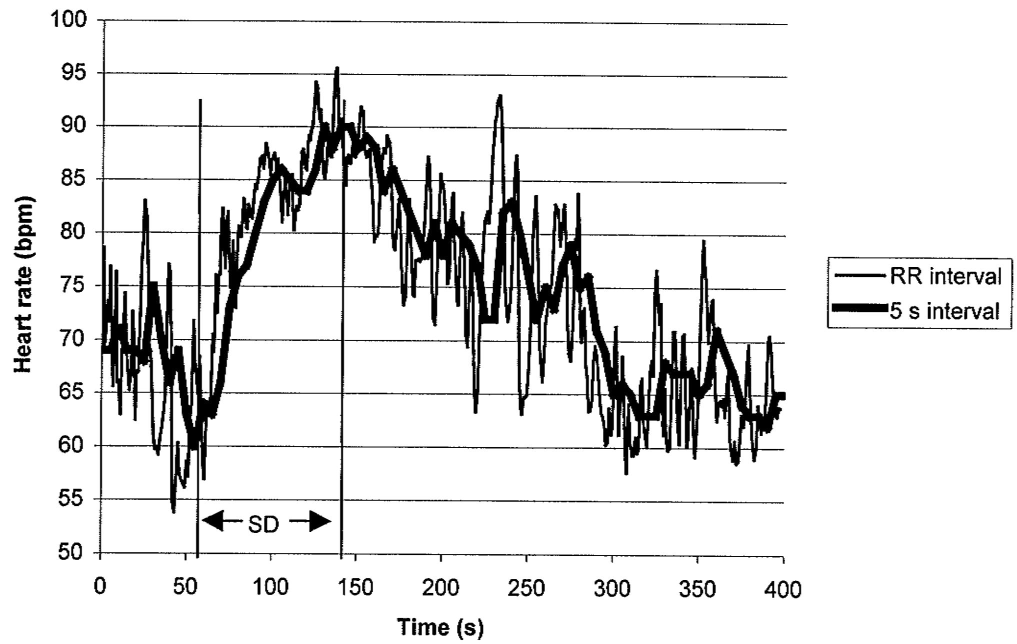


Figure 13. The relationship between simultaneous records of instantaneous HR and 5 s. HR for 1 set of dumbbell row exercise consisting of 25 repetitions. There is a small phase lag between the onset of HR elevation in the instantaneous and the 5-s data; otherwise the basic patterns are consistent. Set duration (SD) is shown in the diagram.

Statistical Analysis

Regression analysis for HR vs. weight and HR vs. number of repetitions for each participant was performed (MS Excel 2000). Regression analysis of the normalized grouped data was analysed using ANOVA analysis (SYSTAT V for Windows). The level of significance was assessed at an alpha level of 0.05. If the r-values were very close to 1 and the p values were lower or equal to a value of .05 ($p<0.05$), the alternate hypotheses were accepted.

RESULTS

Subject Attrition

Thirty-five participants were tested for examination of the three objectives. Data from 4 participants were excluded due to non-compliance of the participant with the protocol or external distractions during the protocol influencing the heart rate. As such, the sample was reduced to 31 participants.

Participant Demographics

The research subjects or participants were recruited from the Health Sciences Centre, Bannatyne and Main Campus at the University of Manitoba. Tables 1, 2, 3, 4 summarize the demographics of the 4 groups of participants who performed exercise with upper body and lower body for objectives 1, 2 and 3. For objective 1, there were 10 participants performing the dumbbell row exercise for UB (Table 1), there were 6 participants performing the hack squat exercise for LB (Table 2). For objectives 2 and 3, there were 10 participants performing the dumbbell row exercise for UB (Table 3), and there were 5 participants performing the hack squat exercise for LB (Table 4).

Table 1. Participant demographics for the upper body peak HR versus weight protocol.

Participant	Gender 5:5 M/F	Age (years)	Body Mass (kg)
1	M	27	84.2
2	M	36	74
3	F	26	90.8
4	F	32	67.8
5	M	35	95.4
6	M	41	96.2
7	F	38	54.5
8	F	38	64
9	M	36	79.6
10	F	21	68.18
	Mean	**33.0**	**77.5**
	SD	**6.4**	**14.1**

Table 2. Participant demographics for the lower body peak HR versus weight protocol.

Participant	Gender 4:2 M/F	Age (years)	Body Mass (kg)
1	F	24	62.7
2	F	44	46.4
3	M	29	65.6
4	M	36	74
5	M	39	89
6	M	28	77.8
	Mean	**33.3**	**69.3**
	SD	**7.6**	**14.6**

Table 3. Participant demographics for the upper body peak HR versus repetitions protocol.

Participant	Gender 9:1 M/F	Age (years)	Body Mass (kg)
1	M	37	67
2	M	34	68.2
3	M	23	76.6
4	M	26	60
5	F	28	60
6	M	27	132
7	M	28	70.45
8	M	30	91
9	M	26	78
10	M	28	84.2
	Mean	**28.7**	**78.7**
	SD	**4.1**	**21.2**

Table 4. Participant demographics for the lower body peak HR versus repetitions protocol.

Participant	Gender 2:3 M/F	Age (years)	Body Mass (kg)
1	F	26	90.8
2	F	31	73.6
3	M	26	63.5
4	F	21	58.5
5	M	24	62.5
	Mean	**25.6**	**69.8**
	SD	**3.6**	**13.0**

Objective 1. Peak HR versus Weight

To address the results for objective 1, it was necessary to identify each set by demarcation of the start and end of each set using the time-stamp markers using the stopwatch function of the HR monitor. Identification of the set duration or work time for each set permitted the determination of the peak HR from the raw profiles as seen in Figure 14. In Figure 14 each set of exercise is clearly observed in the HR profile recorded. From the HR profile alone, the start and end of the set were readily identified from the HR profile, however the timestamp markers were used to verify the visual assessment of each set. As seen in Figure 15, each set of exercise corresponded to a rapid increase in HR with the commencement of exercise followed by the establishment of a peak HR occurring at the end of the exercise, followed by a recovery of HR to near baseline values. For every participant, the actual mass (weight used for each set) was determined and regressed against the peak HR determined for the corresponding set (Figure 15). This analysis resulted in a goodness of linear fit (r – correlation coefficient) for each participant. The peak HR/weight relationships of each participant who performed UB exercise (dumbbell row) are illustrated in Table 5 and the correlation for peak HR to weight for the LB exercise (squat) is shown in Table 6. Excellent correlation coefficients were obtained within the range [r=0.854-0.994] for upper body with a mean of 0.943 and [r=0.866-0.990] for lower body with a mean of 0.948. All relationships were statistically significant with p values less than

0.001.

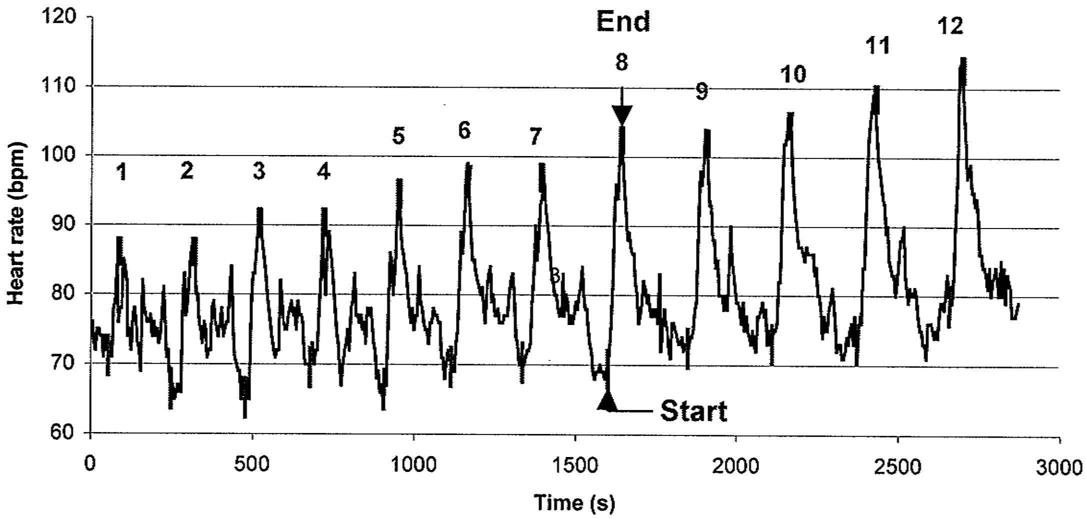


Figure 14. Typical example of a HR profile of a participant performing dumbbell row exercise for 12 sets. The weight was increased progressively from set 1 to set 12. The number of repetitions was maintained at 10 for each set. The start and end of each set is shown for each set based upon the timestamp information downloaded from the HR monitor.

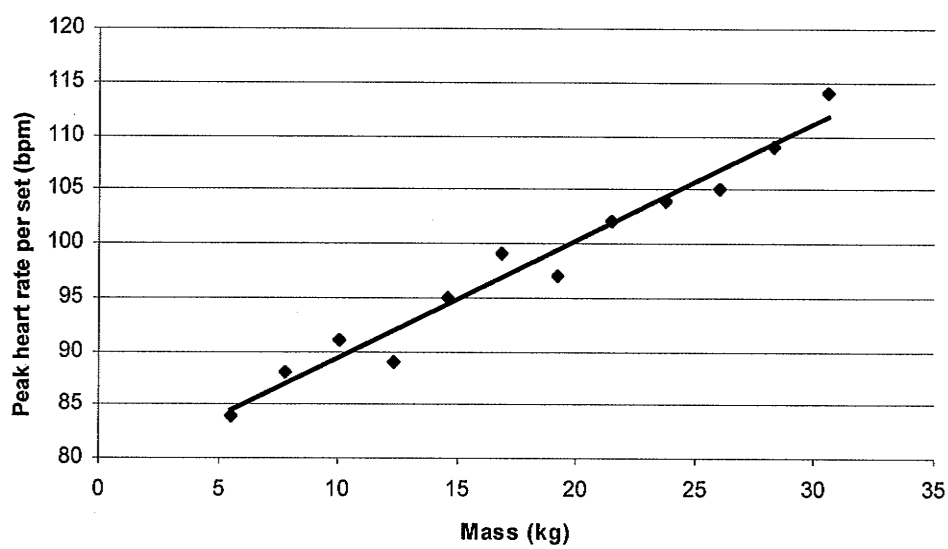


Figure 15. A typical relationship (participant number 7 in Table 5) between the peaks HR recorded for each set and the weight (kg) lifted for each set. The correlation coefficient was 0.98 ($p < 0.001$) based upon the HR data shown in Figure

Table 5. The correlation between peak HR and weight lifted for the upper body exercise group. The maximum weight lifted in the final set is shown, and expressed in absolute terms (kg) and relative body mass (%). The maximum heart rate achieved is also shown. The correlation coefficient (r) is shown for each participant.

Participant	Max Mass (kg)	Max. Mass (% Body Mass)	Max PHR	Total Sets	r value	p value
1	32.8	38.98	114	7	0.990	p< 0.001
2	23.7	32.06	99	5	0.975	p< 0.001
3	23.7	26.13	93	8	0.943	p< 0.001
4	12.4	18.24	108	6	0.854	p< 0.001
5	28.3	29.64	121	9	0.927	p< 0.001
6	30.5	31.75	114	12	0.980	p< 0.001
7	11.2	20.60	105	8	0.911	p< 0.001
8	21.5	33.52	108	13	0.922	p< 0.001
9	28.3	35.52	96	8	0.975	p< 0.001
10	12.4	18.13	112	8	0.949	p< 0.001
Mean	**22.48**	**28.46**	**107**	**8.40**	**0.943**	
SD	**7.99**	**7.38**	**8.86**	**2.46**	**0.041**	

Table 6. The correlation between peak HR and weight lifted for the lower body exercise group. The maximum weight lifted in the final set is shown, and expressed in absolute terms (kg) and relative body mass (%). The maximum heart rate achieved is also shown. The correlation coefficient is shown for each participant.

Participant	Max mass (kg)	Max. Mass (% Body Mass)	Max PHR	Total Sets	r value	p value
1	45.5	72.50	106	4	0.954	p< 0.001
2	39.1	84.25	140	6	0.922	p< 0.001
3	90.9	138.58	147	9	0.970	p< 0.001
4	92.7	125.31	127	5	0.985	p< 0.001
5	209.1	234.93	142	11	0.990	p< 0.001
6	133.6	171.77	157	10	0.866	p< 0.001
Mean	**101.82**	**137.89**	**136.50**	**7.50**	**0.948**	
SD	**62.98**	**59.80**	**17.85**	**2.88**	**0.047**	

In order to aggregate the data for group analysis, a post-hoc normalization was performed upon the heart rate and weight data. The weights used in the exercises were normalized as a percentage of the maximum weight used in the final set. This weight would correspond to the maximum weight that could be lifted for 10 repetitions without accessory or compensatory body movement, in other words the 10 RM weight. The peak HR was normalized by expressing the heart rate as a percentage of the maximum heart rate achieved normally in the final set. In addition, the average resting or baseline heart rate between sets was also used to normalize the HR data. This normalized data permitted the data to be collapsed across subjects into an aggregated peak HR versus weight relationship for the upper body (Figure 16). The relationship using the normalized data set was not expected to obtain r values exceeding the r values determined for each individual since this normalization did not take into consideration the relative fitness levels of each of the subjects or their age-predicted or actual maximum heart rates. Taking these parameters into consideration may have resulted in a tighter relationship. Nonetheless, the correlation coefficients (Table 5 and 6) obtained from the normalized data still yielded very high values (multiple $r = 0.926$ for upper body, $r = 0.924$ for lower body). However, for the purpose of establishing a group statistic via ANOVA, this normalization procedure would suffice. ANOVA Tables are provided for the upper body (Table 8) and the lower body (Table 9) illustrating statistically significant relationships ($p < 0.001$ for both upper and lower body) between weight lifted and the resultant peak HR observed for the group as a whole, consistent with the excellent individual relationships (Table 5 and 6).

As expected, there was a statistically significant and substantial difference (Table 7) in the maximum weight lifted used in the final set between the upper body and lower body exercise. The mean of the maximum weights lifted for the final set of the dumbbell row exercise was 28.46% of the total body mass, while a mean of 137.85% of the total body mass was recorded for the squat exercise. This difference of 109% was statistically different ($p < 0.05$). A statistical significant difference ($p < 0.001$) was found between maximum peak HR for UB (107±8.9 bpm) and LB (136.5±17.85 bpm) exercise. There was no statistical difference between the number of sets performed during UB and LB exercises. The mean number of set was 8.4 ±2.46 for UB and 7.5±2.88 for LB exercise. Set durations ranged between 26.20 and 42.50 s for UB exercise and from 21.30 to 56 s for the LB exercise.

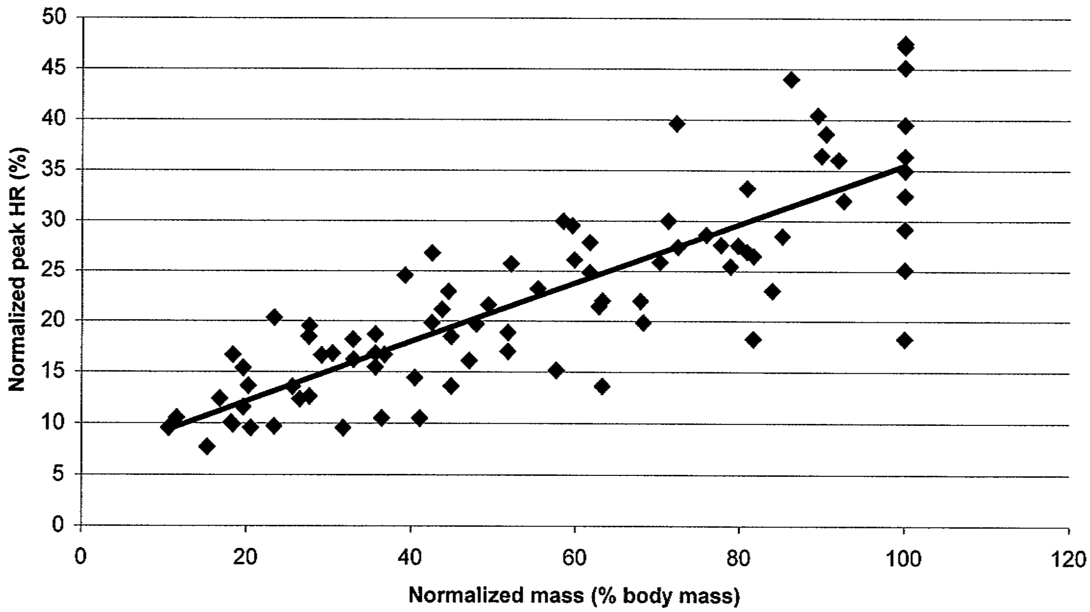


Figure 16. The aggregated linear regression of normalized peak HR versus normalized weight lifted for upper body exercise group is shown in this Figure. The multiple r-value was 0.926 for the group of 10 participants.

Table 7. Comparison between weights lifted for upper body exercise and lower body exercises during peak HR versus weight protocol. There was a significant difference between the weights lifted ($p<0.05$) for the two exercises.

Maximum Mass Lifted (% Body Mass)		
Participant	UB	LB
1	38.98	72.50
2	32.06	84.25
3	26.13	138.58
4	18.24	125.31
5	29.64	234.93
6	31.75	171.77
7	20.60	
8	33.52	
9	35.52	
10	18.13	
Mean	**28.46**	**137.89**
SD	**7.38**	**59.80**

Table 8. Analysis of variance for upper body exercise during peak HR versus weight protocol. As observed in the Table, a correlation coefficient or multiple r-value of 0.926 was found.

Analysis of Variance					
Multiple r = 0.926					
Source	Sum of Squares	Degrees of Freedom	Mean Square	F-Ratio	p-value
Mass	4840.68	1	4840.68	315.9	< 0.001
Subject	1338.9	9	148.8	9.7	< 0.001
ERROR	1133.8	74	15.3		

Table 9. Analysis of variance for lower body exercise during peak HR versus weight protocol. As observed in the Table, a correlation coefficient or multiple r-value of 0.924 was found.

Analysis of Variance					
Multiple r = 0.924					
Source	Sum of Squares	Degrees of Freedom	Mean Square	F-Ratio	p-value
Mass	3224.2	1	3224.2	173.7	< 0.001
Subject	1097.8	5	219.6	11.83	< 0.001
ERROR	723.8	39	18.6		

Objective 2. Peak HR versus Repetitions

To address the results for objective 2, it was necessary to identify the number of sets performed (for this protocol the same number of repetitions were performed per set) from the raw HR profile recorded (Figure 17). This identification also permitted the determination of peak HR per set. For every participant, the number of repetitions was determined and regressed against the peak HR determined for the corresponding set, as seen in Figure 18. In LB exercise, four different time periods were identified from the profiles as follows: work time (A-B), and rest time (B-E) which was divided in three different periods according to the protocol and the representation on the raw profile, as observed in Figure 19. The peak HR/repetitions relationship of each participant who performed the UB exercise (dumbbell row) is illustrated in Table 10 and the correlation for peak HR to repetitions for the LB exercise (squat) is shown in Table 11. Excellent correlation coefficients were obtained within the range [r=0.849-0.964] for upper body with a mean of 0.927 and [r=0.951-0.988] for lower body exercises with a mean of 0.969. All relationships were statistically significant ($p<0.05$).

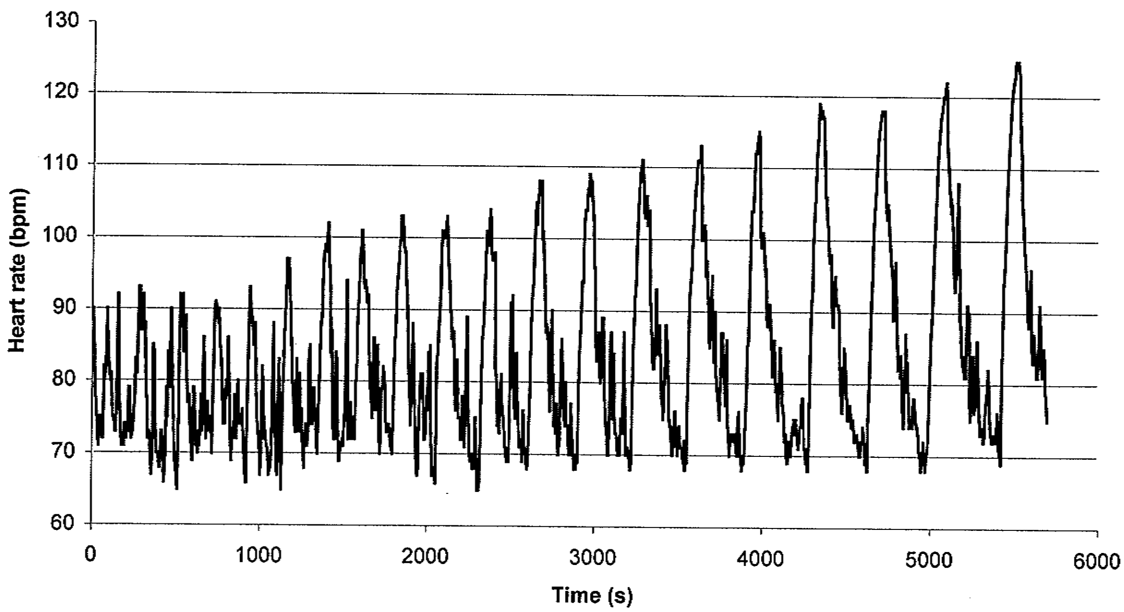


Figure 17. Example of a raw HR profile of a participant performing squat exercise for 20 sets. The weight was fixed for the session and the number of repetitions was increased progressively from set 1 to set 20.

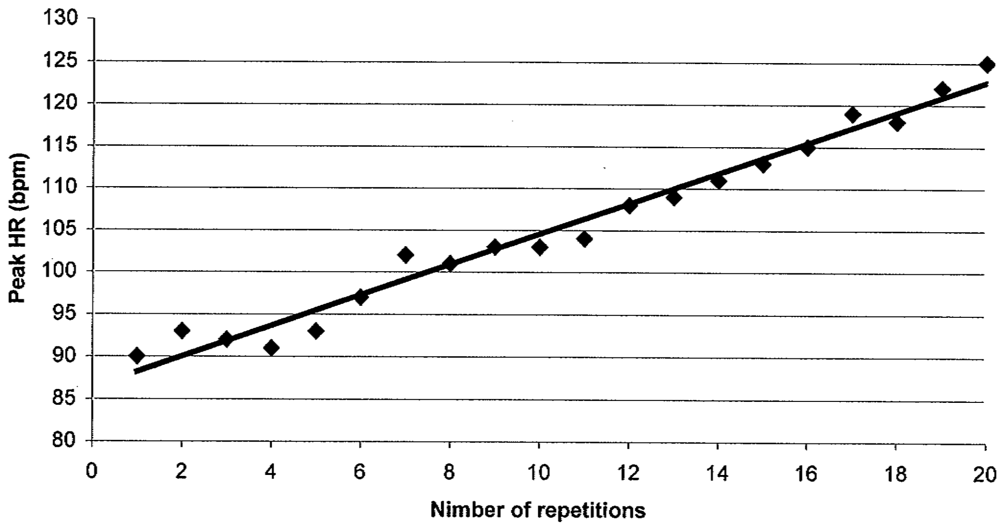


Figure 18. Linear regression of peak HR versus number of repetitions for data shown in Figure 17. A typical relationship (participant number 5 in Table 11) between the peak HR recorded for each set and the number of repetitions lifted for each set. The correlation coefficient was 0.988 ($p < 0.001$).

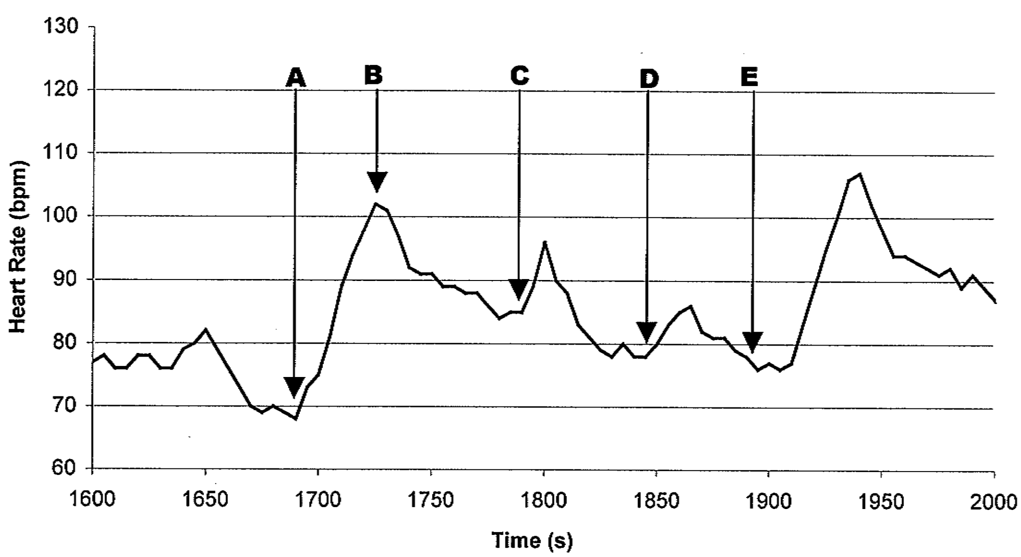


Figure 19. Enlargement of a HR set profile for a squat protocol. A – Start of exercise in machine (Semi-squat), B – Completion of exercise in machine (Semi-squat), C – Leave machine to standing position (Standing), D – Return to machine for next set (Standing), E – Remain stationary for 1 minute (Semi-squat).

Table 10. Correlation between number of repetitions and peak HR for upper body exercise. For each participant the maximum weight lifted is shown, and expressed as a percentage of body mass. The maximum HR recorded and the maximum number of repetitions for the session is also shown. The correlation coefficient (r) is shown along with the corresponding p value.

Participant	Mass (kg)	Mass (% Body Mass)	Max. PHR	Max. Repetitions	r value	p value
1	19.2	28.63	109	8	0.889	p< 0.001
2	16.9	24.79	151	16	0.938	p< 0.001
3	19.2	25.04	125	12	0.964	p< 0.001
4	17.1	28.56	135	17	0.849	p< 0.001
5	9.0	14.92	88	13	0.927	p< 0.001
6	16.9	12.81	112	12	0.927	p< 0.001
7	19.2	27.23	133	13	0.964	p< 0.001
8	19.2	21.08	107	12	0.949	p< 0.001
9	20.3	26.05	113	12	0.954	p< 0.001
10	14.6	17.38	105	16	0.911	p< 0.001
Mean	**17.16**	**22.65**	**117.80**	**13.10**	**0.927**	
SD	**3.34**	**5.78**	**18.21**	**2.64**	**0.036**	

Table 11. Correlation between number of repetitions and peak HR for lower body exercise. For each participant the weight squatted is shown, and expressed as a percentage of body mass. The maximum peak HR recorded and the maximum number of repetitions for the session is also shown. The correlation coefficient (r) is shown along with the corresponding p value.

Participant	Mass (kg)	Mass (% Body Mass)	Max. PHR	Max. Repetitions	r value	p value
1	56.82	62.58	119	25	0.974	p<0.001
2	45.45	61.76	122	13	0.971	p<0.001
3	81.82	128.85	123	13	0.959	p<0.001
4	45.45	77.70	125	15	0.951	p<0.001
5	56.82	90.91	125	20	0.988	p<0.001
Mean	**57.27**	**84.36**	**122.80**	**17.20**	**0.969**	
SD	**14.85**	**27.62**	**2.49**	**5.22**	**0.014**	

Since the participant was given adequate rest between sets and the weight remained constant, this protocol resulted in termination of exercise when the subject was no longer able to comply with the requirement for smooth and controlled motion. As such, the set at which the person failed corresponds to the RM (repetition maximum) value for that weight. For instance, a subject that failed at 8 repetitions with the prescribed weight, would be said to have completed a 8 RM load. For the upper body, the average RM load was 13 RM. This corresponds to an upper value for exercise loading that is normally prescribed (8-12 RM, ACSM 2000). For the lower body the RM value was 17, which is above that normally prescribed for upper body exercise, however, it is commonplace to observe a higher RM value for lower body exercise (unpublished observations).

An example of a raw HR profile reaching a plateau (steady state HR) (25 repetitions) for lower body exercise is shown in Figure 20, and the corresponding linear regression between peak HR and repetitions is shown in Figure 21. The least squares fit line for the first 15 sets is represented in dots, and the steady state plateau is represented in triangles. The correlation coefficient for peak HR to repetitions of the first 15 sets was 0.983 and for the last 10 sets of repetitions was 0.745 with a mean HR of 114 ± 2.756. It is important to mention that a steady state HR was determined visually from the profile and the differences in linear patterns, and a mathematical parameter was not established to define a steady state HR.

There was a statistically significant difference in the weight lifted used in the UB and LB exercise. The mean value of the mass lifted for UB exercise was 22.65% of the total body mass and for LB exercise was 84.86% of the total body mass. This difference of 62.21% was statistically different ($p < 0.05$) (Table 12). No statistical significant difference ($p < 0.001$) was found between maximum peak HR for UB (117.8±18.2 bpm) and LB (122.8±2.48 bpm) exercise. These maximum heart rates for upper body and lower body respectively represent 61.16% (117/(220-28.7)*100) and 63.16% (122.8/(220-25.6)*100) of age predicted absolute maximum heart rates. The maximum heart rates observed are expected in this range due to the fact that the amount of muscle mass involved in the upper and lower body exercises is lower than that used in absolute maximum heart rate determinations, which typically use total body exercise (e.g. running). There was no statistical difference between the number of sets performed during UB and LB exercises. In average, a maximal number of repetitions of 13.10 ± 2.64 were performed for dumbbell rows and 17.20 ± 5.20 for squats. This difference of 4.10 was statistically different between the groups p=0.030 ($p<0.05$). Set durations ranged between 36.80 and 72.40 s for UB exercise and from 36 to 100 s for the LB exercise.

Table 12. Comparison between weights lifted for upper body and lower body exercises during peak HR versus repetitions protocol. There was a significant difference between the weights lifted ($p<0.05$) for the two exercises.

	Maximum Mass Lifted (% Body mass)	
Participant	UB	LB
1	28.63	62.58
2	24.79	61.76
3	25.04	128.85
4	28.56	77.70
5	14.92	90.91
6	12.81	
7	27.23	
8	21.08	
9	26.05	
10	17.38	
Mean	**22.65**	**84.36**
SD	**5.78**	**27.62**

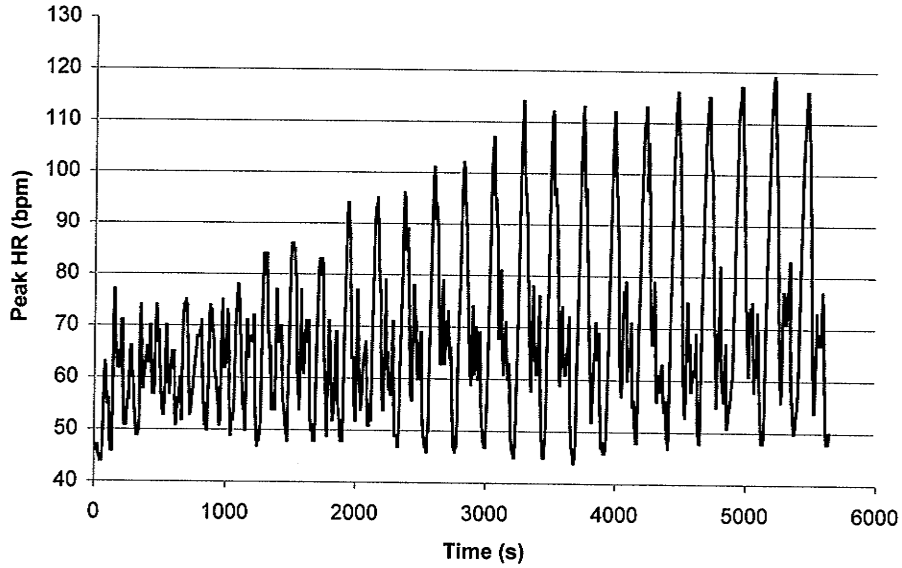


Figure 20. Heart rate profile for the only subject (participant number 1 in Table 10) that established a clear plateau for the lower body exercise (squat) with increasing duration of exercise. The number of repetitions per set increases from 1 to 25 repetitions. The set duration for the last set was 67.4 s.

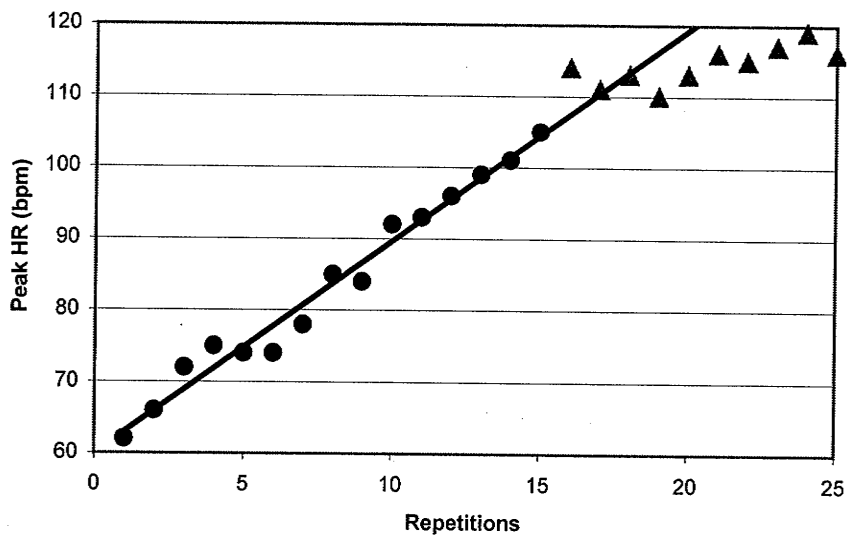


Figure 21. Relationship between peak HR per set and the number of repetitions per set for the only subject (Participant number 1 in Table 10) that demonstrated a clear plateau in HR (data corresponding to Figure 20). A best-fit line is shown for the first 15 sets. The plateau, which may correspond to achievement of steady state, is shown with triangles.

The correlation coefficients (Table 13 and 14) obtained from the normalized data yielded very high values (multiple r=0.926 for upper body exercise, multiple r= 0.940 for lower body exercise). ANOVA tables are provided for the upper body (Table 13) and the lower body exercises (Table 14) illustrating statistically significant relationships (p<0.001 for both upper and lower body) between number of repetitions and the resultant peak HR observed for the group as a whole, consistent with the highly correlated individual relationships (Table 10 and 11).

Table 13. Analysis of variance for upper body exercise during peak HR versus repetitions protocol. As observed in the Table, an overall correlation (multiple r) of 0.920 was found between repetitions and peak HR.

Analysis of Variance					
Multiple r = 0.92					
Source	Sum of Squares	Degrees of freedom	Mean Square	F-Ratio	P value
Repetitions	5258.4	1	5258.4	419.4	< 0.001
Subject	2950.3	9	327.8	26.1	< 0.001
ERROR	1504.6	120	12.5		

Table 14. Analysis of variance for lower body exercise during peak HR versus repetitions protocol. As observed in the Table, an overall correlation of 0.945 was found between peak HR and repetitions for the lower body.

Analysis of Variance					
Multiple r: 0.945					
Source	Sum of Squares	Degrees of freedom	Mean-Square	F-Ratio	P value
Repetitions	8701.566	1	8701.566	329.937	<0.001
Subjects	9274.623	4	2318.656	87.916	<0.001
ERROR	2109.876	80	26.373		

Objective 3. HR estimated Set Duration

To address the results for objective 3, protocol 2 was utilized. On each HR profile, it was necessary to identify each set by marking the start and end of each set using the stopwatch function of the HR monitor on each participant's HR profile (Figure 13). The timestamp markers were used to identify the actual set duration of work time for each set and permitted the correlation with the estimated HR set duration directly from the HR profiles. For every participant, the actual HR set duration was regressed to number of repetitions and also the estimated HR set duration was determined and regressed with the actual HR set duration. The correlation coefficients for HR set duration for upper body exercise are illustrated in Table 15 and for lower body exercise in Table 16. The mean r-values between actual HR set durations/number of repetitions was 0.971 and between estimated/actual HR set durations was 0.951 for upper body exercise; and 0.962 for actual HR set duration/ number of repetitions and 0.886 for estimated/actual HR set durations for lower body exercise.

An example of a correlation between estimated HR set duration versus number of repetitions (r=0.976) and actual HR set duration versus number of repetitions (r=0.992) for upper body exercise, is observed in Figure 22; the correspondent correlation coefficient between estimated/actual HR set duration values was 0.986 (participant 4 in Table 15).

Table 15. Comparison of correlation coefficients between actual HR set duration versus number of repetitions and estimated versus actual HR set durations for upper body exercise.

Set Duration		
Participant	Actual vs. Repetitions r	Estimated vs. Actual r
1	0.958	0.941
2	0.978	0.979
3	0.995	0.977
4	0.992	0.986
5	0.978	0.958
6	0.99	0.976
7	0.982	0.965
8	0.965	0.931
9	0.888	0.849
10	0.983	0.948
Mean	**0.971**	**0.951**
SD	**0.031**	**0.040**

Table 16. Comparison of correlation coefficients between actual HR set duration versus number of repetitions and estimated versus actual HR set durations for lower body exercise.

Set Duration		
Participant	Actual vs. Repetitions r	Estimated vs. Actual r
1	0.946	0.969
2	0.993	0.924
3	0.952	0.674
4	0.931	0.915
5	0.99	0.946
Mean	**0.962**	**0.886**
SD	**0.028**	**0.120**

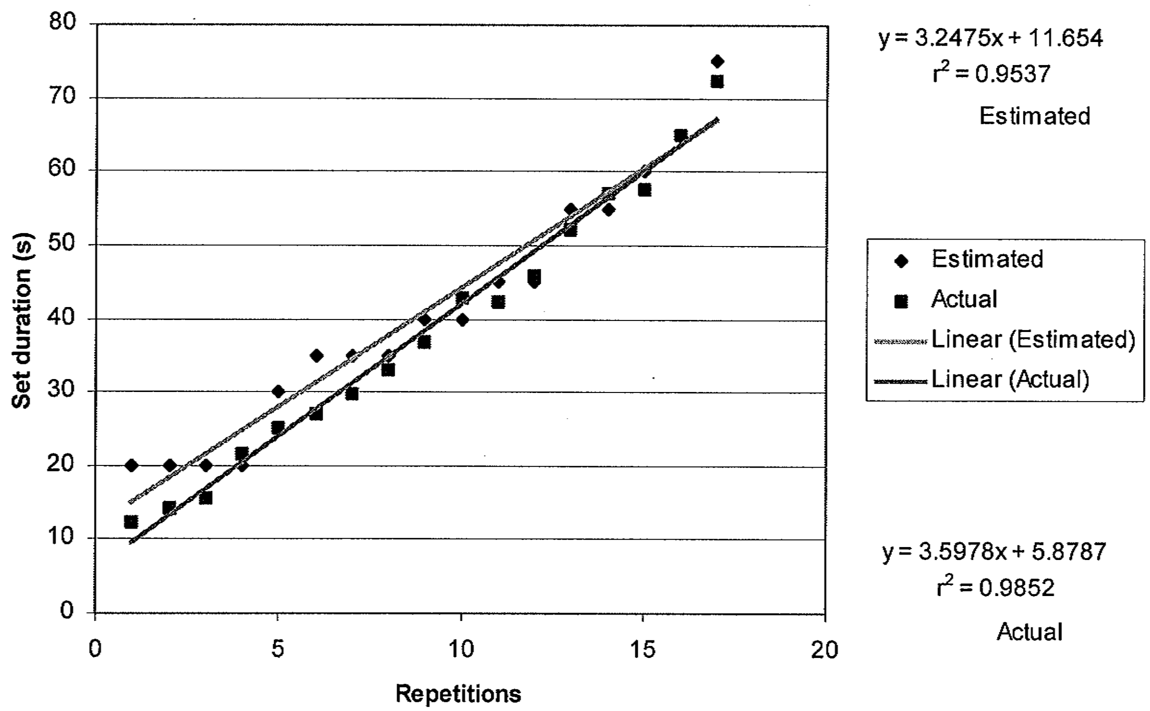


Figure 22. Example of a correlation between estimated HR set duration vs. number of repetitions (r=0.976), and actual HR set duration versus number of repetitions (r=0.992) for a 17 RM dumbbell row exercise (participant 4 in Table 15).

Summary of Results

Objective 1. Strong linear correlations were observed between peak HR recorded per set and the weight lifted per set.

- Each individual correlation was strong and significant for both upper and lower body exercise (Tables 5 and 6).
- The mean of the individual correlations was 0.943 for upper body and 0.948 for lower body. The overall correlation using normalized data was significant ($p < 0.001$) and strong; 0.926 (upper) and 0.924 (lower) (Tables 8 and 9 and Figure 16).

Objective 2. Strong linear correlations were observed between peak HR recorded per set and the number of repetitions per set.

- Each individual correlation was strong and significant for both upper and lower body exercise (Tables 10 and 11).
- The mean of the individual correlations was 0.927 for upper body and 0.969 for lower body.
- The overall correlation using normalized data was significant ($p < 0.001$) and strong; 0.92 (upper) and 0.945 (lower) (Tables 13 and 14).

Objective 3. Strong linear correlations were observed between the set duration measured by HR profiles and those measured by stopwatch (actual set duration).

- There were strong linear correlations ($p < 0.001$) between actual set duration and HR estimated set duration for both upper and lower body exercise (Tables 15 and 16).

DISCUSSION

The main purpose of this study was to investigate HR response during short duration resistance exercise. Knowledge pertaining to the HR response to resistance training exercise is useful for understanding the effects of resistance exercise on the cardiovascular system, as well as for objective evaluation and tailoring exercise programs for individuals, or specific groups of individuals. There is a lack of information regarding HR responses to resistance training in the published literature. Similar to the use of heart rate for assessment of cardiovascular exercise intensity, this study had an overall aim of evaluating heart rate as a tool for assessment of exercise intensity during short duration, non-steady state exercise as found in resistance training. Three objectives were established to fulfil this aim. Two key exercise parameters that are used to alter exercise intensity during free weight or resistance training exercise are 1) the weight lifted, and 2) the number of repetitions. The first two objectives were directed at establishing the relationship between peak HR and these key exercise parameters. The first objective was to determine the relationship between peak heart rate and weight lifted during free weight resistance exercise over a range of weights normally employed in resistance training exercise. The results revealed a strong linear relationship between peak heart rate per set and weight lifted per set for all participants and for both upper and lower body exercise. The second objective was to determine the relationship between peak heart rate per set and the number of repetitions per set. The results showed that there was a strong linear relationship between peak HR and number of repetitions for all subjects for both upper and lower body exercise. Finally this study evaluated the utility of HR profiles to measure set duration. Set duration is a consequence of the number and rate at which the repetitions are performed. This parameter reflects the work time during a set of exercise. By determining the set duration for each set of exercise in an entire exercise session, the total work time can be computed. The results showed that there was a very strong correlation between actual HR set duration and those estimated by HR profiles during upper and lower body resistance training exercise. By establishing that there are strong relationships between peak HR and weight and repetitions for both upper and lower body exercise, this provides the opportunity to use HR profiles in resistance training research, not only for understanding cardiovascular responses to resistance training but also for evaluating exercise parameters (such as weight, repetitions and rest) used in resistance training. This knowledge has immediate applications in a wide variety of applied settings including sport, general exercise and clinical fields.

Heart Rate Response to Short Duration Exercise.

Roach et al. (1999) examined burst morphology of people performing different number of revolutions (1,3, and 5 revolutions) on a cycle ergometer. They measured and reported the variation in heart period during these controlled exercises. The burst patterns and times to peak heart rate for 1, 3 and 5 revolutions (t_{min}, s) were 8.3±3.2, 11.4±3.5, 11.7±3.9, respectively. T_{min} values were very similar to those observed for set duration in this study. The actual set duration for 1, 3 and 5 repetitions had almost identical burst morphology, as follows: 13.33±2.51, 17.08±4.28, 25.26±7.36 for UB and 19.16±3.56, 20.46±3.49, 24.74±6.37 for LB; the actual set durations (time to peak HR) were similar to the minimum times (time to minimum HP) observed in their study.

Resistance training exercise programs that are prescribed usually consist of a number of sets (3-5) of a specific exercise with a fixed number of repetitions per set (6-12). Each set that a person performs results in a specific HR profile. This HR response (See Figure 19 for example) normally consists of a rapid increase in heart rate with the commencement of exercise, followed by a peak HR being reached at cessation of exercise for that set. The HR then recovers as the person rests between sets. The initial increase in heart rate is dependent upon the cardiac output required for the task. The cardiac output, in turn, is dependent upon the exercise intensity imposed on the musculoskeletal system. The exercise intensity during a set is dependent upon the metabolic demands imposed by a combination of the 1) weight used, 2) the number of repetitions, and 3) the amount of muscle mass involved. The elevation of heart rate (resulting in a peak HR) during the set was shown in this study to be proportional (strong linear relationships) to the three aforementioned parameters. Once the exercise is completed during a set, there is an absence of external load on the system, resulting in decreased metabolic demand permitting the recovery of heart rate to pre-set levels. However, this study clearly demonstrated that posture assumed after the set is completed could have impact on the heart rate recovery (See Figure 19 for example). As such, for this study the inter-set posture was controlled.

The Relationship between Peak HR and Weight

In order to analyse the effects of weight on the musculoskeletal system/cardiovascular system, during resistance training exercise, it is essential to clarify the definition of "load". Load about a joint places demands upon the muscles spanning that joint, as well as stabilizers acting about different joints. By and large, the absolute demands upon the prime movers are substantially greater than the stabilizers. The resultant joint moment that is generated during each instant of an exercise reflects the load placed upon the prime movers. As such, the best representation of load during an exercise is obtained by computing the resultant joint moment/time relationship during each repetition of the exercise. The resultant joint moment is dependent upon a number of factors, one of which is the weight lifted during resistance training exercise. Other key factors include the moment arm of the weight about the joint at each instance of the movement, the acceleration of the segment, and the weight lifted. Acceleration dependent loading is a major component of load during free weight resistance training exercise (Lewis, 2002). In this study, the weight was controlled, the range of motion of the exercise was controlled by visual means, and the cadence of the movement was controlled by use of a metronome. These controls would reduce, but not eliminate the impact of acceleration dependent loading during the exercise. Although it would be desirable to control acceleration during the exercise, the technology has not been applied for this purpose to date. Therefore, by controlling the pace of the exercise, which would in turn reduce variation in acceleration, one can use mass or weight as a reasonable measure of the external load used in the exercise. For the purpose of this study, the external load was considered equivalent to the weight of the dumbbell for the upper body exercise and the plate weight added to the hack squat machine for the lower body exercise.

A strong linear relationship between peak HR and weight was established; significant correlation coefficients from 0.854 to 0.990, with a mean of 0.943 for the upper body. For the lower body the mean correlation was 0.948 with a range from 0.866 to 0.990. All 16 participants had a strong linear relationship between peak HR and weight, regardless of performing dumbbell rows or hack squat exercise. This indicates that, independent of muscle mass or limbs used, that the HR response to loading was dependent on weight used during this non-steady state period. It has been established in the literature that steady state of HR normally commences after 2 minutes from the beginning of the exercise if appropriate load and exercise intensity is used. For this protocol, the set duration ranged between 26.20 and 42.50 seconds for the upper body exercise, and 21.30 and 56.00 seconds for lower body exercise. These set durations would likely reflect an inability to achieve steady state for these exercises.

In an attempt to obtain a group statistic, the data was normalized. Participants' data were normalized (i.e. peak HR and mass lifted per set). Peak HRs were represented as relative percentages of the highest set peak HR for participants' HR profile, as follows: peak HR per set minus resting HR (HR at the start of the set), and finally the result were divided by the highest peak HR within sets and multiplied by 100. Mass was normalized taking into account the masses lifted per set during upper body exercise and represented as relative percentages of the highest mass lifted during an exercise session, as follows: maximum mass lifted during a session minus the correspondent mass lifted per set multiplied by 100. It should be emphasized that the results as individual samples were very strong, but as a group they were slightly weaker but still the showed a high degree of linearity ($r = 0.926$ UB, $r = 0.924$ LB, $p < 0.001$). In the future, other methods of normalization of the data based upon true maximum heart rate and fitness level could improve the correlations performed on the aggregate data.

The external loads were significantly different between upper body exercise and the lower body exercise reflecting that a greater muscle mass was involved in the movements.

The effect of an increase in muscle mass would necessarily require a greater cardiac output during exercise. An increased CO would require a greater HR. Indeed, the peak heart rates achieved for lower body exercise were significantly higher, by 30 bpm, than the upper body exercise.

Based upon the results obtained in this study, we can conclude that heart rate profiles can be used to estimate relative loading during resistance training. For instance, if three sets of exercise were prescribed with the same weight and same number of repetitions per set, then it would be expected, due to the strong linear relationship between peak HR and weight lifted, that the peak HR for each set would be consistent. In this way HR profiles could be used as an audit of the actual performance of an individual involved in a training session. The fact that each participant has individual characteristics and methods of performing an exercise means that more research needs to be performed to understand other factors that influence this relationship. So far, standardized HR training zones based upon HR profiles have been utilized to monitor adults during aerobic exercise to monitor desired level of activity. Our goal in the future is to establish standardized HR profiles for different populations (including non-healthy groups) during resistance training exercise.

The Relationship between Peak HR and Repetitions

A strong linear relationship between peak HR versus repetitions was established for each individual participant; significant correlation coefficients from 0.894-0.964 (mean = 0.927) for the upper body and 0.951 to 0.988 (mean = 0.969) for the lower body. All 15 participants had a strong linear relationship between peak HR and repetitions, regardless of performing dumbbell rows of hack squat exercise. This indicates that, independent of muscle mass or limbs used, the HR response to loading was dependent on number of repetitions during this non-steady state period. Set duration was expected to be a consequence of the number and rate at which the repetitions were performed. It has been established in the literature (Exercise Physiology, 4th ed., 1996 p. 190, Physiology of Sport and Exercise, 2nd ed., 1999 p.224) that steady state of HR normally commences 2 after minutes from the beginning of the exercise if appropriate load/exercise intensity is used;

during this brief time period the transfer of chemical energy does not require molecular oxygen. For this protocol, the set duration ranged between 36.80 and 72.40 seconds for the upper body exercise, and 36 and 100 seconds for lower body exercise. These set durations would likely reflect an inability to achieve steady state for these exercises. However, in Figures 20 and 21, one participant did demonstrate a plateau in heart rate after performing 16 or more repetitions of the same weight. Results showed that after the 16^{th} set, the HR reached an apparent steady value. The large muscle mass and the low mass lifted during the session allowed the participant to perform 25 sets, resulting in a total of 335 repetitions with a 3-5 min. rest between the 25 sets being performed during the session. All individual participant data was examined for evidence of HR plateaus (indicative of steady state).

The external loads were significantly different between the upper body and the lower body exercise reflecting that a greater muscle mass was involved in the movements during lower body exercise. The number of repetitions was significantly different between upper body and lower body exercise reflecting that the greater masses lifted for lower body corresponded with the greater number of repetitions performed. Maximal mass per exercise session was correlated with the maximum number of repetitions performed per set and in turn with the exercise session. The effect of an increase in muscle mass would necessarily require a greater cardiac output during exercise. An increase CO would require a greater HR. However, no statistical differences were found between the maximal peak HRs achieved during the two different sessions in regard to maximal mass lifted and maximal number of repetitions.

Using the HR profile to Measure Set Duration

A typical HR profile recorded for a set of resistance exercise is composed of two defined periods: the set duration (work time) and rest time. The rest time consists of a recovery period where the heart rate is returning to baseline (pre-set levels) and a possibility of a true rest period where the heart rate is stable at baseline levels. Depending upon the inter-set interval, the rest time may not permit the heart rate to recover. In this study, the inter-set interval was controlled and did permit adequate heart rate recovery between sets. It is important to note that this demonstrates a useful aspect of heart rate profiles for resistance training exercise. Since the inter-set rest interval can be readily observed and if its duration is too short it could influence the heart rate recovery, and hence the exercise performance in the subsequent sets.

In this study we have established that HR profiles are capable of accurate assessment of set duration. Comparison of the actual HR set duration measured by stopwatch with those of determined by HR profile showed excellent agreement, despite the fact that the HR was recorded on 5-second intervals. The correlation between actual HR set duration and the number of repetitions for upper body showed r-values between 0.888 and 0.995 with p values all significant ($p<0.001$). For lower body, the same correlation showed r-values from 0.931 to 0.993 with p values all significant ($p<0.001$). The correlation between actual and estimated HR set duration for upper body showed r values between 0.849 and 0.986, and for lower body r values between 0.674 and 0.969 with p values all significant ($p<0.001$). The lower r-value obtained for the lower body was examined and it is very likely that the stopwatch was pressed improperly for three sets, resulting in the reduced correlation. If these points are removed for this participant, the correlation achieved is greater than 0.9.

In conclusion, set duration estimated by heart rate profiles can be used for auditing exercise performance during resistance training. Knowledge of set duration provides the ability to determine the total work time during an exercise session, as well as determining the total rest time during an exercise session. Further, it can be used to determine the level of compliance of a person with the prescribed method of performing the exercise, since it is known that the rate and number of repetitions influences the set duration. Finally, the ability to monitor the inter-set interval and its potential impact on heart rate in subsequent sets can also be achieved through heart rate profiles.

Summary

This study has provided the first systematic investigation of the heart rate responses to short duration, resistance-training exercise. The data clearly supports the use of HR as a sensitive measure to variation in key exercise loading parameters including the weight used and the number of repetitions performed in a set, at intensities normally used in resistance training. Further, this study has shown that there are predictable HR responses for each set of exercise and that the onset and offset of the exercise can be determined from these HR responses. This opens new avenues of investigation for understanding HR responses to short duration, non-steady state exercise, as well as the use of HR profiles to objectively assess resistance training exercise sessions for control purposes in scientific research and compliance assessment in applied areas of therapeutic exercise and training in sport.

CONCLUSIONS

The purpose of this study was to investigate HR response to short duration exercise resistance training. HR response to short duration exercise has not been evaluated in relation to exercise intensity. For this study, exercise intensity was manipulated by two different variables: weight and number of repetitions. Set duration, one of the HR parameters of resistance training was assessed through HR profiles comparing the actual and the estimated set durations with the stopwatch function of the HR monitor and the HR profiles. Therefore, the following three conclusions were established:

1. The relationship between peak HR and weight lifted per set over the range of weights normally used during resistance training for both upper and lower body was strong with correlation coefficients close to 1.0. (Upper body mean r=0.943 with a range of [r=0.854-0.990] and lower body mean r=0.948 with a range of [r=0.866-0.990]). A strong linear relationship between peak HR and weight lifted with high levels of statistical significance (p values <0.001) was observed for all relationships therefore supporting our hypothesis for objective 1. As such, HR is dependent upon the weight used during resistance training exercise.

2. The relationship between peak HR and number of repetitions performed per set through a range of repetitions normally used in resistance training exercise for upper and lower body was strong with correlation coefficients near 1.0. (Upper body mean r=0.927 with a range of [r=0.849-0.964] and lower body mean r=0.969 with a range of [r=0.951-0.988]). A strong linear relationship with statistical significance (p<0.05) between peak HR and repetitions was observed in all relationships therefore supporting our hypothesis for objective 2. As such, HR is dependent upon the number of repetitions performed during resistance training exercise.

3. Validity of HR profiles (continuous HR recording) to measure work time during resistance training using set duration was established by the high correlation coefficients obtained. Mean r-values of r=0.951 were established between estimated/actual HR set durations for UB exercise; and mean r=0.886 for LB exercise. As well, mean values between actual HR set duration versus number of repetitions of r=0.971 for UB exercise and r=0.962 for LB exercise were determined. A strong correlation between estimated vs. actual HR set duration was obtained in all relationships with a high level of statistical significance ($p<0.001$). HR can be used to assess the set duration of resistance training exercise and may therefore be used to monitor work time.

FUTURE RESEARCH

Movement around a joint is a dynamic motion and therefore, the resultant moment about a joint should be related to product of the inertia (mass and moment of inertia) and the segmental accelerations (linear and angular). The resultant joint moment is representative of the load about a joint. The study of acceleration, and the effect of acceleration variations on the resultant joint moment (that is, load on the musculoskeletal system) and hence, the effect of load on the cardiovascular system (specifically HR via required increases in CO) would aid in understanding and further clarifying the relationship between HR and load. Although we observed very high correlations between HR and weight or repetitions, there remains some variability in the data which we attribute in part to variation in acceleration with each repetition of the exercise. Because acceleration is an integral component of resultant joint moment, estimating the load imposed upon the musculoskeletal system using weight alone is incomplete. Further research should be directed to the contribution of acceleration variations in load and the subsequent affect on HR.

The differences between HR profiles and type of resistance training exercise should also be studied further. It would be important to establish a standardized process for the utilization of mass during resistance training exercise to more accurately predict or control exercise intensity and/ or loading pattern on the musculoskeletal system in order to ensure reliability when comparing upper body and lower body exercise and cardiovascular effect (HR response). This would establish a systematic understanding of the way in which resistance training could be adapted and standardized for different type of patients considering age, fitness level, body mass, body height, ethnic background, and medical history.

Further study is also required for resistance exercise in different postures, using different exercise equipment (including elastics and hydraulic machines), and different muscle groups, as the cardiovascular system responds differently under these varied conditions and parameters.

It is important to establish whether continuous HR recording (HR profiles) during resistance training sessions can be used as an effective tool for auditing the exercise session in terms of determining the number of sets, the set durations, the consistency in loading between sets based upon peak HR, the total work time, the total rest time, etc. This study has established the groundwork for the use of HR for evaluation and study of resistance training.

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APPENDIX A - PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PAR-Q)

Heart Rate Response To Short Duration Exercise Questionnaire.

Physical Activity Readiness Questionnaire (PAR-Q)

Name:______________________________________Date:__________________

Age: _______

Phone Number__________ Gender (please circle) M or F

Regular physical activity is fun and healthy, and increasingly more people are choosing to become more active every day. Being more active is very safe for more people. However, some people should check with their doctor before they start becoming much more physically active. If you are between the ages of 15 and 69, this test will tell you if you should check with your doctor before you start. Please answer the questions carefully and answer each one: 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?

Yes____ No_____ 2. Do you feel pain in your chest when you do physical activity?

Yes____ No_____ 3. In the past month, have you had chest pain when you were not doing physical activity?

Yes___ No_____ 4. Do you ever lose consciousness or do you lose your balance because of dizziness?

Yes____ No_____ 5. Do you have a joint or bone problem that may be made worse by a change in your physical activity?

Yes___ No______ 6.Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?

Yes____ No_____ 7. Do you know of any other reason you should not exercise or increase your physical activity?

APPENDIX B – SUPPLEMENTAL QUESTIONS TO PAR-Q

Heart Rate Response to Short Duration Exercise

Questionnaire

Version 1.0

Name:____Date:____________________

1. Have you had any type or medical problem within the last 6 months?
_____Yes ______No

2. Do you perform weight lifting during your sessions of exercise?
_____Yes ______No

3. How many times a week do you perform weight lifting?
______1-2 times ______ 3-4 times _____every single day

4. How long do you train during each session for?
____30 min _____45 min _____ more than 45 min

5. How long have you been training for?
____Less than the last three months ____ more than the last 3 months

6. How many hours at day do you sleep?
_____between 4-6 hours ______between 6-8 hours _____more than 8 hours

7. Do you smoke cigarettes?
______Yes _______No

8. Do you suffer from high blood pressure?
______Yes _______No

9. Do you suffer from any cardiovascular disease or electrical arrhythmia?
_______Yes _______No

10. Are you pregnant or breast-feeding? (if applicable)
______Yes _______No

11. Have you consumed coffee or any other medication or herbal product (medicines, stimulants) that may alter your heart rate in the last 24 hours?
______**Yes** ______**No**

12. If **yes**, then please list substances and medication

____

APPENDIX C – PARTICIPANT INFORMATION AND CONSENT FORMS

HR Response to Short Duration Exercise
Participant Information and Consent

Title of Study: Heart rate response to varying weight during short duration exercise.

Principal Investigator: Dean Kriellaars, Ph.D., Associate Professor, School of Medical Rehabilitation, University of Manitoba, 787-2289 or 981-0261 (cellular)

Graduate Student Investigator: Alexandra Ortiz-Lugos, Human Performance Lab, RR311- 800 Sherbrook, 787-4903

You are being asked to participate in a research study. Please take your time to review this consent form and discuss any questions you may have with the study staff. You may take your time to make your decision about participating in this study and you may discuss it with your friends, family or (if applicable) your doctor before you make your decision. This consent form may contain words that you do not understand. Please ask the study staff to explain any words or information that you do not clearly understand.

Purpose of Study

This research study is being conducted to study how the heart rate responds to short duration exercise. Short duration exercise consists of resistance training exercise including the use of free weights and exercise machines using weight stacks. This equipment is commonly found in exercise facilities.

A total of 10 participants will participate in this study.

Study procedures

This study is examining how your heart rate will vary in response to performing a resistance training exercise at different intensities. A heart rate monitor will be placed around your chest to measure how fast your heart is beating while you are performing the exercise.

You will be required to visit the laboratory once. This session will last about 45 minutes to 1 hour in duration. At the session you will be required to complete two questionnaires. The investigator will then weigh you and determine your height. Following this, a heart rate monitor will be attached to you. This heart rate monitor consists of an elasticised strap that fits around your chest (under your shirt) and a heart rate monitoring watch that will be worn around your wrist.

During the visit, you will be required to perform ten sets of free weight exercise. The free weight exercise will consist of either a dumbbell row or standing leg press. You will be required to perform 10 repetitions for each set. The investigator will describe the exercise to you and provide a brief familiarization with the exercise (5 minutes). The amount of weight used for each set will be increased from low weight for the first set to a heavier weight for each successive set. A rest period of about three minutes will be provided between each set of exercise.

The researcher may decide to take you off this study if you not listening and adhering to directions.

You can stop participating at any time. However, if you decide to stop participating in the study, we encourage you to talk to the study staff first.

Risks and Discomforts

There are no major risks associated with the study. It is normal, however, that some participants may experience discomfort (muscle soreness) depending upon their usual participation level in resistance training exercise. This discomfort is usually mild and is an entirely normal consequence of the type of exercise that you will perform, and will resolve on its own. If at any point during the resistance training session you feel any discomfort, tell the investigators immediately so that the testing can be stopped.

Benefits

There may or may not be direct benefit to you from participating in this study. We hope the information learned from this study will benefit other people needing therapeutic exercise programs in the future.

Costs

All the procedures, which will be performed as part of this study, are provided at no cost to you.

Payment for participation

You will receive no payment or reimbursement for any expenses related to taking part in this study.

Confidentiality

Information gathered in this research study may be published or presented in public forums, however your name and other identifying information will not be used or revealed. Despite efforts to keep your personal information confidential, absolute confidentiality cannot be guaranteed. Your personal information may be disclosed if required by law.

The University of Manitoba Health Research Ethics Board may review records related to the study for quality assurance purposes.

Voluntary Participation/Withdrawal from the Study

Your decision to take part in this study is voluntary. You may refuse to participate or you may withdraw from the study at any time. Your decision not to participate or to withdraw from the study will not affect your care at this centre. If the study staff feels that it is in your best interest to withdraw you from the study, they will remove you without your consent.

We will tell you about any new information that may affect your health, welfare, or willingness to stay in this study.

You are not waiving any of your legal rights by signing this consent form nor releasing the investigator(s) or the sponsor(s) from their legal and professional responsibilities.

Questions

You are free to ask any questions that you may have about your rights as a research participant. If any questions come up during or after the study or if you have a research-related injury, contact the study investigator and the study staff: Dean Kriellaars, Ph.D. at 787-2289 or 981-0261 OR Alexandra Ortiz-Lugos at 787-4903.

For questions about your rights as a research participant, you may contact The University of Manitoba, Bannatyne Campus Research Ethics Board Office at (204) 789-3389.

Do not sign this consent form unless you have had a chance to ask questions and have received satisfactory answers to all of your questions.

HR Response to Short Duration Exercise.
Participation Information and Consent

Title of Study: Heart rate response to varying repetitions during short duration exercise.

Principal Investigator: Dean Kriellaars, Ph.D., Associate Professor, School of Medical Rehabilitation, University of Manitoba, 787-2289 or 981-0261 (cellular)

Graduate Student Investigator: Alexandra Ortiz-Lugos, Human Performance Lab, RR311- 800 Sherbrook, 787-4903

You are being asked to participate in a research study. Please take your time to review this consent form and discuss any questions you may have with the study staff. You may take your time to make your decision about participating in this study and you may discuss it with your friends, family or (if applicable) your doctor before you make your decision. This consent form may contain words that you do not understand. Please ask the study staff to explain any words or information that you do not clearly understand.

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A total of 10 participants will participate in this study.

Study procedures

You will be required to visit the laboratory for 45 minutes to one hour. You will be required to complete two questionnaires. The investigator will then weigh you and determine your height. Following this, a heart rate monitor will be attached to you. This heart rate monitor consists of an elasticised strap that fits around your chest and a heart rate monitoring watch that will be worn around your wrist.

Then you will be required to perform a number of sets of free weight exercise. The free weight exercise will consist of either a dumbbell row or standing leg press. The investigator will describe the exercise to you and provide a brief familiarization with the exercise (5 minutes). You will be asked to perform a single repetition with this weight followed by a rest period of about 3 minutes. After this, you will repeat this procedure but the number of repetitions will be increased by one for each set. It is expected to perform a total of 25

The researcher may decide to take you off this study if you not listening and adhering to directions.

You can stop participating at any time. However, if you decide to stop participating in the study, we encourage you to talk to the study staff first.

Risks and Discomforts

There are no major risks associated with the study. It is normal, however, that some participants may experience discomfort (muscle soreness) depending upon their usual participation level in resistance training exercise. This discomfort is usually mild and is an entirely normal consequence of the type of exercise that you will perform, and will resolve on its own. If at any point during the resistance training session you feel any discomfort, tell the investigators immediately so that the testing can be stopped.

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There may or may not be direct benefit to you from participating in this study. We hope the information learned from this study will benefit other people needing therapeutic exercise programs in the future.

Costs

All the procedures, which will be performed as part of this study, are provided at no cost to you.

Payment for participation

You will receive no payment or reimbursement for any expenses related to taking part in this study.

Confidentiality

Information gathered in this research study may be published or presented in public forums, however your name and other identifying information will not be used or revealed. Despite efforts to keep your personal information confidential, absolute confidentiality cannot be guaranteed. Your personal information may be disclosed if required by law.

The University of Manitoba Health Research Ethics Board may review records related to the study for quality assurance purposes.

Voluntary Participation/Withdrawal from the Study

Your decision to take part in this study is voluntary. You may refuse to participate or you may withdraw from the study at any time. Your decision not to participate or to withdraw from the study will not affect your care at this center. If the study staff feel that it is in your best interest to withdraw you from the study, they will remove you without your consent.

We will tell you about any new information that may affect your health, welfare, or willingness to stay in this study.

You are not waiving any of your legal rights by signing this consent form nor releasing the investigator(s) or the sponsor(s) from their legal and professional responsibilities.

Questions

You are free to ask any questions that you may have about your rights as a research participant. If any questions come up during or after the study or if you have a research-related injury, contact the study investigator and the study staff: Dean Kriellaars, Ph.D. at 787-2289 or 981-0261 OR Alexandra Ortiz-Lugos at 787-4903.

For questions about your rights as a research participant, you may contact The University of Manitoba, Bannatyne Campus Research Ethics Board Office at (204) 789-3389.

Do not sign this consent form unless you have had a chance to ask questions and have received satisfactory answers to all of your questions.

Statement of Consent

I have read this consent form. I have had the opportunity to discuss this research study with Dean Kriellaars, Ph.D. or Alexandra Ortiz-Lugos. I have had my questions answered by them in language I understand. The risks and benefits have been explained to me. I understand that I will be given a copy of this consent form after signing it. I understand that my participation in this study is voluntary and that I may choose to withdraw at any time. I freely agree to participate in this research study.

I understand that information regarding my personal identity will be kept confidential, but that confidentiality is not guaranteed. I authorize the inspection of any of my records that relate to this study by The University of Manitoba Research Ethics Board, for quality assurance purposes.

By signing this consent form, I have not waived any of the legal rights that I have as a participant in a research study.

Participant signature________________________ Date ______________________

Participant printed name: ________________________________

I, the undersigned, have fully explained the relevant details of this research study to the participant named above and believe that the participant has understood and has knowingly given their consent

Printed Name: ______________________ Date ___________________

Signature: ________________________________

Role in the study: _________________________________