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Heart rate measurements after group exercise

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HEART RATE MEASUREMENTS AFTER GROUP EXERCISE

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by

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CERTIFICATE OF APPROVAL

MASTER OF SCIENCE THESIS

This is to certify that the Thesis of

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submitted in partial fulfillment of the requirements for the Degree of Master of Science in the School of Health Sciences and Human Performance At Ithaca College has been approved.

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ABSTRACT

The purposes of this study were to measure the typical delay in obtaining palpated postexercise heart rate (HR) by participants in a group exercise class and to determine if actual exercise HR can be predicted from immediate HR recovery (HRR) measures by examining the linearity of HR decline postexercise. To achieve this, 54 females (19.9 ± 1.6 y) were filmed during exercise classes. Videotapes were reviewed to determine time taken by each subject to obtain palpated HR at the exercise class mid-point and end-point. HR was also recorded at 10 s intervals during and for 1 min after exercise with a HR monitor to determine exercise HR and HRR measures. Subjects were blinded to HR monitor measures. Data were analyzed using 2 x 2 ANOVA and regression analysis to compare monitored exercise HR to palpated HR and to predict exercise HR from postexercise HRR measures, respectively. The delay before obtaining palpated HR measures ranged from 17- 20 s. Exercise HR was significantly different from palpated HR at mid-point (169.4 ± 13.4 vs. 143.7 ± 23.2 bpm) and end-point (165.5 ± 15.6 vs. 143.2 ± 19.3 bpm) of the class. It was also seen that exercise HR can be predicted well from monitored postexercise measures due to a linear decline in HRR. The adjusted R^2 values ranged from 0.911 to 0.653 for HR predicted from HRR measures in the first minute postexercise at 10 s increments. One-way ANOVA with repeated measures between means of arithmetically derived prediction equations (Q-Pred) and monitored actual exercise HR showed no significant difference between the two ($F(3, 321) = 1.09$, $p = .353$). In conclusion, the significant difference between actual exercise HR and palpated HR is largely attributable to the near 20 s delay before the typical person obtains a palpated HR postexercise. In addition, the near linear decline in HR in the first minute after exercise can be used to predict exercise HR.

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DEDICATION

I dedicate this project to my mother Mariamma John who would have been very proud of this achievement and whom I miss the most.

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CHAPTER 1

Introduction

During exercise the heart beats faster to meet the metabolic demands of the working muscles. The increase in heart rate (HR) is directly proportional to the intensity of exercise (Mejia, Lentine, Ward, & Mahler, 1999). Therefore, measuring HR during exercise is an excellent way to gauge exercise intensity. Accurate monitoring of HR during exercise also helps to maximize the effectiveness of an exercise session. There are many methods used to monitor HR. Although sophisticated HR monitors are available for this purpose, a common method of measuring HR is by palpation, which involves counting the pulse at the carotid or radial artery. Although a common method, accuracy of the palpation technique is limited. An important limiting factor is the rapid rate of HR recovery (HRR) immediately after exercise related to reactivation of the parasympathetic nervous system (Gaibazzi, Petrucci, & Ziacchi, 2004). Therefore, the palpated HRR reading obtained may not accurately reflect actual exercise HR. After the initial rapid decrease, HR continues to decline further but at a slower rate that is related to the intensity and duration of the performed exercise.

Another factor affecting accuracy is improper technique. Most individuals tend to stop exercise to measure their pulse due to movement artifact (Mejia et al., 1999). If an individual stops exercising to measure HR via the palpation technique, he or she must ensure that the measure is made before a large decline in HR. Delay in making this measure could be a result of an inability to locate pulse quickly. Pulse location and identification may further be exacerbated by movement artifact that exists immediately after exercise. A significant delay in measuring postexercise HR may cause underestimation of true exercise HR. This could lead the individual to exercise more vigorously in subsequent exercise sessions to reach the target HR zone, perhaps resulting in over-exertion. Over-exertion could lead to cardiovascular or musculoskeletal injuries (Thompson, 1996). In the case of elite athletes, over exertion may even result in a drop in performance (Kajiura, MacDougall, Ernst, & Younglai, 1995; Keizer & Kuipers, 1988).

Currently, the duration a typical person waits before measuring HR via palpation after exercise is not known. Given how HRR affects HR measurement, it is essential to determine how long a person waits before measuring HR and how this delay affects the accuracy of the measure. It is also of interest to determine if a relationship exists between postexercise and actual exercise HR that will allow an accurate prediction of exercise HR from postexercise measures.

Statement of Purpose

The purposes of this study were to examine the time frame or delay before a measure of postexercise HR is obtained by the typical individual and to determine if actual exercise HR can be estimated from postexercise HRR measures by examining the slope of the drop in HR.

Hypotheses

The hypotheses for this study are:

1. There will be a significant difference between actual exercise HR compared to HRR measured via palpation or those obtained at 10 s intervals postexercise by a HR monitor.
2. There will be a linear drop in HR for the first minute postexercise that will allow

prediction of actual exercise HR.

Scope of the Problem

The U.S. Surgeon General and the national public health agenda promotes physical activity and recommends that adults engage in at least 30 min of moderate physical activity daily. The increasing public awareness of the importance of physical activity is reflected in a survey conducted in 2003, which revealed that approximately 38 million Americans had enrolled in health clubs. Many more Americans exercise at home, outdoors, and through participation in sports. Irrespective of where or how they exercise, a large portion of this exercising population keeps track of exercise intensity by palpating pulse. Monitoring HR not only helps avoid over-exertion, but also provides a gauge to adjust exercise intensity and optimize results. Due to the large number of people that exercise and monitor exercise intensity with the palpation technique, it is essential that the HR measure is made in a manner that provides accurate results.

There are no studies that have determined the actual delay that occurs postexercise in measuring HR and how this delay affects the accuracy of the measurement. The results of this study could interest exercise instructors and those of the general population that participate in regular exercise by increasing the awareness of the importance of timing in recording postexercise HR.

Assumptions of the Study

The following assumptions were made at the start of the study:

1. The typical time frame for measurement of exercise HR ranges from zero to sixty seconds postexercise for most people.

2. HR begins to recover immediately postexercise and the rate of this decline is directly proportional to the fitness level of the person.
3. The subjects will follow the instructions provided by the investigator to the best of their abilities, and will inform the investigator in case of any discrepancies.

Definition of Terms

The following terms were operationally defined for the purpose of this study:

1. Postexercise HR- HR measured immediately after cessation of exercise.
2. HRR rate- The rate at which HR drops after exercise in bpm.
3. Target HR- The specified HR that should be achieved to ensure effectiveness of cardiovascular exercise.
4. Trained individual- One who exercises for 20 to 60 min at 55 to 90% of maximum HR for 3 to 5 days a week.
5. HR palpation- Counting of the carotid or radial pulse for 6 or 10 s, which is then used to obtain HR in bpm.
6. Heart rate variability (HRV) – Beat to beat variations in heart rate, which fluctuates due to gating of vagal efferent activity to the heart during ventilation (acceleration during inspiration and deceleration during expiration).

Delimitations

The delimitations of the study were as follows:

1. HR was measured with a HR monitor and manually using the palpation method.
2. Testing was done in a group exercise class at an indoor facility.
3. The participants were limited to female Ithaca College students ranging from 18 to

22 years in age with no known heart conditions.

4. The exercise was continuous with the exception of a HR measurement break at the mid-point of the exercise session.

Limitations

The limitations of the study are as follows:

1. The results of this study may not be generalizable to:

   a) An outdoor environment

   b) Individuals with cardiac conditions

   c) Less fit individuals

   d) Males

   e) Elite athletes

2. The results of this study may not be generalizable to individuals who are substantially older or younger than college-aged individuals.

3. The results may not be applicable to individuals that exercise in a non-group setting (i.e., alone).

CHAPTER 2

Review of Literature

Do people who exercise purposefully and monitor HR during exercise do a good job of monitoring exercise intensity? To measure HR more reliably, the exercising population needs to know the proper technique of palpating HR and how HR behaves at rest, exercise, and especially during recovery. This literature review examines the use of measuring HR to gauge exercise intensity, ensure safety in the general population and diseased individuals, as a training tool in athletics, and as a prognostic indicator of mortality. It also examines the physiology of HR response during rest, exercise, and postexercise recovery followed by a discussion on HR adaptations to endurance training seen at rest, during exercise, and in the postexercise recovery stage. Finally, the methods used to measure HR and the problems associated with them are discussed. The chapter concludes with a summary of key points raised in this review.

Gauging Exercise Intensity

'Quantity' and 'quality' are terms often used to describe exercise. Quantity is the amount of time and frequency with which a person exercises, while quality refers to the intensity or workload at which the exercise is performed. Monitoring intensity is considered vital to ensure the quality of the exercise session (i.e., the effectiveness and safety of an exercise session). Exercise intensity is often expressed as a percentage of measured or predicted maximal oxygen uptake or a percentage of maximum HR. HR is an accurate reflector of exercise intensity because of the direct relationship between the two under most circumstances; an increase in HR is directly proportional to an increase in exercise intensity (Mejia et al., 1999). A number of formulated equations are used by exercise professionals in different settings to calculate target exercise intensity or target HR. Professionals believe that exercising at the target HR produces maximum cardiovascular benefits with minimum risk (Whaley, Brubaker, & Otto, 2006, chap. 7, p. 139). Experts recommend that a target HR obtained by measuring pulse periodically during moderate exercise is also a means by which progress can be monitored in a fitness program.

Monitoring HR to Ensure Safety

Moderate intensity exercise is safe for most individuals. Nevertheless, the ACSM recommends a health appraisal before starting an exercise program, because each individual has different physiological and perceptual responses to acute exercise (Whaley, Brubaker, & Otto, 2006, chap. 1, p. 3). Although the risk of serious medical complications during exercise is low, it is higher than during sedentary activities. Hence, unsupervised individuals must be aware of how temperature, humidity, and altitude affect HR during exercise to prevent over-exertion (Whaley, Brubaker, & Otto, Sec. IV, p. 302). In sedentary people, excessive workloads may surpass the body's ability to adapt to increased stress, resulting in over-use injuries. Therefore, caution in selecting an appropriate workload and type of exercise to provide optimal conditioning while minimizing injury or illness is important. Exercise testing is used to gauge physical ability and is necessary to recommend a safe exercise program.

Exercise testing and careful prescription is necessary, because an unsafe intensity of exercise increases cardiac stress, which may lead to sudden cardiac arrest (Pina et al., 2003). In most exercise prescriptions, intensity is kept at a safe level through HR monitoring. The ACSM provides guidelines to choose an appropriate exercise and workload based on various risk factors, which are considered during exercise testing and prescription. Although many of the general principles of exercise prescription are the same for individuals of all ages, special care must be given when setting up a fitness program for older or diseased individuals (Lim, 1999). Experts recommend that exercise prescription for patients undergoing cardiac rehabilitation must be directly based on HR parameters obtained during exercise testing (Nieuwland, Berkhuysen, Veldhuisen, & Rispens, 2002).

Exercise testing and prescription has now become an extremely useful and popular means to help individuals exercise safely by reducing the risks of injuries and to prevent death from the sudden incidence of cardiac arrest. A large number of health organizations recommend obtaining an exercise prescription before the start of an exercise program, especially in the diseased and elderly (Pina et al., 2003).

HR Monitoring of Athletes

While high intensity training is vital to athletic performance in endurance athletes, over-training may lead to underperformance (Kajiura et al., 1995; Keizer & Kuipers, 1988). Since HR is linearly related to exercise intensity and is used to predict VO_2 max, endurance athletes use HR to monitor exercise intensity (Mejia et al., 1999). Although other methods such as ventilatory and lactate thresholds are used to monitor training intensity, HR monitoring is more practical as it is convenient and does not require laboratory testing (Boulay, Simoneau, Lortie, & Bouchard, 1997). However, athletes must be cautious while using HR to measure exercise intensity, because there are many intrinsic and extrinsic factors that affect HR response to exercise. Intrinsic factors include a day-to-day variation of one to six bpm and cardiac drift, a phenomenon where HR tends to increase gradually as exercise duration exceeds 20 min (Gilman, 1996; Lambert, Mbambo, & Gibson, 1998). Extrinsic factors include intensity, posture, time of day, type of exercise and environmental conditions like heat, humidity, wind, terrain, time of day, competition, and altitudes (Creagh & Reilly, 1997; Gilman, 1996; Jeukendrup & Van Diemen, 1998; Lambert et al., 1998; Lear, Brozic, & Ignaszewski, 1999; Sutherland, Wilson, Aitchison, & Grant, 1999).

HR Recovery and Mortality

In the postexercise phase, HR returns towards resting levels because of reactivation of the parasympathetic nervous system. A faster return of HR to resting values reflects an increased parasympathetic tone, which is cardio-protective in nature. A slower return of HR to resting values reflects a decrease in parasympathetic tone and indicates an increased risk of cardiac related death (Cole, Blackstone, & Pashkow, 1999). The rate at which HR recovers immediately after exercise, therefore, can be a predictor of mortality; for example, a slow HRR rate during the early postexercise recovery period in older people is a strong indicator of mortality (Billman, 2002; Cole et al.; Messinger & Pothier, 2003; Nishime, Cole, & Blackstone, 2000; Rardon & Bailey, 1983; Vanoli et al., 1991). A healthy HRR (irrespective of age) in the first minute postexercise ranges from 12-42 beats (Carnethon et al., 2005; Nishme et al.; Kannankeril, Lé, Kadish, & Goldberger, 2004). Postexercise HRR of less than 12 beats in the 1st min postexercise is abnormal and indicates an increased risk of death (Morsheidi-Meibodi, Larson, Levy, O'Donnell, & Vasan, 2002; Nishime et al.).

HR Physiology

HR is determined by the intrinsic pacemaker activity of the sino-atrial (SA) node, which exhibits automaticity determined by spontaneous changes in Ca^{++}, Na^{+}, and K^{+} conductances (Klabunde, 2004). This intrinsic automaticity, if left unmodified by neurohumoral factors, exhibits a spontaneous firing rate of 100 to 115 bpm (Klabunde). In addition to the intrinsic regulation of HR, extrinsic factors also influence HR. Extrinsic regulation is mediated by the brain's higher somatomotor central command via the sympathetic and parasympathetic nervous system (Carter, Banister, & Blaber, 2002; McArdle, Katch, & Katch, 2000). The central command generates impulses based on the input received from the reflex regulatory mechanisms of the cardiovascular system. These reflex impulses are generated in the peripheral nervous system and ascend via small afferent nerves to the cardiovascular center in the medulla (McArdle et al.). The medulla integrates these inputs and responds through the efferent sympathetic and parasympathetic nervous system. These outputs influence the inherent rhythm of the myocardium to optimize tissue perfusion and maintain central blood pressure (McArdle et al.). This type of neural control operates during rest and exercise and is also involved in the pre-exercise anticipatory period (McArdle et al.).

Effects of Sympathetic and Parasympathetic Stimulation

The efferent neural impulses from the cardiovascular control center (i.e., medulla) include both the sympathetic and parasympathetic output. The sympathetic system is responsible for cardioacceleration. Sympathetic activation causes the release of the catecholamines epinephrine and norepinephrine that accelerate SA node depolarization, causing chronotropic and inotropic effects (i.e., increased HR and myocardial contractility) (McArdle et al., 2000). The parasympathetic system when stimulated, releases acetylcholine that retards the rate of sinus discharge, thereby slowing HR (McArdle et al.).

Reflex Mechanisms of the Cardiovascular System

The reflex mechanisms of the cardiovascular system consist of the arterio-baroreceptors, muscle metaboreceptors/chemoreflex, and the muscle mechanoreceptors. Afferent inputs from these mechanisms help to regulate blood flow and cardiac function.

Arterio-baroreceptors. This is a negative feedback control mechanism that plays an important role in the regulation of blood pressure. The baroreceptors are located in the aortic and carotid bodies and sense changes in blood pressure (Rowell & Shepherd, 1996). When blood pressure deviates from the set point, the baroreceptors send feedback to the central nervous system, which causes the cardiovascular system to adjust blood pressure (resets baroreceptor set point).

Muscle chemoreflex/metaboreflex. A discrepancy between blood flow and metabolism causes accumulation of intramuscular metabolites and is detected by chemosensitive nerve fibers within the muscle (Rowell & Shepherd, 1996). Input regarding the chemical state of the muscles is conveyed to the cardiovascular center, which regulates cardiac output, blood pressure, and HR accordingly through activation of the autonomic nervous system (Rowell & Shepherd).

Mechanoreflexes. Mechanoreceptors are present in the form of nerve fibers in the muscles, muscle spindles, and golgi tendons. These receptors monitor muscle stretch and contractions, and send input to the central nervous system. This input is used to adjust cardiac function and blood flow (Rowell & Shepherd, 1996).

HR Behavior at Rest

HR is decreased below the intrinsic rate primarily by activation of the parasympathetic vagus nerve innervating the SA node, which causes the heart to beat between 60 and 80 bpm (Klabunde, 2004). HR will not increase above this rate without a withdrawal of vagal tone and activation of sympathetic nerves (in short, a change in autonomic control via change in central command). Many factors alter resting HR caused by changes in autonomic tone. For example resting HR increases in anticipation of exercise, and due to anxiety or fear. Changes in resting HR also occur due to changes in input from chemoreceptors, mechanoreceptors, metaboreceptors, and baroreceptors that provide information regarding the chemical, physical, metabolite, and barometric (blood pressure) states of the body (McArdle et al., 2000).

HR Response During Exercise

Role of Autonomic Nervous System

At the onset of exercise, the cardiovascular control center withdraws vagal tone to increase HR in an attempt to achieve a new blood pressure set-point, which is directly related to exercise intensity. Although sympathetic activation exists at a reduced level at the onset of exercise, the initial increase in HR (up to a 100 bpm) is directly related to reduced parasympathetic activity, which is independent of exercise intensity (Pierpoint & Voth, 2004; Sone, Tan, Nishiyasu, & Yamazaki, 2004). As intensity increases (beyond 100 bpm), reflex mediated feedback activity increases, stimulating the sympathetic nervous system to further elevate HR rapidly.

Pararasympathetic activity still persists at a reduced level (Kannankeril et al., 2004). This reciprocal change between sympathetic and parasympathetic activity is responsible for the increase in HR seen during exercise. After the initial increase, a steady plateau of HR corresponding to exercise intensity is reached within two to three minutes of exercise. A further increase in intensity will cause a corresponding increase in sympathetic activity. Exercising at high intensity for a long period of time can lead to a further gradual increase in HR. This gradual increase is termed 'cardiac drift'.

Cardiac drift. The gradual increase in HR seen during long durations of high intensity exercise may be related to sweating (Cheatham, Mahon, Brown, & Bolster, 2000). Excessive sweating reduces plasma volume, which decreases stroke volume, and potentially cardiac output. To maintain cardiac output and hence proper blood flow to the active musculature, HR is increased (Cheatham et al.). HR will remain elevated until exercise intensity is reduced. The increased sympathetic nervous activity that mediates the increase in HR may exacerbate cardiac drift by elevating plasma catecholamine levels (Marra & Hoffman-Goetz, 2004). The slow clearance of accumulated catecholamines may also be a factor that causes cardiac drift (Marc, Gonzalez-Alonzo, Montain, & Coyle, 1991).

Role of Cardiovascular Reflex Mechanisms

With an increase in activity, the heart alone cannot increase cardiac output (Rowell & Shepherd, 1996). An increase in cardiac output also requires changes in the peripheral circulatory system that ensures blood pressure maintenance; namely, an increase in venous return and blood flow redistribution. The muscle pumps increase venous return during exercise by transporting peripheral blood volume back into the heart, while the sympathetic nervous system, in response to feedback from the cardiovascular reflex system, reduces blood flow to the inactive musculature and to the renal splanchnic region (Rowell & Shepherd).

Arterio-baroreflex. At the onset of exercise, skeletal muscle activation causes locally mediated vasodilation, which threatens BP maintenance (fall in arterial pressure) (Rowell & Shepherd, 1996). The fall in arterial pressure is sensed by baroreceptors, which send this information to the cardiovascular control center. In response, the cardiovascular control center increases sympathetic nervous activity, thereby maintaining blood pressure by increasing stroke volume and HR, which increases cardiac output (Rowell & Shepherd).

Muscle-chemoreflex/metaboreflex. Accumulation of intramuscular metabolites due to increase in muscular activity is detected by chemoreceptors (Rowell & Shepherd, 1996). Central command receives input from the chemoreceptors and in turn alters stroke volume and HR, and hence, cardiac output. This autonomic nervous system activity maintains BP and indirectly serves to increase muscle blood flow, to reduce the accumulation of muscle metabolites (Rowell & Shepherd). The role of the chemoreceptors is more pronounced during dynamic and static exercise (Iellamo et al., 1999).

Mechanoreflexes. As muscular activity begins and continues to increase, inputs from the mechanoreceptors further refine autonomic output from central command to ensure adequate oxygenated blood to the working muscles (Rowell & Shepherd, 1996).

HR Response During Recovery

When exercise is terminated, HR decreases rapidly towards resting levels (McArdle et al., 2000). The speed at which HR recovers depends largely on parasympathetic reactivation and sympathetic withdrawal in the postexercise phase (Pierpoint & Voth, 2004). HRR has an initial phase during the first 30 s postexercise and a secondary phase after first 30 s postexercise.

The rate of recovery during the initial phase is primarily due to reactivation of parasympathetic tone and is not dependent on sympathetic withdrawal (Imai et al., 1994). In the secondary phase the speed of recovery is dependent on the prior exercise intensity (Kannankeril et al., 2004). HRR for submaximal intensities is more rapid than maximal intensities because of the faster reactivity of the parasympathetic nervous system and slower withdrawal of the sympathetic nervous system, respectively in both stages (Parekh & Lee, 2005; Savin, Davidson, & Haskell, 1982). After high intensity exercise, sympathetic withdrawal begins only after approximately 2 min in the postexercise phase (Imai et al.); the parasympathetic system is activated before withdrawal of the sympathetic system, but at a slower rate compared to its activation after submaximal intensity of exercise (Parekh & Lee). Although quantifying HRR is difficult, Kannankeril et al. quantified postexercise HRR for the first 10 min for high intensity exercise and found that the total recovery during min 2 to 5 was approximately 30 beats. HR, thereafter, remained relatively steady for the remaining 6 min. Most measures of cardiac autonomic modulation return to baseline levels after approximately 30 min, (i.e. HR reaches resting values) (Parekh & Lee, 2005).

Factors That May Affect HRR

While HRR is dominated by parasympathetic activation and sympathetic withdrawal, other factors that may have an impact on complete HRR include slower resetting of cardiovascular reflex mechanisms and delayed clearance of body heat and catecholamines (Javorka, Zila, Balharek, & Javorka, 2002; Parekh & Lee, 2005). Postexercise hypotension after acute exercise could also delay restoration of the parasympathetic tone by stimulating arterial baroreflex, which elevates sympathetic outflow (Parekh & Lee). A slow HRR may also be associated with an abnormal triglyceride-to-HDL (high density lipids) ratio, which is a correlate of insulin resistance (Shishehbor, Hoogwerf, & Lauer, 2004). These factors could play a greater role during higher intensity of exercise and may delay HRR even further (Parekh & Lee).

Training Adaptations

Cardiac Muscle Adaptations

Regular cardiovascular training increases left ventricular size via eccentric hypertophy, which increases end diastolic volume, and therefore, myocardial contractility (Rowell & Shepherd, 1996). There is a close correlation between increase in myocardial dimensions, increased contractile capacity, and intensity of training (Kemi et al., 2005; Pavlik et al., 2005). Cardiac hypertrophy is most commonly seen in athletes as a result of high intensity training. For example, elite Hungarian water polo players demonstrated a left ventricle wall thickness of 15 to 16 mm, which is 2 to 3 mm thicker than the thickness associated with cardiomyopathy (Pavlik et al.). Long-term endurance training also increases plasma volume and the number of red blood cells

(Rowell & Shepherd). The expanded plasma volume further increases stroke volume and therefore cardiac output, which along with the increased red blood cells ensures a greater supply of oxygenated blood to the working muscles. The increased stroke volume also allows the body to maintain blood pressure with less sympathetic nervous activity at any given absolute submaximal workload, which is reflected by a lower HR (Rowell & Shepherd). Another adaptation seen in regular exercisers is a decreased sensitivity to catecholamines, which may contribute to reduce HR during submaximal exercise (Spina et al., 1992). The magnitudes of the aforementioned cardiovascular changes are directly related to exercise intensity and volume of the training program.

Resting HR Adaptation

Endurance training induces intrinsic changes in the heart that lower resting HR. This bradycardia results from adaptations in the sino-atrial node autorhythm and is reflected by a decreased sinus rhythm. This intrinsically caused bradycardia has been observed in elite endurance athletes where resting HR decreased with no further modulation of the parasympathetic system after training (Bonaduace et al., 1998). A similar result was observed in a study conducted by Evangelista, Martuchi, Negrao, & Brum (2005) on rats after detraining, which showed a loss of resting bradycardia due to an increase in intrinsic HR. Reduction in intrinsic HR may not be dependent on exercise intensity. A decrease in resting HR attributable to reduced sinus rhythm has also been observed after moderate intensity exercise training (Leicht, Allen, & Hoey, 2003). Apart from intrinsic changes, resting HR is also modulated by adaptations to autonomic tone after exercise training.

Adaptation of autonomic tone. Endurance training reduces HR by modulating autonomic tone at rest, as reflected by an increase in parasympathetic tone and a decrease in sympathetic tone (Katona, McLean, Dighton, & Guz, 1982). The extent of change in autonomic modulation due to training may depend on exercise intensity and on the size of the musculature that is exercised (Carnethon et al., 2005; Dickhuth, Rocker, Mayer, Konig, & Korsten-Reck, 2004; Leicht et al., 2003). Autonomic modulation induced by months of endurance training decreases HR by about 15 bpm in healthy and obese individuals (Amano, Kanda, Ue, & Moritani, 2001; Yamamoto, Miyachi, Saitoh, Yoshika, & Onodera, 2001). Cardiovascular training also reduces sympathetic neural outflow in cardiac patients recovering from congestive heart failures (Roveda et al., 2003). Gender also affects the extent of autonomic adaptation, as women have a larger response (i.e., greater increase in parasympathetic activity and lesser sympathetic activity at rest) as compared to men after the same exercise program (Carter et al., 2003). Age may also have an effect on the extent of parasympathetic modulation. As age increases, cardiovascular deterioration may take place and decrease the extent of parasympathetic modulation cause by endurance training (Carter et al.). This difference is more visible at rest than during exercise (Carter et al.)

Adaptation of Heart Rate Variability

In addition to its effects on resting HR, endurance training may also affect heart rate variability (HRV). HRV is the beat to beat variation in heart rate caused by the neural activity of the parasympathetic and sympathetic branches of the autonomic nervous system. Increased parasympathetic activity increases HRV. Since high intensity endurance training increases parasympathetic tone at rest, it also increases HRV (Horio, Nakamura, Miyashita, Chiba, & Sato, 2004). The extent of adaptation can be measured by monitoring respiratory sinus arrhythmia, which reflects vagal efferent activity (Scott et al., 2004). In endurance trained athletes, vagus activity impedance is lower as compared to an untrained individual (Scott et al.). Similar HRV adaptations have also been seen in elderly women (Scott et al.). Extent of adaptations in HRV depends on gender (women show more HRV), exercise intensity, and regularity of physical activity (Scott et al.).

HR Adaptations During Exercise

Irrespective of age, short or long-term endurance training decreases submaximal exercise HR by autonomic modulation (Carter et al., 2003). Much of this change results from an attenuated baroreceptor sensitivity and myocardial stretch reflex sensitivity (Carter et al.). Cardiovascular trained middle-aged men exhibit decreased sympathetic and enhanced vagal effects on heart rate during dynamic exercise as compared with similar aged subjects in poor physical fitness. However, it must be noted that the extent of autonomic adaptation decreases with increasing age (Carter et al.; Chacon-Mikahil et al., 1998). Gender may also play a role in the extent of autonomic adaptation seen during exercise. Women may exhibit greater parasympathetic and lesser sympathetic activity during exercise than men after a similar endurance training program (Carter et al.). Autonomic modulation adaptation stops after a certain limit is reached. For example, in the case of elite athletes there may be no added increase in parasympathetic activity (exercise HR does not change with further training in elite athletes), but there is an increase in maximal stroke volume (Spina et al., 1992).

In all, it can be said that cardiovascular training decreases sympathetic outflow, enhances parasympathetic activity, increases stroke volume during submaximal and maximal exercise, and stimulates angiogenesis in the skeletal muscle. All these changes increase the transport of oxygen to the working muscle cells. Furthermore, these changes reduce resting and submaximal exercise HR

Adaptations During HR Recovery

Regular high intensity endurance training enhances parasympathetic modulation, which increases HRR postexercise. Even a short program of high intensity training (6 weeks) causes an autonomic nervous system induced increase in the rate of HRR in the postexercise phase by approximately 15 bpm (Yamamoto et al., 2001). Faster HRR after exercise at the same relative workload is seen across age groups (Carnethon et al., 2005; Darr, Bassett, Morgan, & Thomas, 1988). Moderate intensity exercise does not improve autonomic function and alter HRR as much as high intensity exercise (Carnethon et al.). Maintaining high or increasing from low/moderate to high intensity exercise training also sustains parasympathetic activity during postexercise HRR over prolonged periods of time (Carnethon et al.; Yamamoto et al.). Exercise training also enhances vagal tone in patients with cardiovascular disease, thereby improving HRR, which is an indicator of reduced morbidity in such patients (Rosenwinkel, Bloomfield, Arwady, & Goldsmith, 2001). It must be noted that individual differences can play a role in the rate of HRR (Hautala, 2004). For example, an elite athlete may have a faster rate of HRR than an ordinary individual who trains at high intensity exercise regularly.

Methods of Measuring HR

Exercise intensity is frequently monitored by measuring HR (Vogel, Wolpert, & Wehling, 2004). HR can be measured manually by palpating the pulse at the radial or carotid artery, or electronically with a HR monitor or an electrocardiogram.

Palpation Method

Pulse palpation includes application of mild pressure with the middle and index finger on one of several pulse sites. Pulse is then typically counted for 6 s and multiplied by 10 to determine HR in bpm. The pulse rate is most distinct at the carotid artery on the side of the larynx and is the HR measuring site used by most individuals. Another commonly used site is the radial artery of the wrist. Although the manual method of HR measurement requires no device and does not cost any money, an improper measurement postexercise can yield an inaccurate HR that is 10 to 30 bpm lower than actual exercise HR (Clapp & Little, 1994; DeVan, Lacy, Cortez-Cooper, & Tanaka, 2005; Laukkanen & Virtanen, 1998).

Telemetric HR Monitors

Electronic HR monitors manufactured by companies like Polar, Nike, and Timex are becoming increasingly popular due to ease in use, accuracy, availability, and affordability. HR monitors are usually worn around the wrist and display HR readings received telemetrically from a HR transmitter belt worn around the chest. HR readings obtained from HR monitors are highly correlated (within $\pm$ 8 bpm) to those obtained from an electrocardiogram (Kramer et al., 1993; Treiber et al., 1989; Wajciechowski, Dale, Andrews, & Dintiman, 1991). Recently developed HR monitors provide an athlete with immediate feedback while also storing data. These data can later be analyzed and used to develop individual training programs to improve performance (Gilman, 1996; Hills, Byrne, & Ramage 1998).

Problems in Measuring HR

HR is easily affected by psychological, positional, and environmental circumstances. HR fluctuations are common postexercise under apparently stable conditions (Vogel, Wolpert, & Wehling, 2004). Timing of HR measurement postexercise is an important issue as well. A significant delay in measuring HR postexercise can yield a HR that is 10 to 30 bpm lower than that obtained electronically during exercise (Clapp & Little, 1994; DeVan et al., 2005). Manual HR measures by habitual exercisers taken between 10 and 20 s postexercise were approximately 9 bpm lower than the actual postexercise HR, respectively (DeVan et al.). This underestimation occurs irrespective of whether the intensity of exercise is high or low. Hence the HR obtained by palpation postexercise may not reflect actual exercise HR (DeVan et al.; Laukkanen & Virtanen, 1998; Norton, Vehers, Ryan, & Jackson, 1997).

Another factor that may reduce the accuracy of measuring HR manually is an inadvertent stimulation of the arterial baroreflex, a result of applying external pressure to the reflexogenic area of the carotid artery. This stimulation of the arterial baroflex can cause an unloading of baroreceptors that decreases HR (Boone, Frentz, & Boyd, 1985). This effect is more pronounced in habitual exercisers, as they demonstrate greater arterial baroreflex sensitivity (Boone et al.).

Ultimately, manual postexercise pulse palpation may be inappropriate to measure exercise intensity in habitual exercisers (DeVan et al., 2005). Habitual exercises must look at more accurate means of HR measurements to gauge exercise intensity.

The use of HR monitors is better than the manual method because HR monitors accurately read HR about 95% of the time (Terbizan, Dolezal, & Albano, 2002). Although the measures made by HR monitors during rest and moderate activity are accurate, a study that examined the validity of seven commercially available HR monitors revealed that the accuracy of the measurements decreased at high intensities of exercise (Terbizan et al.). Nevertheless, the use of the more accurate electrocardiogram to monitor HR is too costly and impractical for use everyday.

Summary

Physical activity brings immense health benefits to those who exercise regularly. Regular exercise at high intensity causes physical and autonomic adaptations that enable the heart to function more efficiently. The autonomic adaptation causes an increase in parasympathetic activity and a decrease in the sympathetic activity at rest, during exercise, and in the postexercise recovery stage. Increased parasympathetic tone decreases stress on the heart for any absolute workload after high intensity training. Therefore, it is said that an increased parasympathetic activity is cardio-protective in nature.

The aforementioned benefits of exercise can only be optimized if the exercise is of the correct intensity, duration, and frequency. The toughest to measure among these is intensity and is typically tracked by monitoring HR. Keeping track of exercise intensity is necessary because an unsafe intensity could lead to the occurrence of a cardiovascular incident, including sudden cardiac arrest. HR monitoring is the most practical of all methods to estimate exercise intensity. HR monitoring of exercise intensity is also used by athletes and cardiac patients. Health professionals prescribe exercise based on HR to their clients.

There are numerous methods of monitoring HR, such as manual pulse palpation, HR monitors, and electrocardiogram. Manual pulse palpation is the most commonly used method for obtaining HR because it does not cost anything and is quite easy to do. Although easy to use, HR measurements made by the manual method are not accurate enough to reflect actual exercise intensity. Inaccuracy results from improper technique, movement artifact, or a delay in HR measurement. A lower HR reflected by the manual method may prompt an individual to increase workload, which may result in injury. Given the importance of exercising correctly, it is essential that people measure HR correctly. An improper timing of measurement could mislead the individual to increase workload, which may result in injury.

Using a HR monitor is the most feasible means to monitor HR accurately. But, HR monitors are not as widely used as the palpation method. This may be because HR monitors are costlier and involve wearing equipment. As the use of HR monitors by all exercising individuals is not possible, educating the exercising population about the rate at which HR drops and the time within which it should be measured is therefore fundamental and vital.

CHAPTER 3

Methods

This chapter describes in detail the methodology of the study. This methods section is subdivided into: (a) subject selection and characteristics, (b) measurement and procedures, and (c) data analyses.

Subject Selection and Characteristics

A total of 54 female students with a mean age of 19.9 ± 1.6 years served as subjects. Participants were recruited from group aerobic exercise classes held at the Ithaca College Fitness Center through the distribution of flyers (Appendix A) and a recruitment statement (Appendix B). Volunteers had the project explained to them and after questions were answered, those who wished to continue participating in the study signed an informed consent form (Appendix C). The informed consent form was approved by the college's human subjects review board and contained an agreement that subjects would attend at least four classes with the last one videotaped. All subjects filled out an exercise history questionnaire (Appendix D), which described their exercise habits. Those individuals (non-subjects) present in an exercise class during data collection who objected to being videotaped were given positions in the room to ensure exclusion from the camera's frame.

Measurements and Procedures

A purpose of this study was to measure the time taken to obtain palpated HR by individuals participating in group exercise. To obtain the true delay unaffected by any external influence on the subjects HR measuring habits, two strategies were used. The first was the use of mild deception before and during data collection. The second was subject habituation to the palpation technique of HR measurement and to the presence of HR monitors and video cameras.

Subjects were not informed of the exact nature of the study to minimize biasing their postexercise HR measurement behavior. They were told that investigators were videotaping them to observe the effect of fatigue and irregular breathing on the biomechanics of an exercising individual during the end stages of an exercise session. Subjects believed that the investigator intended to study the effect of changing biomechanics on the efficiency of the exercise being performed, as seen on video recordings of the class. Efficiency was defined as the maximum benefit derived from performing a particular exercise, as measured by HR variations during exercise. Through this mild deception, subjects were blinded to the purpose of videotaping, which was done to study the delay in HR measurement postexecise.

Subject habituation to the palpation technique was achieved by having the subject measure her HR twice during every exercise session with this method as part of the exercise class. Class instructors were familiarized with the concept of target HR and palpated HR measurement, and then taught class participants the technique in the first class. Subjects were informed that measuring postexercise HR immediately after exercise was necessary to accurately quantify exercise intensity. Subjects were allowed to use either a 10 or 6 s pulse count to obtain palpated HR. On the day subjects learned the palpation technique, they were also introduced to HR cards (Appendix E), which they used to record mid-point and end-point HR. Mid-point HR was measured during the middle of the class (i.e., subjects measured palpated HR when the instructor provided a hydration break of approximately three minutes). End-point HR was measured at the end of every exercise session. The class instructor used a stopwatch to time the start, mid-point, and end-point of each exercise session. Subjects were also habituated to the presence of video cameras and to the wearing of HR monitors (Polar S610, Polar Electro INC., Lake Success, NY 11042-1034) during three compulsory practice exercise classes that preceded a fourth class, which was used for data collection. HR monitors were covered with athletic tape to ensure that subjects were blinded to actual HR measures.

The data collection class was similar to the other exercise classes conducted at the Ithaca College Fitness Center (lasting 60 min and typically consisting of 20 to 25 participants). Classes provided cardiovascular challenge to participants and involved coordinated body movements designated under the instruction of a class instructor. Subjects were tagged with an ID card during data collection for identification purposes during film review. In all, four different exercise classes were videotaped for data collection and 54 subjects participated during these classes. None of the 54 subjects were allowed to participate more than once in data collection procedures.

Before data collection, video cameras were turned on and subjects were asked to activate HR monitors before starting exercise. Each subject wrote her ID number on the HR monitoring card. The HR monitors were numbered and care was taken to coordinate HR monitors with matching subject ID number. HR was recorded at 10 s intervals throughout the class by the HR monitor. The last monitored HR measure recorded before cessation of exercise at the mid-point and end-point were considered the actual exercise HR. Recorded HR from the first minute in the postexercise phase at mid-point and end-point of the class were used to determine HRR.

Videotapes were later reviewed by the investigator to determine the time taken by each subject to measure postexercise HR. The end-point of palpated HR measurement was when the subject removed her fingers from the pulse site. Time was measured with a stop watch. Monitored HR measures were downloaded into a computer using software provided by the manufacturer (Polar Electro Inc.). This software displayed monitored HR recordings for each minute of exercise in tabular form with each minute of exercise having six HR measurements at 10 s intervals. The investigator copied the displayed HR information from these tables into an Excel spreadsheet.

Data Analyses

The descriptive statistics for the subjects' age and duration and frequency of exercise participation were calculated. Descriptive statistics were also calculated for the delay in palpated HR measurement for midpoint and endpoint from video data. A 2 x 2 repeated measures ANOVA was used to compare postexercise HR measured by palpation to actual exercise HR measured by the HR monitor at both mid-point and end-point exercise session times. In addition, to evaluate the accuracy of subject palpation, the delay in measurement of palpated HR for each subject was matched to the closest time interval (upwards or downwards) at which HR was measured by the HR monitor. The corresponding monitored HR value was compared to the subject's palpated HR measurement using another 2 x 2 repeated measures ANOVA. Regression analyses were conducted to determine if actual HR could be predicted from HR measures recorded at 10 s intervals in the first minute postexercise as measured by the HR monitor. Prediction equations were formulated using the slope and intercept of the

HRR measures for 10, 30, and 60 s intervals postexercise. Simpler arithmetic quotient prediction equations (Q-pred) were also formulated. Two one-way ANOVA with repeated measures were done to examine if predicted HR measures obtained using both sets of equations were significantly different from actual HR obtained by the HR monitor at 10, 30, and 60 s intervals postexercise. The significance level for all statistical analyses was set at $p < 0.05$. The software package SPSS version 13 was used to analyze all data.

CHAPTER 4

Results

Statistical analyses of data collected in this study are presented in this chapter, which include the following sections: (a) subject characteristics, (b) delay in palpated HR measurement, (c) HR analysis, and (d) summary.

Subject Characteristics

Subjects (N= 54) in this study were female volunteers from group exercise classes held at the Ithaca College Fitness Center with a mean age of 19.9 ± 1.6 years. They typically exercised for approximately 56.0 ± 28.1 min·day^{-1} and 4.3 ± 1.4 days·week^{-1} over the previous 9.2 ± 7.3 months. Additional descriptive data are in Appendix F.

Delay in Palpated HR Measurement

The delay in palpated HR measurement for a subject was the time elapsed in seconds between stopping exercise and completing a pulse count, which was indicated by the removal of the subject's fingers from the pulse site. Subjects were allowed to choose either the 10 or 6 s pulse count during palpation; 41 subjects counted pulse for 6 s while 13 subjects counted pulse for 10 s. Table 1 shows the descriptive statistics for the delay in palpated HR measurement. The average delay for subjects that counted pulse for 10 s was similar at 19.5 ± 4.0 (mid-point) and 17.3 ± 4.2 (end-point) to the average delay of 18.9 ± 3.4 (mid- point) and 16.9 ± 2.2 (end-point) for subjects that counted pulse for 6 s. Essentially, it took 17 to 20 s for these subjects to obtain a palpated HR measure. This delay was present even though the subjects were urged to count their pulse immediately after exercise.

Table 1

Delay in HR Palpation After Exercise 30

Duration of measure	Mid-point		End-point	
	Mean	Std. Dev.	Mean	Std. Dev.
Ten Second	19.4	4.0	17.3	4.2
Six Second	18.9	3.4	16.9	2.2

Note: Values in seconds represent the time delay before subjects obtained palpated HR measurement after stopping exercise. Duration of measure indicate total time taken by subjects to count pulse. Subjects counted pulse for ten seconds (n=13) and six seconds (n=41) at the mid-point (hydration break) and at end-point (end of class).

HR Analysis

Exercise HR vs. Palpated HR

Actual exercise HR was the last HR measure recorded on the HR monitor before a subject stopped exercising to count pulse. Palpated HR measures were obtained from HR recordings made by every subject manually at the end of the exercise session. The mid-point actual exercise HR of 168.5 $\pm$ 12.8 bpm was 18.5% greater than the mid-point palpated HR of 142.0 $\pm$ 23.0 bpm. Similarly, the end-point actual exercise HR of 164.8 $\pm$ 16.0 bpm was 14.9% greater than the end-point palpated HR of 143.3 $\pm$ 19.1 bpm. Figure 1 shows the means and standard deviations of actual and palpated HR measures recorded during mid-point and end-point of the exercise session. A 2 x 2 repeated measures ANOVA was conducted to determine if method (monitored & palpated) and time of measurement (mid-point & end-point) influenced obtained HR. The analysis indicated a main effect for method of measurement, as palpated HR was significantly lower than actual monitored HR (F (1, 53) = 116.44, p = .000). There was no main effect for time of measurement indicating no difference between mid-point and end-point measurements (F (1, 53) = .309, p = .518). No interaction effect was observed between method and time of measurement (F (1, 53) = 3.23, p = .07). Appendix G shows raw data of actual and palpated HR.

HRR Curve

In the postexercise recovery phase, HR dropped at a rate of approximately 28.1 bpm at mid-point and 33.2 bpm at the end-point of the exercise session. Mid-point and end-point HRR curves were obtained by plotting line graphs on the mean HRR measures at 10 s intervals for the first minute postexercise. HRR curve for both

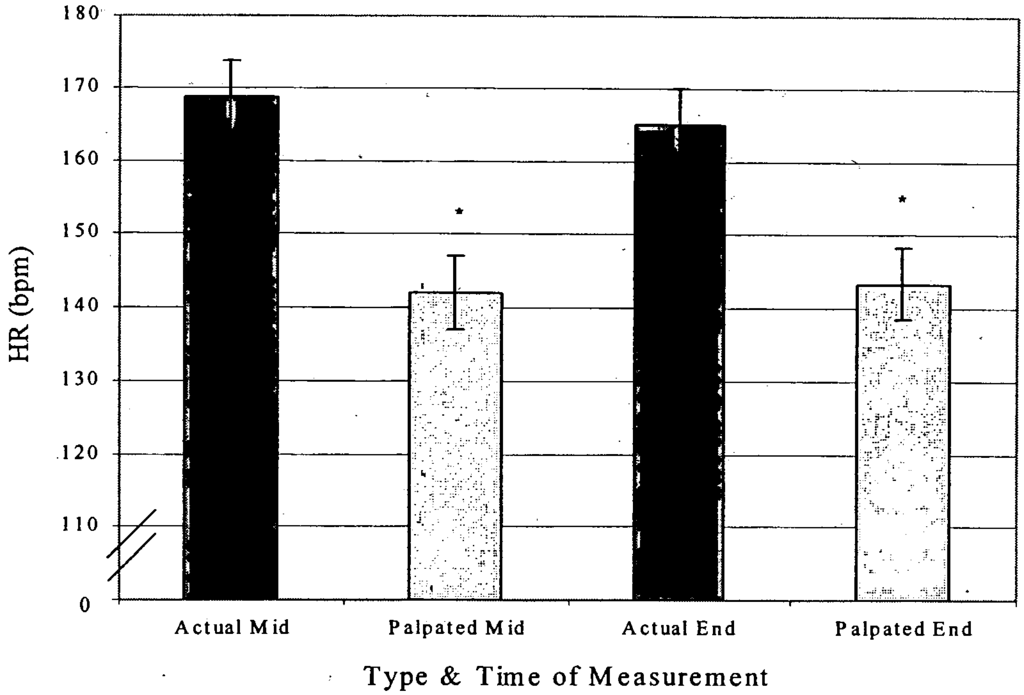

Figure 1. Comparison between monitored actual exercise HR and palpated HR. Values are means and standard deviations for actual and palpated HR for both mid-point and end-point; * indicates that palpated HR was significantly less ($p < .05$) than actual HR at both times.

mid-point and end-point follow a straight path with no major deviation disturbing the linear drop in HR. This HRR linearity illustrated in Figure 2 suggests that exercise HR may be predicted from monitored postexercise HR.

Prediction of Actual HR From HRR Measures

Simple regression analyses were used to determine if actual exercise HR could be predicted from monitored postexercise HRR measures at 10, 30, and 60 s intervals. Because they were similar and to produce only one prediction equation for both time intervals, HR data from mid-point and end-points were simply classified as recovery HR data. In other words, mid-point and end-point exercise HR and HRR measures for a subject were classified under common variables, thereby producing only one actual exercise HR variable and three HRR variables (i.e., 10, 30, & 60 s). Therefore, there were 108 measures for each variable (54 subjects x 2). Regression analyses indicated that HRR measures after 10, (adj. $R^2 = .911, p = .000$), 30, (adj. $R^2 = .705, p = .000$), and 60 s (adj. $R^2 = .653, p = .000$) of exercise are significant predictors of exercise HR. Table 2 shows regression analyses data.

Prediction equations for exercise HR from HRR measures at 10, 30, and 60 s postexercise were formulated from the slope and intercept of the three HRR measures.

The prediction equations are as follows:

(a) $PHR = 0.97(HRR_{10}) + 10.1$

(b) $PHR = 0.78(HRR_{30}) + 48.3$

(c) $PHR = 0.72(HRR_{60}) + 68.1$

Where PHR, HRR_{10}, HRR_{30}, and HRR_{60} represent predicted HR and recovery HR at 10, 30, and 60 s, respectively.

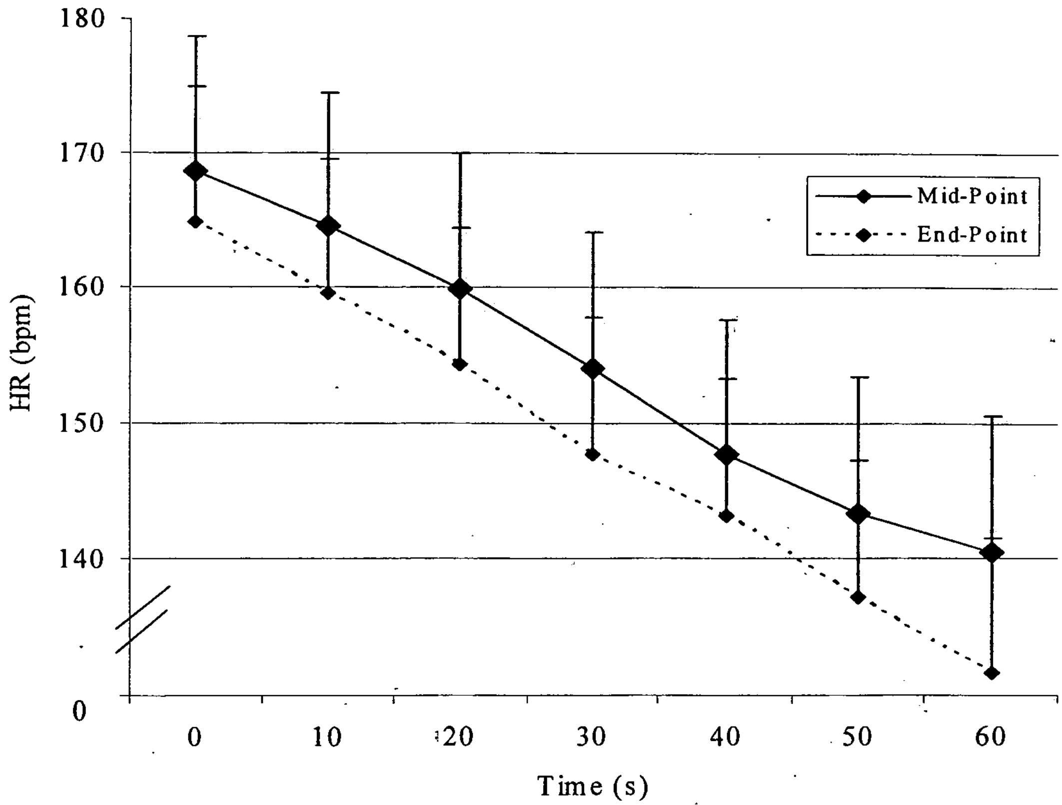

Figure 2. Line graphs plotted on mean HRR measures obtained from HR monitors at 10 s intervals in the first minute postexercise.

Table 2

Regression Analysis for Predicting Exercise HR from HRR

HRR	R	R^2	Adjusted R^2	SEE	Sig.
10 s	0.955	0.912	0.911	4.340	0.000*
30 s	0.842	0.708	0.705	7.918	0.000*
60 s	0.810	0.656	0.653	8.599	0.000*

Note: 10, 30, and 60 s are time intervals postexercise; * $p<0.05$.

A one-way ANOVA with repeated measures showed that mean HR computed from the above equations were not significantly different from mean monitored exercise HR (F (3, 321) = 1.805, p = .146). Appendix H shows raw data for exercise HR, HRR measures at 10, 30, and 60 s, and predicted exercise HR.

Although results of the regression analyses show a high predictability of actual exercise HR from HRR measures at 10, 30, and 60 s, using these equations would be impractical in an exercise setting. Therefore, simpler equations were devised using arithmetic calculations. Each monitored exercise HR measure was divided by the monitored HRR measure at 10, 30, and 60 s. For example, actual exercise HR of 176 bpm for a subject was divided by her monitored HRR measure at 30 s, which was 164 bpm, to produce the quotient 1.07. The means of the quotients for all subjects at the 10 (M = 1.03), 30 (M = 1.1), and 60 s (M = 1.23) intervals were multiplied by the corresponding monitored HRR measure to produce predicted HR for all data. Thus, the following equations were devised and were labelled the ‘Quotient Method of HR Prediction’ (Q-Pred).

a) $PHR = HRR_{10} \times 1.03$

b) $PHR = HRR_{30} \times 1.1$

c) $PHR = HRR_{60} \times 1.23$

Where PHR, HRR_{10}, HRR_{30}, and HRR_{60} are predicted exercise HR and HRR measures at 10, 30, and 60 s respectively. Table 3 contains means and standard deviations of monitored exercise HR and predicted HR using Q-Pred equations with monitored HRR measures at 10, 30, and 60 s intervals.

Table 3

Means and Standard Deviations of Monitored Actual HR and Predicted HR From Monitored HRR Measures at 10, 30, and 60 s Intervals Using the 'Q-Pred' Equation'

Measure	Mean	Std. Dev.
Actual HR	166.7	14.6
Pred10	167.4	14.9
Pred30	165.9	17.2
Pred60	167.3	20.1

Note: All measures are in bpm

A one-way ANOVA with repeated measures showed no significant difference between the means of monitored actual exercise HR and the three predicted HR from the Q-Pred equations (F (3, 321) = 1.09, p = .353). Consequently, the Q-Pred equations accurately predict exercise HR.

Due to large standard deviations in Q-pred exercise HR, and high standard error of the estimate of predicted exercise HR from the regression equations, predicted HR were classified based on accuracy of prediction. Predictions made within 5 bpm of exercise HR were considered to be accurate. Table 4 shows this classification. It can be seen that regression equations are better predictors of HR at the three time intervals when compared to the Q-Pred equations. Although both methods were able to predict exercise HR within 5 beats of actual monitored exercise HR in at least 83% of the subjects at 10 s postexercise, the regression equations appear more accurate than the Q-Pred method at 30 and 60 s postexercise, as these equations only predicted a HR within 5 beats of monitored exercise HR 65% of the time.

Postexercise Palpated HR vs. Postexercise Monitored HR

To determine if subjects could accurately measure HR using the palpation technique, palpated HR was compared to monitored postexercise HR measures recorded at the moment the palpated measure was obtained. This comparison was simply to determine if there was a significant difference in palpated HR and monitored HR unrelated to the measurement delay. The delay in measurement of palpated HR for each subject was matched to the closest time interval (upwards or downwards) at which HR was measured by the HR monitor. The corresponding postexercise monitored HR value was compared to the subject's palpated HR

Table 4

Classification of Predicted HR Obtained From HRR Measures at 10, 30, and 60 s Using Q-Pred Equations and Regression Equations

Method	≤5 beats	>5 & ≤10 beats	>10 beats
$Qpred_{10}$	90	14	4
$Qpred_{30}$	56	30	22
$Qpred_{60}$	45	39	24
$Rpred_{10}$	92	16	0
$Rpred_{30}$	71	21	16
$Rpred_{60}$	68	23	17

Note: Method indicates the equation used to predict HR at 10, 30, and 60 s interval. Values represent number of data points where predicted HR were within or equal to 5 beats, >5 but ≤10 beats, and >10 beats of monitored exercise HR.

measurement. For example, if the delay in palpated HR measurement for a subject was 25 s, the corresponding postexercise HR measure would be the value at the 20 s interval monitored by the HR monitor. Therefore, the maximum error/difference between delay in palpated HR measurement and postexercise monitored HR interval was 5 s. Means and standard deviations of palpated HR and postexercise monitored HR measures after delay can be seen in Figure 3. A 2 x 2 repeated measures ANOVA was conducted to determine whether method (palpated and monitored) or time of measurement (mid-point & end-point) influenced the accuracy exercise HR. The analysis showed that palpated HR was significantly lower than monitored HR (F (1, 53) = 43.56, p = .000). There was no main effect for time at the mid-point and end-point measurements (F (1, 53) = .497, p = .484). There was also no interaction effect between method and time of measurement (F (1, 53) = 3.85, p = .055).

Summary

Analyses of data showed that college-aged, regular participants (N =54) in group exercise classes took about 17 to 20 s to complete HR measurement using the palpation method. Their palpated postexercise measures were significantly lower than actual HR obtained from a HR monitor during exercise. The subjects were also unable to obtain accurate palpated HR unrelated to a delay in palpated HR measurement. Monitored HRR measures in the first minute postexercise decreased linearly, suggesting that HRR measures could be used to predict actual exercise HR from HRR measures. Regression analyses between actual HR and monitored HRR measures at 10, 30, and 60 s intervals showed that actual HR was accurately predicted from monitored HRR measures. A simpler method (Q-Pred) for predicting exercise HR from recovery measures yielded acceptable though less accurate predictions.

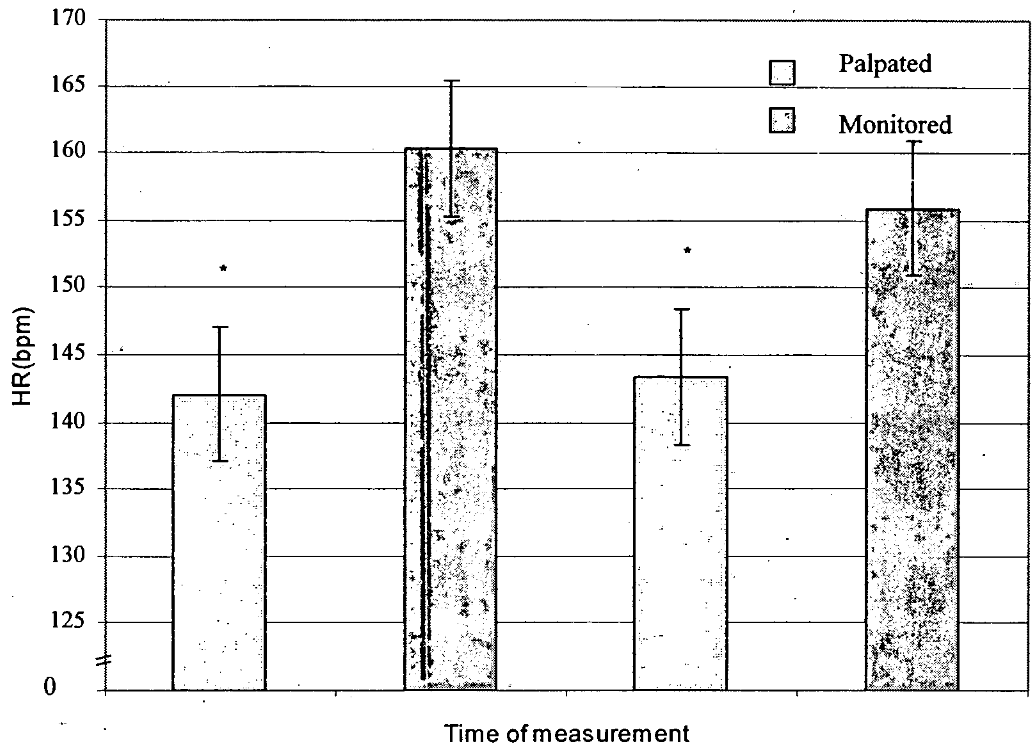

Figure 3. Comparison between palpated HR and monitored HR. Values are means and standard deviations. Significant differences (*$p<0.05$) were found between palpated and monitored HR values for mid-point and end-point times.

CHAPTER 5

Discussion

The purposes of this study were to determine the delay in obtaining palpated HR by members of group exercise classes, to examine the effect of the delay on the accuracy of the palpated measure, and to determine if HR recovered linearly. Subjects obtained postexercise HR via palpation after a delay of approximately 17-20 s, which caused palpated HR measures to be lower than HR monitored during exercise by 21-27 beats. However, HRR measures followed a linear path in the first minute postexercise allowing equations to be formulated for predicting exercise HR from HRR measures. This chapter will include discussions on: a) delay in obtaining palpated HR, b) inaccuracy of palpated HR measure, c) HRR linearity curve and prediction of exercise HR, d) practical issues related to HR measurement, and e) summary.

Delay in Obtaining Palpated HR

Delay in obtaining postexercise HR was approximately 17 to 20 s, which occurred because most subjects did not measure HR immediately after exercise, even though class instructors had emphasized the importance of doing so for both mid and end-points of an exercise session. Visual observations and informal interviews during and after exercise sessions were used to explain subject behavior and HR measuring habits that caused the delay in HR measurement.

Observations revealed that subjects delayed HR measurement because they: a) waited a few seconds for postexercise hyperventilation to decrease, b) drank water, and c) could not locate pulse. Factors a and b could be attributed to subjects' incomplete understanding of the importance of measuring HR immediately after exercise. Low understanding was also reflected by other subject behaviors, such as walking around and chatting with classmates before measuring HR, or remembering to measure HR only after seeing others do so. Inability to locate pulse probably resulted from lack of skill or incorrect technique and movement artifact. Collectively the visual observations and informal interviews revealed that the delay in measurement of palpated HR resulted from the subjects not realizing the importance of measuring HR immediately after exercise and their inability to quickly locate pulse.

Inaccuracy of Palpated HR Measure

The finding that palpated HR is 21 to 27 beats lower than actual exercise HR is consistent with current literature. Devan et al. (2005) demonstrated that palpated HR underestimated actual exercise HR by 20 to 27 beats. This difference between palpated HR in recovery and monitored exercise HR is caused by poor technique, including a delay in palpation and an inability to locate pulse quickly and palpate accurately.

Of the aforementioned two factors affecting accuracy of palpated HR, delay in measurement is the most significant due to rapid HRR after exercise. The rate of HRR depends on various factors such as age, fitness level, and disease. In this study, exercise HR and HRR were recorded by HR monitors at 10 s intervals. In the first minute postexercise, HR recovered rapidly at the rate of 11 beats per 20 s during the first 40 s of recovery. HRR was slower in the last 20 s, as it only decreased by 7 beats. In all, HRR averages 29 beats in the first min postexercise in this study. The rate of recovery in the current subjects in the first min postexercise was not as high as that recorded by Kannenkeril et al. (2004), where an average HRR of approximately 42 bpm was observed. The difference in HRR between the current study and that by Kannenkeril et al.

could be because the subjects in this study were standing and continuously moving, which is a modest form of active recovery. In contrast, subjects in Kannenkeril et al. were seated after exercise, a form of passive recovery. Active recovery elicits a slower rate of sympathetic nervous system withdrawal (Takahashi, Hayano, Okada, Saitoh, & Kamiya, 2005), which would cause a slower HRR. Increased HRR observed by Kannenkeril et al. could not be attributed to fitness levels or age as their subjects were sedentary and older in contrast to the non-sedentary and younger subjects in this study. A slower HRR of 11 bpm was also observed in patients with congestive heart failure by Arena, Guazzi, Myers, & Peberdy (2006), but these findings are not applicable to the current study, where subjects were healthy and devoid of overt heart disease.

Since HR recovers at a rapid rate, the timing of the measurement is of utmost importance in obtaining a palpated measure that accurately reflects actual exercise HR. Increasing the delay in HR measurement leads to a greater difference between actual and palpated HR. Delay can be reduced by increasing awareness of the importance of measuring HR immediately after exercise. This awareness is necessary if postexercise HR measures are to be used to approximate exercise HR and gauge exercise intensity.

The delay in palpating HR postexercise was just one source of error in obtaining exercise HR. Another possible reason for the difference between palpated and monitored exercise HR was poor skill that is typical with the palpation method. Wrong technique is best illustrated by the difference between palpated HR and HRR measures monitored at the time interval closest to when the subjects obtained palpated HR (i.e., removing the effect of delay). It was seen that palpated HR obtained by the subjects were 12 to 18 beats lower than delay-adjusted monitored HRR measures. It must be noted that the aforementioned HRR comparison point had a maximum error of 5 s built in and HRR during the unaccounted error interval was not considered while comparing palpated HR to HRR measures.

Inability to accurately measure HR via palpation may reflect the large individual variability in aquiring skill (Erdmann, Dolgener, & Hensley, 1998; Sedlock, Knowlton, Fitzgreald, Tahamont, & Schneider, 1983) and is seen even though subjects practiced palpating HR in at least three exercise sessions before data collection. From observations, the primary difficulty in measuring palpated HR accurately was locating pulse, which is exacerbated after exercise if active recovery is used. Exercise hinders site location because of movement artifact, which has similar vibrations to a pulse beat and can be mistakenly identified as a pulse beat during palpation. Movement artifact may exist even when an individual stops exercising especially in non-laboratory settings like group exercise classes or outdoor exercise where participants do not completely stop moving. In such conditions, people normally recover actively by walking around, stretching, or by stepping in place to avoid a sudden drop in blood pressure. Similar actions were observed in this study's subjects. Hyperventilation after exercise could be another source of artifact while palpating pulse at the carotid artery.

The difficulty in measuring palpated pulse accurately may exist among a majority of people that use the palpation technique. Given the inaccuracy caused by low user skill, the present findings have practical implications for habitual exercisers that use palpation to monitor exercise HR, and therefore, exercise intensity. The findings of this study, which agree with those by DeVan et al. (2005), Erdmann et al. (1998) and Sedlock et al. (1983), demonstrate that postexercise palpation counts greatly underestimate the true exercise HR, therefore, are not indicative of actual exercise intensity. Thus, to properly monitor exercise intensity, an alternative mode for monitoring exercise HR should be used, such as a portable HR monitor. These units are widely available and provide accurate and immediate feedback, as well as data storage for later analyses (Laukkanen & Virtanen, 1998). If this alternate method is not possible, users of the palpation technique of HR measurement must be highly skilled in locating and counting pulse without any delay after stopping exercise.

HRR Linearity Curve and Prediction of Exercise HR

Previously, no other study has examined linearity of HRR in the first minute postexercise to determine if exercise HR could be predicted from monitored HRR measures. Numerous HRR studies on healthy and diseased population have determined that normal HRR ranges between 12 to 42 beats in the first minute postexercise (Carnethon et al., 2005; DeVan et al., 2005; Kannankeril et al., 2004). Although the aforementioned studies concluded that HR recovers at a very rapid rate after exercise, HRR was not quantified at a smaller level (5 or 10 s intervals) in the first minute postexercise.

The current study showed (see Figure 2) that HRR measures in the first minute postexercise followed a linear path. The linearity of HRR suggested that accurate postexercise HR measures can be used to predict exercise HR. If exercise HR can be correctly predicted from accurate HRR measures, the error in palpated HR (assumed as exercise HR) arising from a delay in measurement would be minimized. The accuracy of the prediction would also depend on the ability of the exerciser to obtain an accurate palpated measure. Since palpated HR is usually measured within the first minute postexercise (DeVan et al., 2005; Erdman et al., 1998; Sedlock et al., 1983), the current study measured HRR at 10 s intervals in the first minute postexercise to allow formulation of exercise HR prediction equations. Regression analyses showed that exercise HR could be predicted from monitored HRR measures at 10, 30, and 60 s in the postexercise phase. The simple Q-Pred equations also allowed satisfactory exercise HR prediction. Although there were no significant differences between actual exercise HR and predicted HR from regression and Q-Pred equations, a count of predictions within 5 beats showed that the regression equations were somewhat more effective in predicting exercise HR than Q-pred equations. The superiority of the regression equations was especially evident at 30 and 60 s after exercise. Reasons for decreased accuracy of the Q-Pred equations at 30 and 60 s postexercise were not identified. It is necessary to examine if accuracy of Q-Pred equation for 30 and 60 s increases after modifications such as addition or subtraction of small decimal values to the quotient are made (e.g. - using 1.25 instead of 1.23).Therefore, to obtain a good estimate of exercise HR, exercisers must accurately palpate pulse immediately after exercise (within 10 s) and then compute exercise HR using regression or (Q-pred) equations.

Practical Issues Related to HR Measurement

HR Monitor Use

This study found that the palpation technique, as typically used postexercise, is not an appropriate indicator of actual exercise HR. An alternative and easy method to accurately measure exercise HR is the use of a HR monitor (Kramer et al., 1993; Treiber et al., 1989; Wajciechowski et al., 1991). Since they are more accurate, HR monitors will enable exercisers to reduce potential over-exertion and maintain safety. Although the use of HR monitors is widespread, those not using these monitors outnumber those who do. This could be due to the cost involved in the use of HR monitors (minimum of $50). If HR monitors prove cost prohibitive, the exerciser must rely on accurately recording a palpated HR postexercise and then using a prediction equation to best estimate actual exercise HR.

Use of Prediction Equations by the Regular Exerciser

Since regression and Q-Pred methods predict exercise HR (within 5 beats of actual HR) from HRR measures at 10 s postexercise 83% of the time, and are reasonably accurate predictors at 30 and 60 s, the formulated prediction equations will improve the accuracy of estimating exercise HR over a simple postexercise HR measure. The prediction equations will be effective only if the user obtains an accurate palpated HR measurement within 10 s of stopping exercise. Exercisers not adept at palpating pulse can increase skill through regular practice of the technique. The ideal method of prediction would be to use the 6 s pulse count immediately after exercise and then use 10 s postexercise regression or Q-pred equations.

Another factor to be kept in mind while using prediction equations is exercise intensity. All exercise classes held at the Ithaca College Fitness Center were of high intensity and ensured that participants exercised at more than 75% of their maximum HR. It can therefore be said that, the prediction equations (Q-pred and regression) were reasonably accurate for high intensity exercise. We did not identify if these equations could accurately predict exercise HR at lower submaximal intensities. It is necessary to study the applicability of the aforementioned equations to lower exercise intensities because HR response fluctuates depending on increasing or decreasing sympathetic tone.

The level of sympathetic influence increases or decreases based on exercise intensity. Cross-validation of prediction equations at other intensities will increase the generalizabilty of prediction equations allowing them to be used by more exercisers.

Effect of Individual Characteristics on HR Predictions

Some key factors that can affect applicability of the Q-pred and regression equations to general population are gender, fitness level, and age of the exerciser. This section discusses a few individual specific factors that can affect predicted HR.

Effect of varying fitness level and disease. Although we did not measure fitness, on the basis of exercise history reported by each subject, it is believed that the participants in this study were endurance trained. Even a short endurance training program increases autonomic response, and thereby increases HRR by approximately 15 bpm (Bassett et al., 1988; Carnethon et al., 2005; Carter et al., 2003; Yamamoto et al., 2001). Therefore, the regression equations derived presently may be specific to endurance trained individuals only. An untrained individual using the determined regression or Q-Pred equations may overestimate exercise HR due to a lower HRR rate. Similar overestimation of exercise HR could occur also in the case of individuals with heart disease due to decreased parasympathetic reactivation after exercise (Arena et al., 2006). Overestimation of exercise HR could cause the exerciser to wrongly decrease exercise intensity and thereby not accrue the benefits of cardiovascular training. Therefore, further studies need to examine the applicability of prediction equations to an untrained population and people with cardiovascular disease. Modification of these equations is likely needed for this population of varying fitness level.

Gender effect. All subjects in the current study were women. Women have an increased rate of parasympathetic activity and reduced rate of sympathetic activity as compared to men after the same exercise program (due to different steroid hormones, metabolism, and autonomic control) (Carter et al., 2003). The applicability of the derived prediction equations to men needs to be examined. If the present equations are used by men, adjustments may be needed to achieve the accuracy obtained in this study.

Age effect. Cardiovascular deterioration due to structural changes of the heart and reduced inotropic and chronotropic response cause differences in HRR patterns with the progression of age (Carter et al., 2003). Since the subjects were all college-aged individuals, the prediction equations may not be accurate when used by individuals from different age groups (especially the older population). If the current equations are used by an older population, the predicted HR may not be an accurate reflection of actual exercise HR. The applicability of the prediction equations to age groups older and younger than college-aged students needs to be examined.

It is therefore necessary to test the accuracy of the derived prediction equations when it is subject to various factors such as gender, age, and fitness level of the user. Accuracy of prediction equations should also be cross-validated on a larger scale (greater subject pools) to be deemed applicable for regular use.

6 vs. 10 s Pulse Counts

To measure HR via palpation, most subjects in this study used a 6 s pulse count, which was then multiplied by ten to obtain HR for one minute. Although both 6 and 10 s pulse counts yielded inaccurate exercise HR, measuring HR immediately after exercise using the 6 s count could reduce delay in obtaining palpated HR to less than 10 s.

Monitored HRR measures at the 5 s interval showed that the aforementioned reduced delay would decrease inaccuracy of the palpated measure and subjects would have obtained HR within 5 to 8 beats of actual exercise HR. Although some subjects used the 10 s pulse count to measure HR, it seems more practical to use the 6 s count and effectively reduce delay by 4 s. Prediction equations for the shortest delay (10 s) after exercise yielded the greatest prediction ability. Rapid postexercise HR measurement seems the most acceptable strategy to obtain accurate exercise HR.

Using a 6 s count also results in an easy arithmetic calculation simply requiring a zero to be added to the pulse count to obtain palpated HR. The subjects who used the 10 s count reported occasional difficulty in multiplying the obtained pulse count by 6. Conversely, the drawback of using the 6 s pulse count was that the obtained palpated HR would always be rounded to the 'tens' place (e.g., 140, 150). Accordingly, if a subject stopped counting pulse a little over or under 6 s, her estimated palpated HR could be off by a factor of ten. Error is not magnified as much with a 10 s count. Since both 6 and 10 s pulse counts have a certain amount of error built in, it is necessary to determine the more accurate method of the two, which will give the regular exerciser a choice of using the more accurate method of HR palpation. Once an accurate palpated (or monitored) HR is obtained the regular exerciser can achieve better exercise HR estimation by using the Q-pred or regression equations established within this study.

Summary

Members of groups exercise classes displayed low proficiency in measuring HR using the palpation technique and low understanding of the importance of measuring HR immediately after stopping exercise. This caused a delay in obtaining HRR measures and yielded inaccurate palpated measures that were significantly different from monitored HR. Although exercise HR is most accurately predicted using 10 s postexercise HRR and accuracy of prediction decreases with increasing duration after exercise, regression prediction equations at 30 and 60 s after exercise also displayed satisfactory results. Applicability of all prediction equations for everyday use with respect to gender, age, and fitness levels of users need to be examined. It seems clear that adjustment of HRR measures is needed if exercise HR is to be well approximated and used as a gauge of exercise intensity. It is reasonable to make this adjustment of HRR measures from population-specific exercise HR prediction equations.

CHAPTER 6

Summary, Conclusions, and Recommendations

Summary

HR measurement is the most commonly used method to monitor exercise intensity. Most exercisers that measure HR use the palpation technique postexercise to keep track of exercise HR. It has been previously found that postexercise HR palpation does not provide an accurate estimate of exercise HR (Erdmann et al., 1998; Sedlock et al., 1983). A recent study by DeVan et al. (2005) quantified the inaccuracy of postexercise palpation to estimate exercise HR at 21 to 27 bpm. This inaccuracy may be reduced significantly if palpated HR was accurately measured during exercise. Palpated HR measurement during exercise, however, is hampered by movement artifact and difficulty in locating pulse. Thus, palpated HR measurement is mostly done after stopping of exercise. On cessation of exercise, HR recovers at a very rapid rate of up to 42 beats in the first minute after exercise (Kannenkeril et al., 2004). It is this rapid recovery of HR, combined with the delay and inaccuracy involved in measuring pulse that invariably results in a poor estimation of exercise HR with postexercise palpation.

The main contributor to the aforementioned inaccuracy of palpated HR is the use of an incorrect technique, which involves delay in measurement (causes rapid HRR), and location of pulse. Palpation technique skill can be acquired through sufficient practice, but the longer the delay before measuring postexercise palpated HR, the greater the error in measurement. Since actual exercise HR measurement is not possible manually, it becomes necessary to accurately measure postexercise HR immediately after exercise to be able to predict exercise HR.

The purposes of this study were to determine the time taken by members of Ithaca College Fitness Center group exercise classes to obtain palpated HR and to determine the linearity of HRR in the first minute postexercise. Quantifying the delay in postexercise HR measurement would help increase the general awareness about the effects of delay on the accuracy of the palpation technique, while determining the HRR curve allowed formulation of exercise HR prediction equations.

Female students (N=54) with a mean age of 19.9 $\pm$ 1.6 years, recruited from group exercise classes held at the Ithaca College Fitness Center, served as subjects. They typically exercised for approximately 56.0 $\pm$ 28.1 $min \cdot day^{-1}$ and 4.3 $\pm$ 1.4 $days \cdot week^{-1}$ over the previous 9.2 $\pm$ 7.3 months. All participants were taught the palpation technique and used it to record HR twice during every class on a HR recording card. The subjects were not told the true nature of the study to avoid any influence on their palpated HR measuring habits. Subjects signed an informed consent form, filled out an exercise history questionnaire, and attended three mandatory practice classes prior to a videotaped data collection trial class. In the practice classes, subjects exercised in the presence of video cameras and wore HR monitors to get accustomed to data collection procedures. All data collection procedures were completed during the video taped class. Actual exercise HR and postexercise HRR were measured at 10 s intervals by a HR monitor during the full class time and for one minute postexercise. Film review was done after data collection and delay for each participant in obtaining palpated HR was recorded with a stop watch. Delay was the time elapsed in seconds between stopping exercise and completion of pulse count indicated by the removal of fingers from the pulse site.

Descriptive statistics for delay in obtaining palpated HR at the mid-point and end-point of the exercise class showed that subjects took 17 to 20 s to obtain palpated HR. 2 x 2 ANOVA were conducted to determine if method (monitored & palpated) or time of measurement (mid-point & end-point) influenced accuracy of obtained palpated HR. Palpated HR was significantly lower when compared to exercise HR and delay-adjusted HRR measures. Simple regression analyses between monitored exercise HR and HRR measures at 10, 30, and 60 s intervals determined linearity of HRR and produced prediction equations. More practical Q-Pred equations were also formulated using simple arithmetic between the aforementioned monitored exercise HR and HRR measures. Predicted HR obtained from regression equations and the Q-Pred equations were not significantly different from each other, although predictions made from regression equations using HRR at 10 s after exercise were most accurate.

Conclusions

Based on the finding of this study, the following conclusions were drawn:

1. Pulse palpation postexercise is not an appropriate method of measuring exercise HR as delay and incorrect technique while making the measure caused the measured HR to be inaccurate by 21 to 27 beats.
2. Postexercise HR recovers linearly in the first minute postexercise allowing prediction of exercise HR with reasonable accuracy using regression and Q-Pred equations.
3. Postexercise HR must be measured immediately after stopping exercise. This will allow the use of the prediction equation (regression or Q-pred) at 10 s of HRR, which predicts exercise HR more reliably than equations at 30 or 60 s.

4. To best ensure measurement of an accurate exercise HR, one must wear a HR monitor that records exercise HR while exercise is being done.

Recommendations

Recommendations for future areas of investigation include the following:

1. Examine the existence of a delay in palpated HR measurement in people that exercise alone, either in an indoor or outdoor setting.
2. Examine awareness of measuring HR after exercise among the general population who receive no HR palpation instructions.
3. Examine on a large scale if individuals use the correct technique to palpate HR. This will help to understand if incorrect technique is a large contributing factor to an inaccurate HR measure. Future studies must cross-validate the use of prediction equations with palpated HR to predict exercise HR.
4. Accuracy of prediction equations needs examination on a larger scale (greater N) to determine their applicability for everyday use by a variety of exercisers (e.g., different gender, ages, and fitness levels).
5. Applicability of prediction equations to low and moderate intensities needs to be tested.
6. Examine if exercisers can be taught to palpate HR accurately within 10 s postexercise. A rapid and accurate HR measure should allow 10 s postexercise Q-pred or regression equations to accurately predict exercise HR.

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Appendix A

Flyer

Research Study Announcement

The effects of heavy breathing and fatigue on biomechanics during high intensity exercise in a group exercise class

Researchers in the Department of Exercise and Sports Sciences at Ithaca College are seeking volunteers from group exercise classes to participate in a research project that is examining the effects of fatigue and increased breathing rates on body movements during an exercise class. Changes in movement can reduce the efficiency at which you exercise. Efficiency is the maximum amount of benefit you can derive from exercising at a particular intensity. This experiment requires one of your class sessions to be video taped for analysis of biomechanical changes. You will have to attend at least 3 exercise classes before being video taped so that you are used to the kind of exercise that is being done in the class, which ensures that the changes in your body movements will not be a result of unfamiliarity class activities. You will also be required to wear heart rate (HR) transmitter belts and a HR monitor, which will record your HR via radio signals/telemetry during the exercise session so efficiency can be studied. Since, you will not be asked to do anything different from your regular exercise class, you should not experience any addition discomfort from participating in this project. Participation is voluntary and you can withdraw from the study at any time without penalty. You must be at least 18 years or over to participate. Total participation time is equal to the typical length of the class over four classes.

For more information please contact:
Dinesh John
Dept. Exercise and Sports Sciences
Ithaca College

Email: djohn1@ithaca.edu.
Phone: 607-262-0516.

Appendix B

Subject Recruitment Statement

I want to see if you would like to participate in a research project that is examining the effects of fatigue and increased breathing rates on body movements during an exercise class. Changes in movement can reduce the efficiency at which you exercise. Efficiency is the maximum amount of benefit you can derive from exercising at a particular intensity. This experiment requires one class to be video taped for analysis of biomechanical changes. You will have to attend at least 3 exercise classes before being video taped so that you are used to the kind of exercise that is being done in the class, which ensures that the changes in your body movements will not be a result of unfamiliar class activities. You will also be required to wear a heart rate (HR) transmitter belt on your chest and a HR monitor on your wrist, which will record your HR via radio signals/telemetry during the exercise session so efficiency can be studied. Since, you will not be asked to do anything different from your regular exercise class, you should not experience any additional discomfort from participating in this project. Participation is voluntary and you can withdraw from the study at any time without penalty. You must be at least 18 years or over to participate. Total participation time is equal to the typical length of the class over four classes. Do you have any questions? Would you like to read the informed consent, which describes what will occur in greater detail?

Appendix C

Informed Consent Form For
Participation in Human Subjects Research
Ithaca College

The effects of heavy breathing and fatigue on biomechanics during high intensity exercise in a group exercise class

1. Purpose of Study
The purpose of this study is to examine if fatigue and increased ventilation (breathing) during high intensity exercise causes biomechanical changes in participants of a group exercise class.

2. Benefits of the Study
You may benefit from this study because you will get an understanding of how biomechanical changes towards the end-stages of high intensity exercise may reduce your ability to continue exercising with the same efficiency and vigor. The results may help you increase exercise efficiency by using correct biomechanical movements and by controlling your breathing.

3. What You Will be Asked to Do
If you agree to participate in the study, you will have to attend at least 4 exercise classes including one that will be filmed and analyzed at a later stage. The length of each of these 4 classes will be 60 minutes long; similar to any other class you attend at the Ithaca College Fitness Center. You will not be asked to exercise harder or longer than you regular exercise class and total participation time pertaining to this study will be 240 minutes. It is necessary that you participate in at least 3 classes before attending the class that will be filmed because you should get used to the kind of exercise that is being done in the class It ensures that the changes in your body movements will not be a result of unfamiliarity to the kind of exercise performed in the class. You will also be required to wear a heart rate (HR) transmitter belt on your chest and a HR monitor on your wrist, which will record your HR via radio signals/telemetry. Changes in HR may reflect altered efficiency.

Risks
Your risks of participation are minimal and are no more than the risks faced during a regular exercise class. These include fatigue, soreness, and injury. The only added risk due to the study may be that of irritation to the skin caused by wearing a HR transmitter belt around your chest. Although no special medical arrangements have been made, in the event of injury, standard first aid available at the fitness center will be provided by fitness center employees as all are CPR certified. All fitness center emergency

*Initial*_______

procedures will be followed if need arises. If outside care is warranted then 911 will be called. There is no compensation available for injury; you are responsible for all medical costs.

4. If You Would Like More Information About the Study

Please contact principal investigator, Dinesh John, or faculty advisor, Dr. G. A. Sforzo to get more information about this study, or to get a copy of the results.
Email/phone- Dinesh John- djohn1@ithaca.edu./607-262-0516
Dr. G. A. Sforzo- sfrozo@ithaca.edu./607-274-3359.

5. Withdrawal From the Study

You may stop participating, or withdraw from this study at any time without any penalty.

6. Confidentiality of the Data

All collected data will be confidential. The data files will be kept in the graduate office in the Center for Health Sciences at Ithaca College in a secure lockable cabinet. Computer files will be accessed only by the principal investigator with a password. Your name will not be used in connection with this study. However it is asked with your consent that these video tapes/data remain available for use during professional meetings.

I have read the above and I understand its contents. I agree to participate in this study. I acknowledge that I am 18 years of age or older. I have received a copy of this consent form for my own records.

Name (PRINT): ____________________________

Signed (SIGN): ____________________________ Date: __________

I give my permission to be videotaped for presentations and publications.

Signed (SIGN): ____________________________ Date: __________

Appendix D

Exercise History Questionnaire

General Instructions: Please complete this form in as much detail as possible.
Name (please print) ___________________
Age____Phone#____________Email_______________

Status (circle one) FR SO JR SR GRAD FAC / STAFF

Please rate your exercise level on a scale of 1 to 5 (5 indicating very strenuous)_______

Do you start exercise programs but then find yourself unable to adhere to them?
❑ Yes ❑ No

Do you currently exercise?
❑ Yes ❑ No. If yes, indicate the major activities____
Enter duration of exercise/day_________ No. of days/week you exercise___________

I have been doing the above mentioned/similar exercise for______weeks/months/years now (circle).

Rate your perceived exertion during your current exercise program (check the corresponding box):

❑ Light ❑ Fairly Light ❑ Somewhat Hard ❑ Hard

How long have you exercised on a consistent basis? ________ months _________ years

Please indicate the types of equipment you enjoy using at the IC finess center:
❑ Exercise Bike ❑ Elliptical Trainer ❑ II Rower ❑ Treadmill
❑ Step Machine ❑ Cybex (variable resistance machines) ❑ Free Weights

Use the following scale to rank your fitness goals:

Extremely important				Somewhat important				Not at all important	
1	2	3	4	5	6	7	8	9	10

______ Improve cardiovascular fitness ______ Body-fat weight loss

______ Reshape or tone my body ______ Improve sport performance

______ Improve mood and stress tolerance ______ Improve flexibility

______ Increase strength ______ Increase energy level

Appendix E

HR Card

Name-
Class Time-
Class Type-
ID no-

Date	Mid-Point HR	End-Point HR

Appendix F

Raw Data for Subject Exercise Habits

Subject No.	Age-years	Minutes	Days/Week	Months
1	19	30	5	1
2	18	40	4	3
3	19	60	5	36
4	21	60	5	12
5	22	120	5	12
6	19	25	4	2
7	19	30	6	6
8	19	30	3	7
9	20	0	0	0
10	21	60	4	15
11	18	50	4	8
12	19	60	5	4
13	19	60	5	3
14	20	60	2	12
15	22	30	4	8
16	24	60	5	3
17	20	50	5	3
18	22	90	6	24
19	18	90	7	3
20	22	60	5	5
21	22	90	4	12
22	21	30	5	8
23	23	40	4	24
24	19	120	7	10
25	18	60	4	12
26	18	60	3	12
27	18	30	5	5
28	21	40	2	6
29	18	30	4	12
30	18	120	4	8
31	22	60	5	15
32	18	60	5	6
33	19	60	5	6
34	19	90	5	8
35	21	90	4	24
36	20	0	0	0

Appendix F

Raw Data for Subject Exercise Habits (continued)

Subject No.	Age-years	Minutes	Days/Week	Months
37	20	120	3	5
38	18	60	4	1
39	19	30	7	10
40	22	30	6	24
41	20	40	4	12
42	19	90	4	12
43	19	30	4	1
44	19	60	5	8
45	22	60	6	24
46	21	40	4	12
47	20	60	7	6
48	18	50	3	3
49	22	90	4	5
50	21	30	3	4
51	22	60	4	12
52	22	60	4	12
53	20	30	4	4
54	18	40	3	8

Appendix G

Raw Data for Actual and Palpated HR

Subject No.	Actual mid HR	Actual End HR	Palpated Mid	Palpated End
1	176	164	150	120
2	171	160	150	130
3	167	190	150	180
4	181	168	160	160
5	162	157	130	140
6	159	154	160	120
7	172	181	170	140
8	166	155	130	140
9	181	165	150	150
10	188	175	140	130
11	190	182	200	190
12	171	181	170	170
13	176	186	156	144
14	165	159	114	144
15	166	164	156	138
16	187	177	168	138
17	148	136	180	180
18	170	161	138	126
19	167	164	138	138
20	175	172	144	120
21	159	154	150	132
22	176	182	174	168
23	161	160	138	132
24	175	174	150	156
25	183	178	156	156
26	178	167	130	140
27	164	171	110	150
28	161	143	130	130
29	149	143	140	120
30	127	206	90	160
31	157	154	110	140
32	183	153	150	110
33	174	179	140	140
34	172	164	120	130
35	164	139	150	130
36	193	179	150	150

Appendix G

Raw Data for Actual and Palpated HR (continued)

Subject No.	Actual mid HR	Actual End HR	Palpated Mid	Palpated End
37	158	145	100	140
38	163	152	140	140
39	152	140	100	120
40	196	187	180	190
41	164	163	130	140
42	168	190	150	180
43	181	155	150	150
44	163	158	130	140
45	164	168	110	150
46	150	143	140	120
47	169	179	140	140
48	185	179	150	150
49	152	140	100	120
50	176	186	150	140
51	150	138	180	180
52	174	172	150	120
53	159	147	100	140
54	166	162	130	140

All values are in bpm

Actual HR (Mid and End) - Obtained from HR monitor during exercise.
Palpated HR – HR recorded by subject on HR card using palpation method.

Appendix H

Raw Data for Actual Exercise and Predicted HR Recorded by HR Monitors at 10 s

Set No.	HRACT	HR10	HR20	HR30	HR60	Pred10	Pred30	Pred60
1	176	171	170	164	146	176	176.22	173.22
2	171	171	170	168	141	176	179.34	169.62
3	167	163	163	157	140	168.3	170.76	168.9
4	181	180	174	170	155	184.8	180.9	179.7
5	162	163	155	147	132	168.3	162.96	163.14
6	159	154	146	140	138	159.5	157.5	167.46
7	172	172	167	156	151	177	169.98	176.82
8	166	160	155	158	137	165.4	171.54	166.74
9	181	181	184	180	156	185.7	188.7	180.42
10	188	179	176	168	151	183.8	179.34	176.82
11	190	190	185	180	169	194.5	188.7	189.78
12	171	170	164	158	153	175.1	171.54	178.26
13	176	161	156	156	148	166.3	169.98	174.66
14	165	158	154	142	138	163.4	159.06	167.46
15	166	157	155	150	142	162.4	165.3	170.34
16	187	184	180	175	162	188.6	184.8	184.74
17	148	143	138	128	97	148.9	148.14	137.94
18	170	165	157	145	134	170.2	161.4	164.58
19	167	161	155	153	141	166.3	167.64	169.62
20	175	171	165	157	145	176	170.76	172.5
21	159	156	147	145	131	161.5	161.4	162.42
22	176	168	160	151	148	173.1	166.08	174.66
23	161	155	147	142	135	160.5	159.06	165.3
24	175	170	163	156	146	175.1	169.98	173.22
25	183	181	178	173	146	185.7	183.24	173.22
26	178	176	167	162	151	180.9	174.66	176.82
27	164	165	152	149	142	170.2	164.52	170.34
28	161	160	162	155	135	165.4	169.2	165.3
29	149	145	138	135	128	150.8	153.6	160.26
30	127	123	118	114	101	129.5	137.22	140.82
31	157	155	151	144	131	160.5	160.62	162.42
32	183	178	170	158	155	182.8	171.54	179.7
33	174	173	170	165	146	178	177	173.22
34	172	160	161	161	143	165.4	173.88	171.06
35	164	161	160	156	158	166.3	169.98	181.86
36	193	189	187	179	163	193.5	187.92	185.46

Appendix H

Raw Data for Actual Exercise and Predicted HR Recorded by HR Monitors at 10 s (continued)

Set No.	HRACT	HR10	HR20	HR30	HR60	Pred10	Pred30	Pred60
37	158	151	145	139	125	156.6	156.72	158.1
38	163	157	155	148	139	162.4	163.74	168.18
39	152	151	144	127	111	156.6	147.36	148.02
40	196	195	190	183	167	199.3	191.04	188.34
41	164	163	162	163	135	168.3	175.44	165.3
42	168	165	163	157	140	170.2	170.76	168.9
43	181	176	175	175	156	180.9	184.8	180.42
44	163	160	152	151	137	165.4	166.08	166.74
45	164	166	152	147	142	171.2	162.96	170.34
46	150	146	136	134	128	151.8	152.82	160.26
47	169	167	170	163	146	172.1	175.44	173.22
48	185	181	174	171	160	185.7	181.68	183.3
49	152	148	144	129	116	153.7	148.92	151.62
50	176	161	156	156	148	166.3	169.98	174.66
51	150	145	139	129	99	150.8	148.92	139.38
52	174	170	168	155	144	175.1	169.2	171.78
53	159	150	148	135	125	155.7	153.6	158.1
54	166	163	160	160	134	168.3	173.1	164.58
55	164	163	154	148	134	168.3	163.74	164.58
56	160	158	151	145	131	163.4	161.4	162.42
57	190	180	161	143	125	184.8	159.84	158.1
58	168	161	158	154	136	166.3	168.42	166.02
59	157	150	149	145	107	155.7	161.4	145.14
60	154	148	146	139	127	153.7	156.72	159.54
61	181	174	162	146	130	178.9	162.18	161.7
62	155	151	146	138	126	156.6	155.94	158.82
63	165	159	153	155	118	164.4	169.2	153.06
64	175	168	163	159	144	173.1	172.32	171.78
65	182	169	167	157	123	174.1	170.76	156.66
66	181	177	170	166	148	181.8	177.78	174.66
67	186	171	164	159	138	176	172.32	167.46
68	159	154	155	148	130	159.5	163.74	161.7
69	164	160	158	151	142	165.4	166.08	170.34
70	177	172	169	161	154	177	173.88	178.98
71	136	132	124	122	100	138.2	143.46	140.1

Appendix H

Raw Data for Actual Exercise and Predicted HR Recorded by HR Monitors at 10 s (continued)

Set No.	HRACT	HR10	HR20	HR30	HR60	Pred10	Pred30	Pred60
72	161	157	157	156	132	162.4	169.98	163.14
73	164	158	154	154	140	163.4	168.42	168.9
74	172	168	167	165	146	173.1	177	173.22
75	154	154	146	139	130	159.5	156.72	161.7
76	182	180	176	170	155	184.8	180.9	179.7
77	160	155	150	146	136	160.5	162.18	166.02
78	174	170	169	161	140	175.1	173.88	168.9
79	178	176	176	168	150	180.9	179.34	176.1
80	167	165	159	159	144	170.2	172.32	171.78
81	171	167	157	144	131	172.1	160.62	162.42
82	143	138	127	110	111	144	134.1	148.02
83	143	140	135	128	118	146	148.14	153.06
84	206	198	191	187	183	202.2	194.16	199.86
85	154	153	155	149	126	158.6	164.52	158.82
86	153	157	157	155	117	162.4	169.2	152.34
87	179	182	182	177	163	186.7	186.36	185.46
88	164	163	157	144	136	168.3	160.62	166.02
89	139	131	121	121	117	137.2	142.68	152.34
90	179	158	156	148	140	163.4	163.74	168.9
91	145	140	131	124	113	146	145.02	149.46
92	152	145	146	138	132	150.8	155.94	163.14
93	140	140	140	138	118	146	155.94	153.06
94	187	183	172	160	145	187.7	173.1	172.5
95	163	150	147	137	119	155.7	155.16	153.78
96	190	181	163	143	125	185.7	159.84	158.1
97	155	159	153	152	118	164.4	166.86	153.06
98	158	151	145	138	127	156.6	155.94	159.54
99	168	167	155	144	131	172.1	160.62	162.42
100	143	139	135	126	117	145	146.58	152.34
101	179	182	177	177	161	186.7	186.36	184.02
102	179	163	156	148	140	168.3	163.74	168.9
103	140	140	140	132	118	146	151.26	153.06
104	186	171	164	159	138	176	172.32	167.46
105	138	132	126	122	100	138.2	143.46	140.1
106	172	166	165	162	145	171.2	174.66	172.5
107	147	139	131	125	113	145	145.8	149.46
108	162	151	148	135	118	156.6	153.6	153.06

HR-ACT- Monitored actual HR recorded before end of exercise. HR10, HR30, HR60- Monitored HRR measures at 10, 30, and 60 s, respectively in the first minute postexercise. Pred10, Pred30, and Pred60- HR predicted from HR10, HR30, and HR60, respectively.

Ithaca College
School of Health Science and Human Performance
Ithaca, New York

CERTIFICATE OF APPROVAL

MASTER OF SCIENCE THESIS

This is to certify that the Thesis of

Dinesh John

submitted in partial fulfillment of the requirements for the
Degree of Master of Science in the School of
Health Sciences and Human Performance
At Ithaca College has been approved.

Thesis Advisor:

Committee Member:

Candidate:

Chair,
Graduate Program:

Dean of Graduate Studies:

Date: