Masters Thesis:

The Effect of Warm-ups and Elevated Oxygen Consumption on Running Performance in Trained Collegiate Distance Runners

by

David Witiluk

Advisor: Dr. Derek Kivi

Committee member: Dr. Ian Newhouse

Committee member: Mr. Glen Paterson

Lakehead University

Abstract

The mobilization hypothesis (Andzel & Gutin, 1976) states that starting a performance with an elevated baseline oxygen consumption will improve performance by reducing the oxygen deficit at the beginning of the task, allowing for greater anaerobic capacity at the end. The purpose of this study was to examine how recovering to different percentages of heart rate reserve (HRR) and oxygen consumption reserve (VO_2R) after a warm-up influences running performance in distance runners. Two research questions were developed: how does recovering to 50% HRR vs. 35% HRR after a warm-up influence run to exhaustion performance, and do % VO_2R and % HRR decrease similarly when recovering to 35% and 50% HRR. Sixteen trained middle- and long-distance runners were recruited from the Lakehead University varsity track-and-field team and the Lakehead Athletics Club. Testing was completed over three sessions. First session involved treadmill accommodation and VO_2max testing. The second and third sessions involved performing a warm-up followed by recovering to either 35% or 50% HRR before completing the performance of running at 105% vVO_2max with 1% grade until exhaustion. Paired samples t-test found no significant differences in run to exhaustion time [$t_{(15)} = -1.016$, $p = .326$] after recovering to either 50% HRR or 35% HRR. One-sample Chi-square goodness-of-fit test found values of %VO_2R were significantly lower than the expected values for both 35% and 50% HRR recovery trials ($p = .000$, for both trials). In conclusion, participants may have been too close to baseline measures to facilitate the mobilization hypothesis. Alternatively, both trials may have been elevated sufficiently but there was no significant difference between the trials. % HRR and % VO_2R were not equal during recovery, but this was likely impacted by the intensity of the stride (15-seconds at 105% vVO_2max). Further research into the methods used to warm up prior to long-duration performance is recommended.

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Warm-up

The primary role of the warm-up is to prime the body's cardiovascular, muscular and neural systems to meet the demands of a specific activity (Curry, Chengkalath, Crouch, Romance, & Manns, 2009). Performing a warm-up prior to exercise is widely accepted for both athletic performance and injury prevention, as coaches and athletes are interested in how to maximize or improve performance while reducing the risk of injury. Warm-ups are performed by athletes from a wide variety of athletic backgrounds as well as recreationally active individuals. Although the specific nature of the warm-ups may vary between athletic events, the primary goal of the warm-up remains the same for all athletes, which is to prepare the body for the demands of the upcoming performance. The importance of performing a warm-up prior to intense activity is widely accepted, the understanding of type (Škof & Strojnik, 2007; Ce, Margonato, Casaco, & Veicsteinas, 2008), duration (Genovely & Stamford, 1982;) and intensity (Wenos & Konin, 2004) of the warm-up is often debated when preparing a warm-up for an athlete. The majority of current research regarding warm-ups is on the effectiveness of static stretching and dynamic stretching (i.e., Sim, Dawson, Guelfi, Wallman, & Young, 2009; Herman & Smith, 2008; Gelen, 2010; Wilson et al., 2010; Chaouachi et al., 2010; Needham, Morse, & Degens, 2009; Kistler, Walsh, Horn, & Cox, 2010). Results from these studies generally indicate that dynamic stretching helps improve sprint time, jump height, and agility while pre-performance static stretching is often detrimental to performance or has no improvement on performance. A few studies showed no statistically significant differences in performance but the results generally indicated that dynamic warm-ups provided a performance gain (Holt & Lambourne, 2008; McMorris, Swain, Lauder, Smith & Kelly, 2006). Statistical significance may be overlooked by the practical significance of the results, as the smallest improvement in performance can frequently lead to better results, especially in events such as sprinting, jumping, and throwing, where one centimetre can result in a win or even a new world record.

While warm-ups are widely accepted and performed, coaches and athletes may not fully understand all the specifics of how the warm-up prepares the athlete for training or competition. Various physiological aspects related to the warm-up have been identified (Bishop, 2003a), which provide a greater understanding of how warm-ups affect the human body. The effects of the warm-up may be divided into two categories: temperature related and non-temperature related (refer to Table 1).

Table 1

Effects of Warm-up

Temperature Related • Decreased viscous resistance of muscles and joints • Greater release of oxygen from hemoglobin and myoglobin • Speeding of metabolic reactions • Increased nerve conduction rate • Increased thermoregulatory strain
Non-temperature Related • Increased blood flow to muscles • Elevation of baseline oxygen consumption • Postactivation potentiation • Psychological effects and increased preparedness

Bishop (2003a, p. 440).

Temperature related effects of warm-ups. The term “warm-up” implies that temperature has an effect on physiological mechanisms. Performing a warm-up prepares the body for exercise by raising the body’s temperature, elevating heart rate and increasing rate of perspiration, but with further research it has been seen that the benefits of performing a warm-up far exceeds simply raising heart rate and rate of perspiration. While still not fully understood, various physiological adaptations occur to help the body perform at an optimal level. Table 1 presents five main temperature related changes that occur.

Decreased viscous resistance of muscles and joints. Performing a warm-up results in an increase in muscle temperature which, to a limited extent, decreases resistance of muscles and joints (Bishop, 2003a), which helps reduce muscle stiffness. Figure 1 outlines the changes in body temperature at various sites when performing exercise. Rectal temperature is a measure frequently used to examine core temperature and remains highly regulated as seen by having the smallest and most gradual increase. Muscle temperature increases the most, deeper muscle being slightly warmer than superficial muscle since heat is dissipated more readily from superficial muscle. The plateau for muscle temperature illustrates that the participant has warmed-up and reached steady-state, meaning the body has adapted to the exercise intensity. Skin temperature decreases and plateaus in a similar manner as the muscle temperature increases, illustrating the thermoregulatory response. To manage the overall temperature of the body the rate of perspiration increases to help cool the body and prevent overheating.

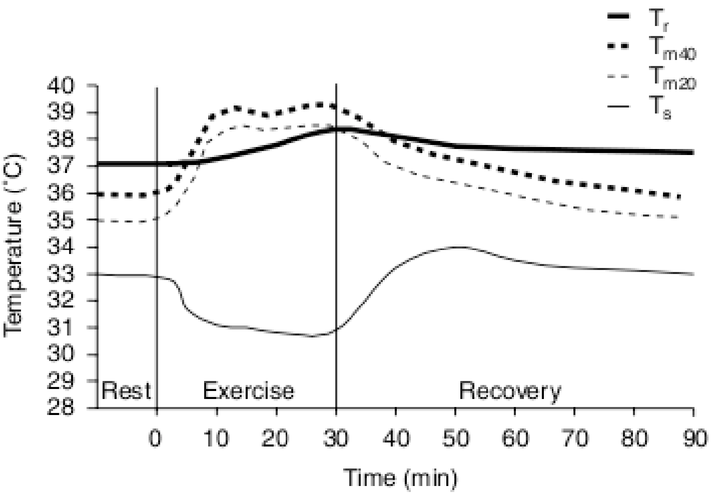


Figure 1. Effect of exercise on body temperature. Temperature measured at rest, during moderate exercise and during recovery for the rectal (Tr), skin (Ts), and muscle at probe depth of approximately 20mm (Tm20) and 40mm (Tm40), in commonly-observed ambient conditions (10-30°C) (Bishop, 2003a, p. 441).

Oxyhemoglobin and myoglobin dissociation. Oxyhemoglobin refers to O_2 that is bound to hemoglobin and is responsible for 99% of the O_2 transported in the blood (Powers & Howley, 2009). At rest the oxygen requirements are relatively low, but demand can increase significantly when performing intense exercise with tissues extracting up to 90% of the O_2 carried by hemoglobin (Powers & Howley, 2009). The oxyhemoglobin dissociation curve is influenced by three factors that effect the loading and unloading of O_2: temperature (Barcroft & King, 1909), acidity (Böning, Hollnagel, Boecker & Göke, 1991) and 2,3-diphosphoglyceric acid (2-3 DPG) (Duhm, 1976). Both temperature and acidity can be impacted by a warm-up, while 2-3 DPG is not. When temperature and acidity are altered a shift in the oxyhemoglobin dissociation curve is seen, changing hemoglobin’s affinity to O_2. A rightward shift in the oxyhemoglobin dissociation curve, referred to as the Bohr effect, promotes unloading of O_2 to tissues. An increase in blood temperature weakens the bond between O_2 and hemoglobin, assisting in the unloading of O_2 to muscle (Koga, Shiojiri, Kondo & Barstow, 1997). During exercise or warm-up, there is increased heat production in the working muscles which promotes a rightward shift, facilitating unloading of O_2 to the tissue (Figure 2). As the curve shifts to the right it can be seen that the percent of oxyhemoglobin saturation is lower at a given partial pressure of O_2 indicating that there is greater unloading of oxygen to the tissue.

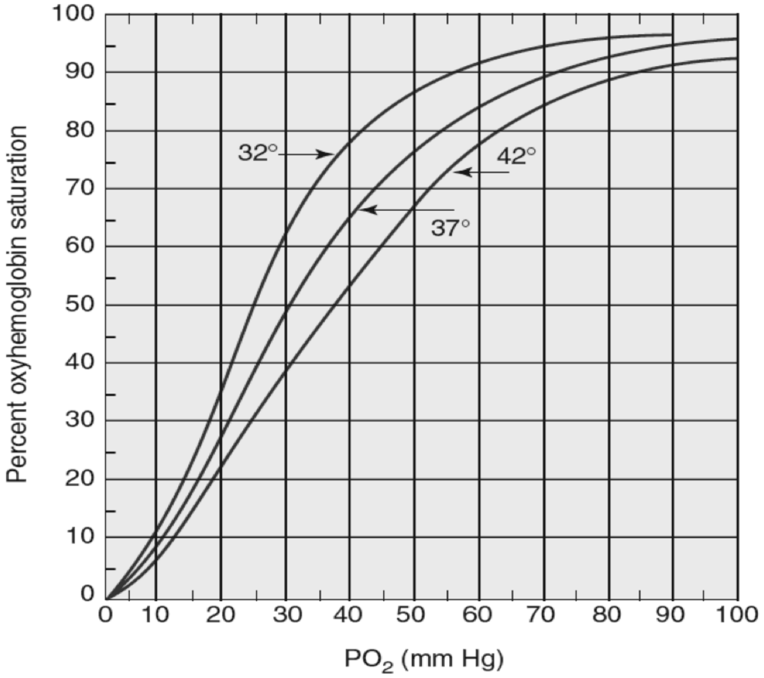


Figure 2. Effect of temperature on oxyhemoglobin dissociation curve. The effect of changing blood temperature on the shape of the oxygen-hemoglobin dissociation curve (Powers & Howley, 2009, p.214).

Performing a warm-up also causes an increase in anaerobic metabolism, accelerating the breakdown of muscle glycogen, which also causes a decrease in blood pH, in turn causing a rightward shift in the oxyhemoglobin dissociation curve. The decrease in pH is partially caused by CO_2 and lactic acid in the capillaries of the working muscles (Böning et al., 1991). The normal pH of blood is regulated around 7.35-7.40, and when there is a decrease in pH the acidity of the blood is increased, in turn weakening the strength of the bond between O_2 and hemoglobin. The result of this decrease in pH is an increased unloading of O_2 to the tissue, providing the tissue with more O_2 to facilitate aerobic energy production. Similar to the curve involving changes in temperature, Figure 3 illustrates the change in pH has on the oxyhemoglobin dissociation curve.

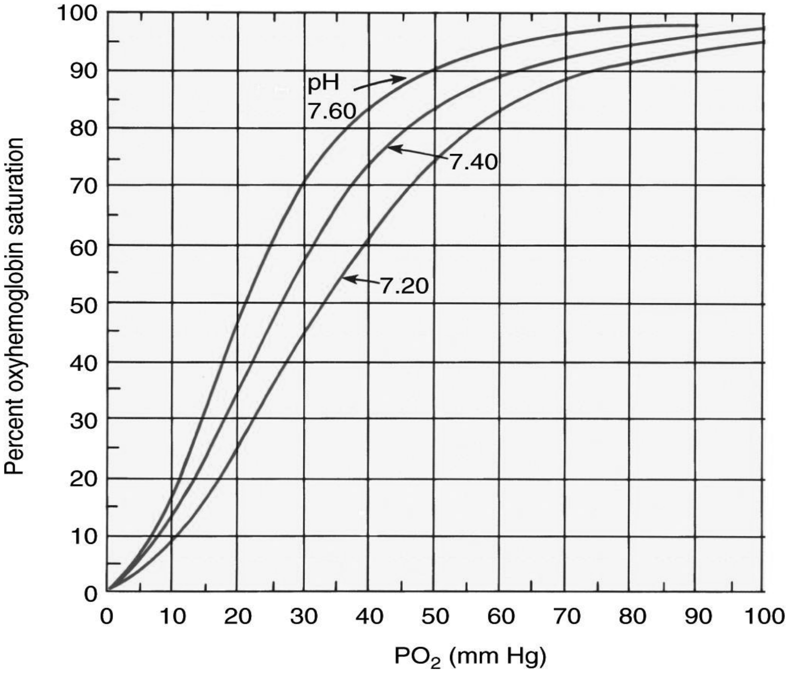


Figure 3. Effect of pH on oxyhemoglobin dissociation curve. The effect of changing blood pH on the shape of the oxyhemoglobin dissociation curve (Powers and Howley, 2009, p. 214).

The warm-up not only has the effect of increasing the dissociation of oxygen of hemoglobin, it also has an influence on myoglobin, an oxygen carrying protein found in muscle. This protein acts as a transporter and moves O_2 to the mitochondria from the muscle cell membrane. Myoglobin is found in greater quantities in slow-twitch muscle fibres (red fibres), with limited amounts in fast-twitch muscle fibres (white fibres). An important trait of myoglobin is the ability to store oxygen within the muscle, which may help provide oxygen to muscles during transition periods from rest to exercise. The myoglobin dissociation curve is different from the oxyhemoglobin curve, as it does not share the S-shape seen with hemoglobin, Figure 4. A notable difference that can be observed in Figure 4 is when comparing the saturation of oxygen at PO_2 of 40 mmHg, where myoglobin retains 95% of oxygen while hemoglobin retains approximately 75%. The myoglobin dissociation curve also is not affected by the same factors that alter the hemoglobin curve, such as temperature and pH, so myoglobin does not exhibit a

Bohr effect.

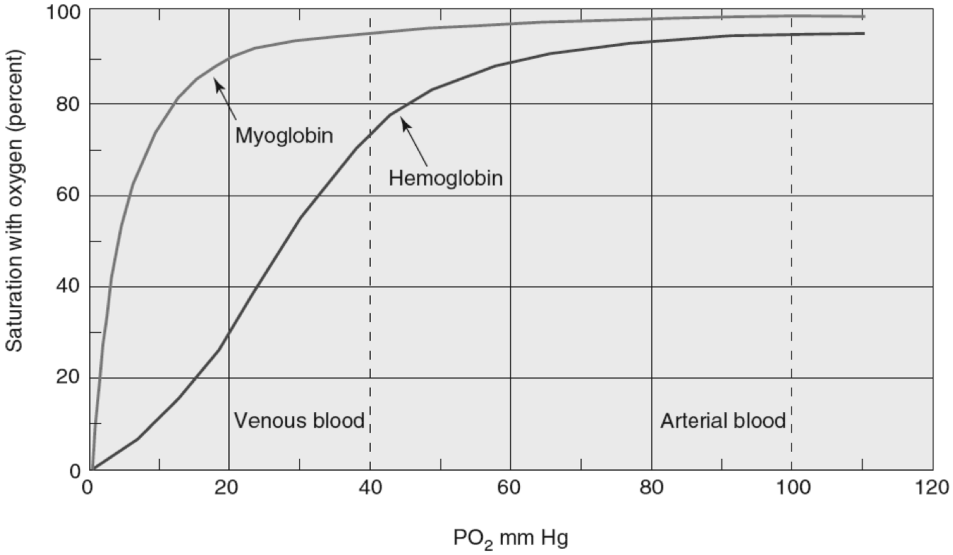


Figure 4. Myoglobin dissociation curve. Comparison of the dissociation curve for myoglobin and hemoglobin. The steep myoglobin dissociation demonstrates a higher affinity for O_2 than hemoglobin (Powers & Howley, 2009, p. 215).

Also assisting with O_2 delivery is the increase in blood flow to tissue. Barcroft and Edholm (1943) found an increased blood flow and vasodilation is produced in the forearm by water temperature higher than 35°C. The increase in body temperature and blood flow, along with the rightward shift in the dissociation curves allows for an increase in O_2 delivery to muscles. Although O_2 delivery is improved through the warm-up, Grodjinovsky and Magel (1970) found that warm-ups did not improve VO_2max. The warm-up helps prepare the body to use oxygen more readily but the capacity to utilize oxygen is primarily related to the ability of the heart and circulatory system to transport blood (and oxygen) and to the ability of body tissues to extract (utilize) oxygen from the blood.

Speeding of metabolic reactions. Performing a warm-up influences metabolic reactions as the temperature of the body changes. The speeding of metabolic reactions can be divided into an increased rate of rate-limiting oxidative reactions, and an increase in anaerobic metabolism. In relation to speeding of rate-limiting oxidative reactions, Koga et al., (1997) proposed that elevated muscle temperature may enhance aerobic energy production by accelerating the rate-limiting reactions associated with oxidative phosphorylation. Bishop (2003a) stated that if increasing muscle temperature speeds rate-limiting oxidative reactions, this should be accompanied by a speeding of VO_2 kinetics, which is the rate oxygen is transferred. This speeding of VO_2 kinetics may enable the athlete to reach steady-state sooner and rely less on anaerobic energy production, leaving more of the anaerobic capacity for the latter part of competition. Further research is required in order to understand how warm-up affects the speed of rate-limiting oxidative reactions.

Increased anaerobic metabolism is likely to benefit short-duration and intermediate-duration performance. Gray, Devito and Nimmo (2002) found there was less accumulation of blood and muscle lactate during intense dynamic exercise when preceded by an active warm-up. Since there was less lactate accumulation, the authors suggested there may be a decreased reliance on energy derived from anaerobic sources during exercise after an active warm-up. In addition to the speeding of rate-limiting oxidative reactions and increased anaerobic metabolism an increase in body temperature also affects enzyme activity, with an optimal range varying between 37°C and 40°C (Figure 5).

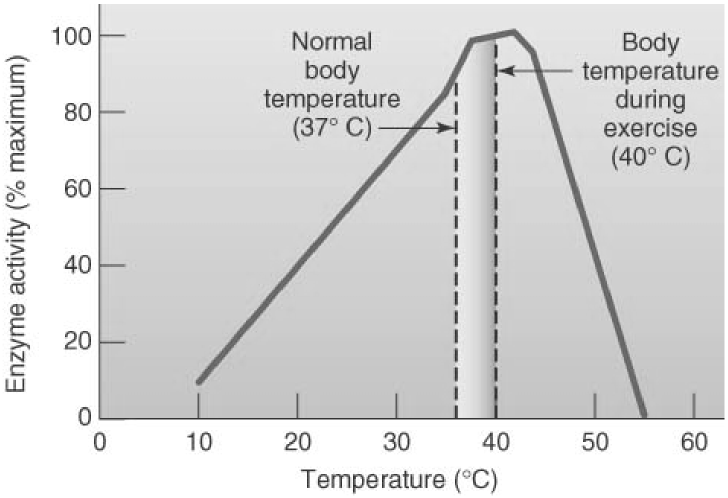


Figure 5. Body temperature and enzyme activity. The effect of body temperature on enzyme activity. Notice that an optimal range of temperatures exists for enzyme activity. An increase or decrease in temperature away from the optimal temperature range results in diminished enzyme activity (Powers & Howley, 2009, p. 29).

Enzyme activity resembles an inverted-U and if the temperature of the body increases or decreases too much there will be a decrease in enzyme activity. Increased enzyme activity and increased rate of oxidative reactions are closely related to increased body temperature resulting from performing a warm-up. The increase in body temperature during exercise improves enzyme activity which helps enhance ATP production through speeding up of the rate of reactions. Enhanced ATP production helps fuel the body with energy to continue performing exercise.

Increased nerve conduction rate. Recruitment of motor units is directly related to speed of nerve impulse conduction, which is influenced by changes in temperature. A motor unit is made up of muscle fibres and motor neurons, and acts as the functional unit of movement. Motor neurons cell bodies are located in the spinal cord and signals are sent away from the cell body through the axon to the innervated muscle An increase in muscle temperature may improve performance by improving the transmission speed of nerve impulses (Bishop, 2003a). The improvement in nerve conduction rate may be essential for athletes completing complex body movements, generally anaerobic and short in duration, such as diving, jumping, throwing or starting in blocks for sprinters. Long-duration performance may benefit from increased nerve conduction as Paavolainen, Nummela and Rusko (1999) suggested that improvement in force production is related to maximal and submaximal running performance as athletes are required to maintain a relatively high velocity for the duration of a race. The neuromuscular system can be improved through training (Bonacci, Chapman, Blanch, & Vicenzino, 2009), but further research is required to understand the influence temperature and training has on the nervous system and performance.

Increased thermoregulatory strain. The thermoregulatory system works to keep the body core temperature closely regulated at approximately 37°C. Thermoregulatory strain is the increased strain imposed on the body to either warm-up or to cool down. Exercising generally produces a considerable amount of heat that raises muscle and core temperatures more than if the individual was at rest. Muscle temperature increases more rapidly during the onset of exercise and then plateaus once a constant workload is maintained. In comparison, core temperature has a more gradual increase and takes longer to reach steady state. As the temperature of the body increases, the athlete is more likely to experience heat related conditions such as heat cramps, heat exhaustion and heat stroke because the body is having difficulties controlling the increased temperature. Wang, Li, Lui, and Lai (1995) stated that the diagnosis of heatstroke is based on clinical history with an altered mental state and a rectal temperature of 39.5°C or more. Along with an increase in thermoregulatory strain, fatigue generally affects athletes between 38 and 40°C (Kenefick & Sawka, 2007).

Thermoregulatory strain must be taken into consideration with environmental conditions (Noakes, 2003; Bishop, 2003a) as the body can become too hot and limit performance. Thus, heat capacity is a limiting factor of the thermoregulatory system and extensive warm-ups on hot days may strain the system too much and decrease performance. Monitoring weather conditions can help athletes determine if the environmental temperature is too hot for optimal performance. One method for an athlete to check for optimal conditions is to perform a “start-line test,” to identify if the athlete feels cool when standing on the start line. If the athlete does not feel cool, then the weather is too hot for optimal performance (Noakes, 2003). The warm-up the athlete performs may be altered depending on the influence of the coach and preferences of the athlete.

Hydration status also plays a role in thermoregulatory strain, and is important for the athlete to monitor. Dehydration is a result of water loss, which is experienced through performing a warm-up as the athlete experiences an increase rate of perspiration due to increase in muscle and core temperatures (Ament and Verkerke, 2009). Dehydration is also influenced by environmental conditions such as heat and humidity. After the warm-up it may be necessary for the athlete to rehydrate prior to exercise, as dehydration causes an increase on thermoregulatory strain as the body’s ability to dissipate heat is reduced. Thermoregulatory strain and dehydration may be more of a concern for endurance athletes because these athletes are performing for an extended period of time.

Non-temperature related. While the term “warm-up” may imply the influence of temperature, the non-temperature related effects of the warm-up can have a major impact on athletic performance.

Increased blood flow to muscles. As stated previously, there is an increase in oxygen delivery to tissue with an increase in temperature, but the increase in blood flow to muscles is a function of exercise. During activity blood is shunted from non-essential organs (intestines), in order to provide more blood to the working muscles. Blood shunting is accomplished by blood vessels constricting in the non-essential organs, while blood vessels dilate in the working muscles.

Elevation of baseline oxygen consumption. Completing a warm-up elevates baseline oxygen consumption prior to training or competition. Starting training or competition with an elevated level of oxygen consumption is most beneficial to athletes competing in long-duration and intermediate-duration events, as aerobic metabolism influences performance. Elevation of baseline oxygen consumption has also been referred to as the *mobilization hypothesis* (Andzel & Gutin, 1976), as it is believed that the warm-up (prior exercise) acts as a mobilizing stimulus for the oxygen transport system. The hypothesis also states that by starting a performance with an elevated oxygen consumption results in a lower O_2 deficit at onset and spares some of the anaerobic capacity which could potentially be reserved for use at the end of the task. In addition to starting a performance with an elevated oxygen consumption, researchers have found a bout of heavy-intensity exercise prior to moderate intensity exercise helps improve VO_2 kinetics for elderly individuals (Scheuermann, Bell, Paterson, Barstow, & Kowalchuk, 2002), as well as for healthy young adults (Gurd, Scheuermann, Paterson, & Kowalchuck, 2005). Trained endurance athletes typically have better VO_2 kinetics compared to untrained athletes, and the results from Gurd et al. (2005) found that individuals with slower VO_2 kinetics demonstrated more of an improvement in VO_2 kinetics than individuals with faster kinetics. Figure 6 shows the differences between (a) performing no warm-up and (b) performing a warm-up. This theoretical diagram shows that VO_2 kinetics are slightly improved and it is shown that steady state is reached sooner after performing a warm-up due to elevated oxygen consumption and slightly improved VO_2 kinetics. The O_2 deficit for both graphs would be the portion of anaerobic metabolism above the curve before the athlete reaches steady state. As the graph illustrates, an individual performing no warm-up has a greater O_2 deficit compared to an individual performing a warm-up and this leads to lower anaerobic metabolism at the end of the task. By completing a warm-up, less of the initial work is completed anaerobically leaving more anaerobic capacity in reserve for the end of the task (Bishop, 2003a). Sparing the anaerobic capacity is valuable for intermediate-duration and long-duration athletes even if a submaximal steady state oxygen consumption is not attained by the athlete. Intermediate-duration athletes will not reach a submaximal steady state oxygen consumption as the intensity of exercise is generally at or over 100% maximal oxygen uptake (Barstow & Molé, 1991). Athletes should also try to limit the time between warm-up and competition as oxygen consumption can return to resting values within approximately 5-minutes (Özyener, Rossiter, Ward, & Whipp, 2001). If the athlete returns to baseline measurements, the athlete may still have slightly improved VO_2 kinetics but the potential benefits of a decreased O_2 deficit at the onset of exercise may be lost.

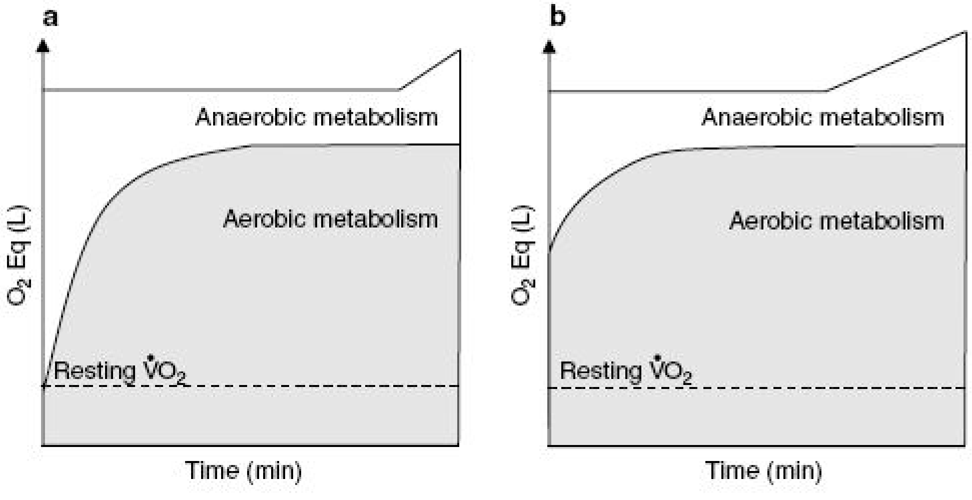


Figure 6. Change in baseline oxygen consumption. Schematic representation of the aerobic and anaerobic contribution to an all-out task with (a) and without (b) prior warm-up. O_2 Eq = oxygen equivalents, VO_2 = oxygen consumption (Bishop, 2003a, p. 444).

Postactivation potentiation. Postactivation potentiation is the temporary increase in muscle contractile performance, which can be described as the muscle contracting with more explosive force after completing exercise of higher intensity, as illustrated in Figure 7. The contractile performance of the muscle is influenced by the number of motor neurons that are signalled resulting in more motor units being recruited (Reyes & Dolny, 2009). Performing a warm-up that includes high intensity exercises, such as sprinting, may improve performance by increasing muscle contractile performance (Bishop, 2003a). Postactivation potentiation is believed to have the potential to benefit both power and endurance athletes, but not in the same regard. Power athletes may benefit from an increased rate of force development, while endurance athletes may benefit from postactivation potentiation offsetting fatigue (Sale, 2002). Research on postactivation potentiation has been focused mainly towards power performance (Faigenbaum, Bellucci, Bernieri, Bakker & Hoorens, 2005; Faigenbaum, McFarland et al., 2006; Fletcher & Monte-Colombo, 2010; Needham et al., 2009; Gelen, 2010; Reyes & Dolny, 2009) because it is greater in fast Type II muscle fibres (Hamada, Sale, MacDougall & Tarnopolsky, 2000). A study by Pääsuke et al. (2007) compared power-trained and endurance-trained athletes and found that postactivation potentiation in knee extensor muscles is enhanced in power but not in endurance-trained female athletes. The study also found that the decay was slower among power-trained athletes compared to endurance-trained, possibly indicating how postactivation is related to fatigue. Sale also suggests that postactivation potentiation is responsible for athletes “feeling better” once exercise has been underway for a short time. Further research regarding athletic performance and the role of the warm-up in facilitating postactivation potentiation is still required.

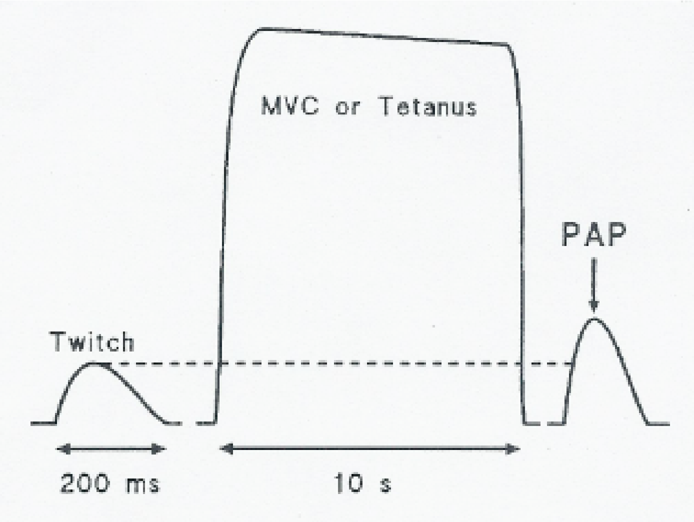


Figure 7. Postactivation Potentiation. An example of postactivation potentiation (PAP). First, a baseline twitch is evoked in a muscle that has been at rest for some time. Then, a conditioning contraction, such as an electrically evoked titanic contraction or a maximal voluntary contraction (MVC) is done. A twitch contraction evoked soon after the conditioning contraction shows the increased force and shortened time course typical of PAP (Sale, 2002, p. 139).

Psychological effects. Along with the physiological benefits, the warm-up also has psychological benefits. During the warm-up, individuals should also prepare mentally for the main part of the training session or competition by visualizing the exercises and motivating themselves for the eventual strain of training (Bompa & Carrera, 2005). Athletes may focus on becoming more psychologically prepared than individuals who are recreationally active, as the athlete is looking to optimize performance during training or competition. The psychological aspect of performance, as well as the warm-up, is important but also difficult to study as every athlete is different and the perception of being prepared can be rather subjective. Regardless of the differences between athletes, it is widely believed that performing some skill-related activity prior to competition helps mentally prepare the athlete for the upcoming performance. Prior to the warm-up the athlete may mentally rehearse skill-related movements, but implementing the movements into the warm-up allows the athlete to mentally and physically rehearse the movements together prior to performance. Being psychologically ready may be as important as being physiologically prepared, as the athlete can easily lose focus which may impair performance. The importance for an athlete to be psychologically prepared is seen among all sports, whether the event lasts 10-seconds or endures for over 2-hours. The athlete must be prepared to perform to his or her limits whether performing an explosive coordinated movement, or maintaining focus throughout the duration of the event. Schucker, Hagemann, Strauss, and Volker (2009) found that internal attentional focus resulted in improved running economy for trained distance runners, meaning that concentrating on the running movement and breathing was more economical than concentrating on surroundings. While the study by Schucker et al. did not focus on warm-ups, the results demonstrate the importance of how psychological factors can affect performance. The athlete's personal beliefs about performing a warm-up may also have an influence on the subsequent performance. Since different athletes, even within the same sport, perform different warm-ups there may be a preconceived idea of what the individual athlete needs to complete in a warm-up to feel prepared. With the combination of both physiological and psychological factors it is of no surprise that the warm-up plays an important role in preparing athletes to perform to their maximal potential.

Neuroendocrine system. The effects of performing a warm-up may have been divided into temperature and non-temperature related factors, but it is important to understand that many of these factors are due to changes in the neuroendocrine system. The neuroendocrine system is comprised of two systems: the nervous system and the endocrine system. The nervous system is responsible for sending messages to the endocrine system, which is then responsible for the secretion of hormones. “Hormones are chemical messengers and are secreted from glands and cells found throughout the body” (Bunt, 1986, p. 332). These hormones are responsible for homeostasis but also allow adaptations to occur in the body during exercise. Changes in hormone levels during exercise influence the sympathoadrenal stress response, the regulation of energy metabolism, the maintenance of fluid and electrolyte balance, as well as growth and development (Bunt, 1986; Coker & Kjaer, 2005; McMurray & Hackney, 2005). Examples of the changes that occur include, but are not limited to, increased breathing rate, increased heart rate, increased sweating, shunting of blood to working muscles, as well as changes to fuel mobilization, enzyme actions and energy utilization. Some of these changes, shunting of blood for example, may be a combination of both temperature related and neuroendocrine related. Certain hormones are responsible for specific changes, yet many times a number of hormones will influence the same response. The adrenal hormones including the catecholamines (epinephrine and norepinephrine) and cortisol respond to the total stress of the body and accommodate for increased demands of respiratory and cardiovascular systems and metabolic processes (Bunt, 1986; Kraemer, 1988). A few hormones that play a role in fuel mobilization include; cortisol, insulin and glucagon. McMurray and Hackney state that catecholamines, cortisol, human growth hormone and thyroid hormones have a primary role in lipid metabolism, while glucagon, insulin, androgen and estrogens may be involved in certain situations. The hormones aldosterone and antidiuretic, assist in temperature regulation through the conservation of sodium and water (Bunt, 1986). These changes in the body occur without a conscious effort during exercise but some of the changes do not occur immediately. Some hormones have a delayed response from 15-minutes up to an hour, depending on exercise duration and intensity (Bunt, 1986). By performing a warm-up the neuroendocrine system becomes engaged prompting the release of hormones to help prepare the body for exercise acting in combination with the other systems and tissues of the body.

Warm-up benefits. Understanding how warm-ups affect the human body is important, but for coaches and athletes, the primary concern is how these changes will benefit performance as well as reduce the risk of injury.

Performance. Generally speaking the main purpose of the warm-up is to prepare the body for physical activity, but for athletes the warm-up also prepares the body for optimal performance. Athletes of all backgrounds perform warm-ups, yet athletes from these different sports may wish to improve different aspects of performance. Bishop (2003b), in his description of how a warm-up influences performance, divided performance into three categories: short-term maximal effort for less than 10 seconds; intermediate-term effort for greater than 10 seconds but less than 5 minutes and long-term which is a fatiguing effort for more than 5 minutes. Since the definitions of the performance measures involve a duration of time, the use of the word “duration” instead of “term” may be more appropriate when discussing the different performance measures. The word “term” may imply a timeline such as a week, month or year, while “duration” implies the amount of time to complete the task. For this study the performance categories will be referred to as short-duration, intermediate-duration and long-duration performance.

The majority of current research has been focused on short-duration performance measures. Many of the televised sports in North America (football, hockey, basketball, soccer and baseball) are mainly anaerobic in nature, so it is no surprise that the majority of the research conducted is focused on these popular (in both participation and viewing) and explosive sports. In track-and-field jumping, throwing and sprinting are all part of the short-duration performance category. With short-duration performance even small improvements in performance can drastically affect the outcome of an event, whether it is evading a defender in soccer or jumping an extra centimetre in the long jump. Research for short-duration performance involves measures of power, speed and agility, which are measured through various tests such as vertical jump, 100-

m sprint, and T-drill, to name a few. Dixon et al, (2010) and Holt and Lambourne (2008) found performing a warm-up improved counter movement jump among Division I athletes. Gelen (2010) found that after a warm-up was performed, sprint time, slalom dribbling and penalty kick performances were improved with professional soccer players. Chaouachi et al. (2010) reported that performing a warm-up showed improvements in agility, sprinting and jumping performance of highly trained male student athletes and McMillian, Moore, Hatler, and Taylor (2006) found that performing a dynamic warm-up resulted in improved performance in T-drill, 5-step jump and medicine ball throw for distance among cadets from the United States Military Academy. Yamaguchi, Ishii, Yamanaka, and Yasuda (2007) conducted an in-depth analysis into how dynamic stretching influences performance by measuring time to peak torque, rate of torque development and peak velocity during a concentric dynamic constant external resistance leg extension. The study found that performing dynamic stretches during a warm-up reduced time to peak torque, increased rate of torque development and increased peak velocity. Many of the studies reported significant differences in performance between warm-ups involving static and dynamic stretching, but a few reported there were no significant differences. Studies that reported no significant differences may have had issues regarding testing or aspects of the warm-up, for example a prolonged post warm-up recovery period was experienced before testing took place. Faigenbaum, McFarland et al. (2006) found dynamic warm-ups with and without weighted vests significantly improved performances in vertical jump and long jump but not in seated medicine ball toss or 10-yard sprint. The insignificant results regarding the 10-yard sprint may be due to the short duration of the task, which may not have permitted enough variation among trials (Faigenbaum, McFarland et al., 2006). While all performance measures were short duration, the 10-yard sprint was a continuous task while the others were discrete. Dalrymple, Davis, Dwyer, and Moir (2010) found no significant increase in performance in vertical jump height when comparing dynamic and static warm-ups for NCAA Division II volleyball players. Although the results from the study by Dalrymple et al. showed no statistical differences, the majority of subjects produced greatest jump heights after performing a dynamic warm-up.

Intermediate-duration performance involving bouts of exercise lasting greater than 10 seconds but less than 5 minutes can relate to many sports, such as hockey, soccer, football, basketball, as well as a wide range of running events in track-and-field. Intermediate-duration performance for these sports generally involves short bouts of intense exercise, interspersed with varying periods of rest throughout the entire match. Many sports that fit into this category are intermittent sports, meaning that the sports involve periods of exercise followed by periods of rest. In relation to track-and-field this would include events between 200-m and 1500-m, encompassing a wide range of athletes as sprinting 200-m is primarily anaerobic while the 1500-m has a greater aerobic component. The track and field events are more of a continuous nature, with events being complete once the participant has stopped. Intermediate-duration performance benefits from many of the same temperature related effects of warm-ups as short-duration performance. The more aerobic performances such as the 1500-m may also benefit from decreasing the initial oxygen deficit which may leave more of the anaerobic capacity for later in the task (Bishop, 2003b). As explained by the mobilization hypothesis, performing a warm-up the athlete can start the event with an elevated baseline VO_2 and be able to utilize anaerobic capacity near the end of the event. The elevated baseline VO_2 may be most relevant towards track athletes competing in events between 800-m and 1500-m, but the extra anaerobic capacity could prove to be important for many sports as the last few minutes of play are often intense and having the availability of anaerobic energy could prove useful.

Long-duration events include running events ranging from 3000-m up to 42.2-km (marathon), speed skating events over 5000-m, as well as many cross country skiing and cycling events. Athletes competing in longer events lasting more than 5 minutes are likely not to improve by the same temperature-related mechanisms that improve short-duration performance (Bishop, 2003b). Long-duration performance is influenced by the increase of baseline VO_2 when compared to short-duration or intermediate-duration performance. Wilson et al. (2010) found that static stretching reduced distance covered during a 30-minute performance run and increased energy cost of running at 65% of VO_2max for the participants. Curry et al. (2009) stated that acute static stretching may inhibit performance by reducing force production, balance, reaction time, sprint times and power output. There is little current research conducted on long-duration performance and benefits of performing a warm-up, possibly due to the variability in performance over the period of time it takes to complete the task. Wittekind and Beneke (2009) is one article on long-duration performance that is somewhat controversial to the understanding of warm-ups and performance. The study found that time to exhaustion was not significantly increased by active warm-ups, although the time to exhaustion was increased (by approximately 30-seconds) after performing a warm-up. Further research is required to address how warm-ups influence long-duration performance.

Injury prevention. Aside from its influence on performance, the warm-up also prepares the body in order to prevent an injury from occurring. Warm-ups are believed to help prevent injuries but the mechanism for this is not fully understood. As stated previously, a traditional warm-up included a general aerobic portion followed by a period of time involving static stretching of the muscles because it was believed to help reduce the risk of injury. With current research indicating the benefits of dynamic stretching over static stretching in regards to performance (Chaouachi et al., 2010; Gelen, 2010, Dixon et al, 2010; Holt & Lambourne, 2008; McMillian et al, 2006; Faigenbaum, McFarland et al., 2006; and Dalrymple et al., 2010; Yamaguchi, Ishii, Yamanaka et al., 2007), then dynamic stretching may be better for injury prevention as well. There is a lack of scientific evidence that supports the use of static stretching in a warm-up for injury-prevention and that the primary injury-prevention benefit is related to the increased temperature of the muscle primarily resulting from the general portion of the warm-up (Knudson, 1999; Small, McNaughton, & Matthews, 2008). As mentioned in the temperature related effects of warm-up, an increase in temperature decreases the viscous resistance of muscles and joints. This decrease in resistance helps reduce risk of injury because the muscles are not as stiff and movement occurs with more ease. With athletes moving away from static stretching during the warm-up, it is possible that dynamic stretching helps reduce risk of injury as well since a dynamic warm-up usually is combined with some aerobic activity.

Warm-up Types (Components). For athletes to benefit the most from performing a warm-up should be sport or activity specific. Fradkin, Zazryn, and Smoliga (2010) stated that warm-ups that showed a detriment in performance were generally inappropriate for the activity. The two basic types of warm-ups can be described as active and passive (Brown, Hughes, & Tong, 2008; Bishop, 2003a), with active warm-up divided into a general and specific warm-up. Active and passive warm-ups can be performed independently or in combination.

Active. An active warm-up, as the name suggests, involves actively performing an exercise or series of exercises to increase body temperature. The active warm-up should activate specific muscles in a way that mimics the anticipated activity that brings about full range of joint motion. Active warm-up involves exercise to induce greater metabolic and cardiovascular changes than passive warm-up (Bishop, 2003a). Active warm-ups can be divided into general and specific, with both often performed together.

General. The general warm-up involves light aerobic activity to increase the temperature prior to more vigorous exercise. The activities performed in the general warm-up require movement of the major muscle groups, such as jogging, cycling or jumping rope (Bompa & Carrera, 2005) and use body movements that may not be specific to the upcoming performance. The definitions provide a broad understanding of what a general warm-up involves, but the general warm-up will still be influenced by the athletic event the athlete will be competing in. For example, a runner's general warm-up is likely to involve jogging (which is related to specific neuromuscular actions) while a boxer maybe complete a general warm-up by cycling, skipping or jogging.

General warm-ups typically involve 5-15 minutes of light aerobic activity. In an athletic setting the duration of the general warm-up is dependent upon the event being performed, for example a distance runner may do a longer general warm-up than a sprinter. Traditionally, the general warm-up was followed by a period of static stretching, but coaches and athletes are starting to move away from this warm-up approach because research is indicating that static stretching is not beneficial and is actually detrimental to performance. The use of static stretching is no longer believed to improve performance or prevent injury, and Knudson (1999) stated that the benefits of static stretching prior to competition may be the profession's largest "stretch" of the scientific literature.

Specific. Specific warm-ups incorporate movements similar to the movements of the athlete's sport and may include dynamic stretches. Dynamic stretching is an activity-specific functional stretching exercise that should utilize sport-specific movements to prepare the body for activity (Kovacs, 2010), for this reason specific warm-ups are often referred to as dynamic warm-ups. Specific warm-ups, similar to general warm-ups, can last between 5-15 minutes (Herman & Smith, 2008; Needham et al., 2009). The specific warm-up also serves as a mental rehearsal of the upcoming activity as it incorporates more sport specific movements. Warm-ups including dynamic stretches are becoming more popular in many sports as dynamic stretching incorporates whole body movements actively and rhythmically contracting a muscle group through part of its functional range of motion (Curry et al., 2009). Examples of dynamic stretches include leg swings and arm swings, as well as skipping, hopping, and galloping and rotational movements of the limbs. Fletcher and Monte-Colombo (2010) found with semi-professional soccer players using a warm-up with dynamic stretching improved countermovement vertical jump, 20-m sprint time, and Balsom agility test time, when compared to just an active warm-up and an active warm-up combined with static stretching. Leg extension power after static stretching was no different than after no stretching, but dynamic stretching enhanced leg extension power (Yamaguchi & Ishii, 2005). Researchers have also been interested in the effect of performing dynamic warm-ups with weighted vests (Reiman et al., 2010; Faigenbaum, McFarland et al., 2006) and have found that it can help improve performance when less than 6% of body mass.

Passive. Bishop (2003a) states that a passive warm-up involves raising core and muscle temperature by some external means such as heating pads, saunas, or hot showers. Massage and passive stretching with a training partner or therapist may also be performed as part of a passive warm-up. Passive warm-ups are not always practical for athletes but the use of a passive warm-up allows one to test the hypotheses in regards to temperature related changes. Brunner-Ziegler, Strasser, and Haber (2010) found that passive warm-ups are not as useful for elevating VO_2 values as performing an active warm-up. These findings make sense as a passive warm-up alone would not involve an aerobic component (general warm-up) which would be responsible for elevating baseline oxygen consumption. Wenos and Konin (2004) tested passive warm-up effects on flexibility and found range of motion was significantly increased from the control group, but passive warm-up had lower results than active warm-ups. Ce et al. (2008) results found passive stretching did not negatively affect maximal anaerobic power but highest values were obtained after an active warm-up.

Performing only a passive warm-up prior to exercise or competition may not always be recommended, but may be useful when used in conjunction with general and/or a specific warm-up. With the diversity in warm-up protocols an athlete may use to prepare for competition, it is important to understand how the athlete will benefit from adopting a new or different approach to his or her warm-up.

Warm-up duration and intensity. The relationship between warm-up duration and intensity is highly dependent on the preferences of coaches and athletes. Duration generally relates to the amount of time spent warming up, while intensity refers to the effort utilized. Duration can also be influenced by the volume of exercises performed during the warm-up. Volume refers to the sets or intervals involved with training. A defining difference between duration and volume is the difference between how long and how much. The general and specific components of a warm-up can be modified with respect to duration, volume and intensity, to the coaches and athletes preferences.

Duration and intensity are two variables that can influence the effectiveness of a warm-up in preparing the athlete for competition, and are often discussed together as one influences the other. The total duration of a warm-up is an issue to consider as different athletes may require a longer warm-up than others which involves altering volume and intensity. For example, a sprinter may perform a longer warm-up to ensure he or she is prepared for the explosive movements that are about to be performed; on the other hand a marathon runner may perform a short warm-up or no warm-up at all, as the first few kilometres of the race will be considered a warm-up period. Another issue that arises when discussing warm-up duration is the experience level of the athlete, as an elite athlete may warm-up longer at a higher intensity than a recreational athlete. The majority of research that is conducted often utilizes a 5-minute general warm-up followed by approximately 10 minutes of testing condition (specific warm-up) (Gelen, 2010; Chaouachi et al., 2010; Needham et al., 2009; Brown et al., 2008; Holt & Lambourne, 2008; Curry et al., 2009; Young & Elliot, 2001; Fletcher & Monte-Colombo, 2010). Few researchers have utilized longer warm-up protocols (Brunner-Ziegler et al., 2010; Škof & Strojnik, 2007; Genovely & Stamford, 1982; Ce et al., 2008; Nelson & Kokkonen, 2001), and some studies do not indicate the total duration of the warm-up (Dixon et al., 2010). The use of 5-minutes for the general warm-up is widely utilized because many of the studies are interested in short-duration performance and 3-5 minutes of moderate intensity can see significant performance gains in short-duration performance because of a rapid increase in muscle temperature. Since short-duration performance benefits the most from temperature related effects of increasing body temperature it is understandable that 5-minutes is commonly used in research. A relative plateau in muscle temperature can be seen after 10-22 minutes of exercise, but core (rectal) temperature requires approximately 30 minutes to reach homeostasis (Asmussen & Bøje, 1945; Saltin, Gagge & Stolwijk, 1968). In the few studies that involved longer warm-up duration, none of the studies focused on duration of warm-up as the independent variable. Research from Genovely and Stamford may have utilized a prolonged warm-up, but the focus of the research was on intensity above and below anaerobic threshold. For athletes wanting to improve intermediate-duration and long-duration performance, the temperature related effects of warm-up are not as significant and the main benefit of performing a warm-up is an elevated baseline VO_2. Steady state oxygen consumption can be reached between 5-10 minutes of exercise depending on intensity (Özyener et al., 2001). For long-duration performance, thermoregulatory strain and glycogen depletion become a concern, as warm-ups of prolonged duration can negatively affect both.

With the understanding that warm-up duration varies among athletes, it is important to understand how duration and intensity influence each other. McMillian et al., 2006; Faigenbaum, McFarland et al., 2006) stated that the warm-up should progress gradually at sufficient intensity to increase muscle and core temperatures without fatigue or reducing energy stores. Intensity often varies among warm-ups, whether an athlete is training for a short event or preparing for a longer event. For short-duration performance, Bishop (2003b) indicated that performing an intense warm-up may decrease the availability of high-energy phosphates, which is an important energy source for short-duration performance. For intermediate-duration and long-duration performance a warm-up of a slightly higher intensity may be more beneficial. Andzel (1982) found a warm-up at approximately 50% of VO_2max resulted in faster one mile performance times when compared to no warm-up or warm-up at 40% VO_2max for non- competitive runners. Stewart and Sleivert (1998) indicated that a warm-up at an intensity of 60-70% of VO_2max improved range of motion and enhanced subsequent anaerobic performance. Škof and Strojnik (2007) determined that completing a more intensive specific warm-up after a general warm-up (totalling 25-27 minutes) resulted in a more significant increase in maximal voluntary contraction torque and in an enhanced muscle activation. Wenos and Konin (2004) found participants reached steady state quicker during a warm-up at 60% heart rate reserve, compared to a warm-up at 70% heart rate reserve. More recent research on warm-up duration and intensity has found that performing a shorter (17-minutes) warm-up at a lower-intensity (progression from 50% to 70% HRmax) was beneficial to performance in sprint track events in cycling when compared to a traditional longer, more intense warm-up (Tomaras & MacIntosh, 2011).

Rest intervals (recovery). As duration and intensity influence each other, the whole warm-up is also influenced by the recovery period between the completion of the warm-up and the onset of training or competition. The amount of recovery that is required to help optimize performance partially depends on the athlete as well as the type of performance. An athlete competing in short-duration events may recover for a longer duration to replenish phosphocreatine stores. On the other hand athletes competing in intermediate-duration and long-duration, especially long-duration, are more concerned with starting competition with elevated oxygen consumption and may take a shorter recovery. Andzel and Gutin (1976) tested the mobilization hypothesis using untrained female physical education students by using no warm-up, warm-up with no rest, warm-up with 30 seconds rest and warm-up with 60 seconds rest. Results found that performances following 30 and 60 seconds rest were significantly better than no warm-up and warm-up with no rest. Andzel (1978) found that a relatively short rest interval of 30 to 60 seconds can benefit endurance performance, when compared to no warm-up (prior exercise) and rest intervals of 90 and 120 seconds. A few issues arise with the results from Andzel and Gutin and Andzel as the studies did not use trained endurance athletes, warm-up intensity was at approximately 50 percent VO_2max as measured by a heart rate of 140 beats per minute, used a stationary recovery instead of an active recovery and lastly VO_2 was not measured. Andzel and Busuttil (1982) followed the same warm-up protocol as previous studies and used 30 and 90 second rest intervals before a strenuous aerobic task. This study recorded

VO_2 results and found similar performance among 30 second recovery and no warm-up with 90 seconds being significantly worse than both.

Theory. The influence performing a warm-up has on performance has been extensively researched, yet there is still a lack of evidence about what is considered to be the most effective warm-up (Gelen, 2010; Chaouachi et al., 2010; Sim et al., 2009; Ce et al., 2008). The warm-up athletes perform is often dependent on what the coach instructs the athlete to do and may disregard individual differences between athletes (Daniels, Flotrack, 2007). While warm-ups generally consist of aerobic progression with a sport specific activity to prepare the body, coaches may emphasis different aspects of the warm-up. Intensity and components of the warm-up may vary between coaches, as some may instruct all athletes to perform the warm-up at a certain pace yet one athlete may benefit more from performing a quicker warm-up while another may benefit from a slower. In this regard coaches should try to minimize fatigue and have athletes perform the least amount of work in order to be the most prepared for the workout or competition. If an athlete’s warm-up is more than what is necessary there will be a depletion of glycogen stores for endurance athletes and a depletion of high energy phosphates for power athletes. Performing the warm-up may contain aspects that are physically demanding, such as strides, but are performed in a way that allows the athlete to recover adequately prior to competition or training. Athletes also might perform a warm-up which involves a constant build up in intensity with almost no distinction between the end of the warm-up and the beginning of the workout or competition. Gradually increasing the intensity of the warm-up can be applied in different ways depending on the training or competition that is going to be performed. For example, a middle distance runner may perform the strides that gradually increase in intensity for the short-hard days on the track, but during a continuous tempo workout the athlete may gradually increase the intensity of the warm-up to eventually reach the desired pace of the workout. The approach an athlete takes towards performing a warm-up is often dependent on others, such as the coach or other athletes, while in reality it should be focused on what the individual needs to perform at his or her best.

Application (middle and long distance runners). Warm-ups in the world of track-and-field are fairly common practice and completed by athletes of all events. Warm-up protocols differ from athlete to athlete but generally contain the same components. The warm-up is aimed to prepare the muscles of the lower limbs (quadriceps, hamstrings, gluteals, hip flexors, tibialis anterior, gastrocnemius and soleus), which are primarily used in running (Modica & Kram, 2005). Middle distance and long distance runners are a diverse group participating in events ranging from 800-m to 10 000-m. The middle distance group (800-m to 3000-m) may benefit from more of the temperature related effects of the warm-up compared to the long distance group, but both would benefit from starting with an increase in baseline oxygen consumption. When comparing running economy with warm-ups there seems to be an inverse relationship as running economy becomes more important for athletes competing in longer distance rather than shorter distances.

On the other hand the inclusion of dynamic stretches and movements in a warm-up may benefit middle distance runners more than long distance runners because middle distance events are more anaerobically demanding. Regardless of the differences between events, a proper warm-up is important to all runners because of the repetitive strain that training and competition can impose on the body.

Running Performance

Performance for an endurance runner is influenced by three main components: maximal oxygen consumption, lactate threshold (ventilatory threshold), and running economy. Running performance may also be influenced by age, sex, experience, genetics, and muscle fibre type (Daniels, 1985; Noakes, 2003).

Maximal oxygen consumption. Maximal oxygen consumption is synonymous with terms such as maximal oxygen uptake, maximal aerobic power, aerobic capacity or simply as VO_2max. VO_2max has received a lot of attention as a factor contributing to endurance performance as it is well established that a high maximal ability to metabolize energy aerobically is a prerequisite for success in endurance running events (Craib et al., 1996). Aerobic metabolism refers to the body's ability to take in, transport and utilize oxygen to produce ATP aerobically while breathing during exercise. VO_2max is influenced by a variety of factors including muscle capillary density, hemoglobin mass, stroke volume, aerobic enzyme activity and muscle fibre type composition (Saunders, Pyne, Telford, & Hawley, 2004). Many of the factors that influence VO_2max are generally related to all the variables that influence endurance performance. VO_2max can be determined through laboratory testing as the point where oxygen consumption plateaus (as seen in Figure 8) or increases only slightly with additional increases in exercise intensity. The measurement for VO_2max is most commonly explained in relative terms as millilitres of oxygen per minute per kilogram of body mass (ml//kg/min).

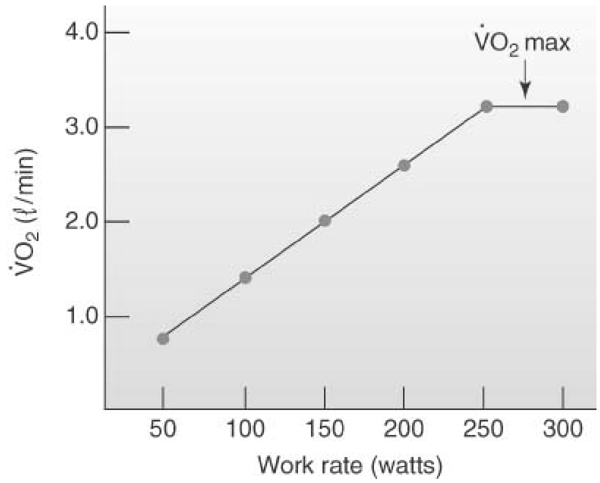


Figure 8. Reaching maximal oxygen consumption. Changes in oxygen uptake (VO_2) during an incremental exercise test. The observed plateau in VO_2 represents VO_2max (Powers & Howley, 2009, p. 57).

Noakes (2003) explained there are various factors that influence VO_2max such as age, gender, fitness, changes in altitude and ventilatory muscle action. Muscle fibre type also plays a role in the individuals VO_2max, as an individual with a higher percentage of slow twitch (oxidative) muscle fibres will have a greater aerobic capacity at the muscular level than someone who has a higher concentration of fast twitch muscle fibres (Noakes, 2003). Genetics plays a role in the percentage of each muscle fibre type, which also relates to the trainability of improving VO_2max. An athlete can improve his or her VO_2max through training to a limited degree (Noakes, 2003). The greatest improvements are found when an untrained athlete starts training, then improvements slow down and occur gradually (Midgley, McNaughton, & Wilkinson, 2006).

VO_2max is an important component of endurance performance because if an athlete has a higher VO_2max he or she is capable of transporting more oxygen to the working muscles. It can then be stated that athletes with a higher VO_2max are generally better at endurance events than athletes with a lower VO_2max. However, when athletes with similar running performances are studied, the VO_2max becomes a far less sensitive predictor of performance (Noakes, 2003).

VO_2max is a good indicator of what event an athlete should focus on but when looking at a homogeneous group it is not a good predictor to determine performance.

Anaerobic threshold. Anaerobic threshold has been associated with the intensity of exercise above which lactate levels rise and ventilation increases disproportionately in relation to oxygen consumption (Plowman & Smith, 2008). Based on the association that has been described between anaerobic threshold with lactate and ventilation, it is of no surprise that terms anaerobic threshold is used synonymously with lactate threshold and ventilatory threshold. Lactate threshold can be explained as the point when lactate production overcomes lactate removal or consumption, and ventilatory threshold is the inflection point when a person starts breathing heavily. An increase in anaerobic metabolism often limits aerobic performance because not as much ATP is created to fuel the body. Lactate threshold and ventilatory threshold have a good correlation and generally occur around the same time during exercise, as seen in Figure 9. In each case the inflection point is estimated at approximately the same instance (at 2 l/min for oxygen uptake) which would indicate that both thresholds are similar. Lactate threshold is determined using invasive procedures, as a blood sample is required, so ventilatory threshold is often used to estimate when lactate threshold occurs.

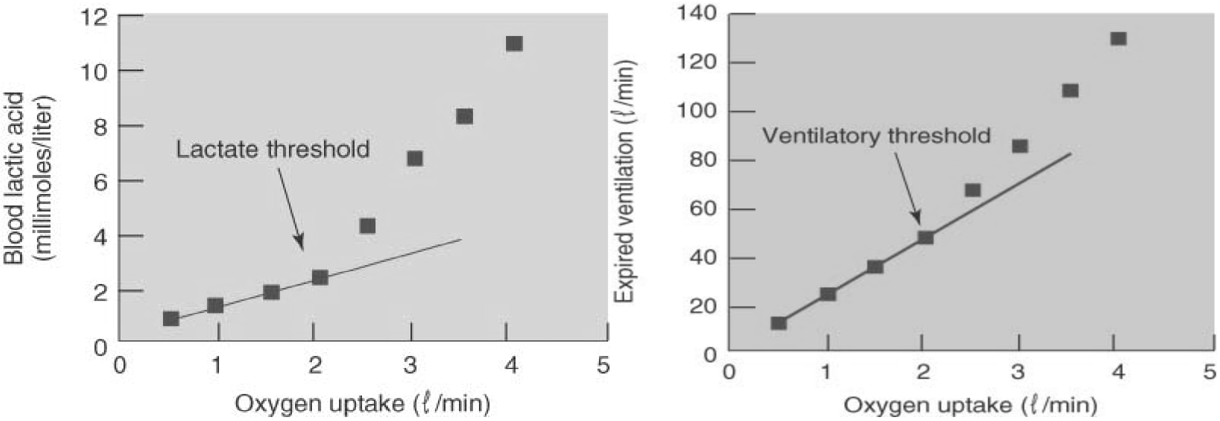


Figure 9. Lactate threshold and ventilatory threshold. The figure illustrates the comparison between lactate threshold and ventilatory threshold during an incremental exercise test (Powers

& Howley, 2009, p. 436-437).

Through training, lactate threshold can be improved and has been seen to occur in highly trained athletes when running at an effort of 65-80% of their VO_2max, while untrained athletes would reach threshold around 50% to 60% VO_2max (Powers & Howley, 2009; Smith & O'Donnell, 1984). The delayed onset of the lactate threshold is important to endurance performance as the athlete will be able to run a faster pace for a longer duration before lactate starts to accumulate. Lactate is often labelled as being the cause of fatigue during intense exercise but Noakes (2003) stated that the cause of fatigue is from the excess acidic ions released during rapid carbohydrate turnover. For this reason Noakes has also stated that lactate is often misconceived as being responsible for muscle cramps, the stitch, post exercise muscle soreness, and oxygen debt. Although there is still a lot to know about how lactate affects the body, the influence of anaerobic threshold, lactate threshold and/or ventilatory threshold on endurance performance is well understood.

Running economy. Running economy is another component in predicting performance and possibly the most important. Running economy is often defined as the energy demand for a given velocity of submaximal running, and is determined by measuring the steady-state consumption of oxygen and the respiratory exchange ratio (Saunders et al., 2004; Bonacci et al., 2009; Conley & Krahenbuhl, 1980) and can vary among runners by as much as 30% (Daniels, 1985). Different factors affect running economy such as; muscle capacity to store energy, biomechanical factors, technique (stride length), fitness (experience), age, fatigue, nutrition, and temperature (Noakes, 2003; Daniels & Daniels, 1992). Biomechanical factors and technique are related but are still separate factors. The biomechanical factors relate more to the individuals body regarding differences in limb lengths and body weight distribution, while technique would relate to the individuals running form. Coaches will often try to change the athletes running technique to help with the athletes stride, as well as to improve running economy. In some cases changing the running stride can actually decrease running economy because the movement does not feel natural to the athlete. Running economy is trainable throughout a runners career and having good running economy can often make the difference in race performances (Noakes, 2003). With continuous training for many years the body will become more efficient at the movements that are practiced daily and running economy tends to improve with age as the athletes running form becomes more efficient (Krahenbuhl & Williams, 1992). Kyrolainen, Belli, & Komi (2000) stated that subjects trained in endurance running are more economical than their untrained counterparts, yet even with moderate to highly trained subjects there can be intra-individual variations in running economy between 1.5% and 5% (Bonacci et al., 2009).

The concept of running economy is fairly complex, as it is subjective to each athlete. Running economy relates to the amount of oxygen used by the athlete when running at a constant (submaximal) running speed, whereas VO_2max refers to the rate of oxygen use by the athlete when running at the maximum speed that particular athlete can maintain for 5 to 8 minutes (Noakes, 2003). Athletes with better running economy can make up for having a slightly lower VO_2max because the athlete is able to run at a submaximal effort with more ease. When looking at a homogeneous group of distance runners VO_2max is no longer valuable in determining performance, but running economy seems to be able to discriminate in a homogeneous group of long-distance runners (Wilson et al., 2010). Figure 10 illustrates the differences in running economy between two subjects, assuming the subjects have similar VO_2max values it can be seen that Runner B is more economical than Runner A as oxygen consumption is lower at all velocities.

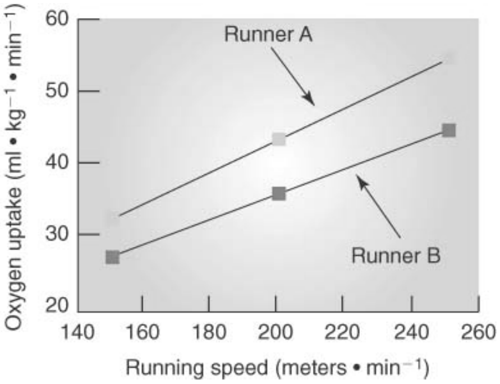


Figure 10. Running economy. An oxygen cost-of-running curve for two subjects. Note the higher VO_2 cost of running at any given running speed for subject A when compared to Subject B, (Powers & Howley, 2009, p. 438).

Daniels (1985) stated that VO_2 related to a particular velocity of running provides a useful way of comparing individuals, or any individual within himself or herself under various conditions. In line with the velocity of running, running economy may be expressed as a percentage of the velocity at VO_2max (vVO_2max). For two athletes with the same VO_2max, if one athlete is a capable of running faster at vVO_2max, he or she would be deemed more economical.

The efficiency of running is crucial to distance runners as it will reduce the energy requirements to complete the movement. Gleim, Stachenfeld and Nicholas (1990) stated that increased metabolic demand from inefficient movement causes additional work for the cardiorespiratory system, thus it is no surprise that running economy plays such a significant role in running performance. Running economy, although it can vary, is possibly the best measurement when testing for aerobic differences. An individual's VO_2max should remain fairly consistent and should be replicated if tested numerous times under similar conditions (VO_2max may vary slightly depending on the season the athlete is currently in, for example base training compared to competition and environmental changes such as altitude). VO_2max is often utilized to determine performance among a heterogeneous group of trained and untrained individuals. Running economy is utilized to determine performance among a homogeneous group, such as elite distance runners.

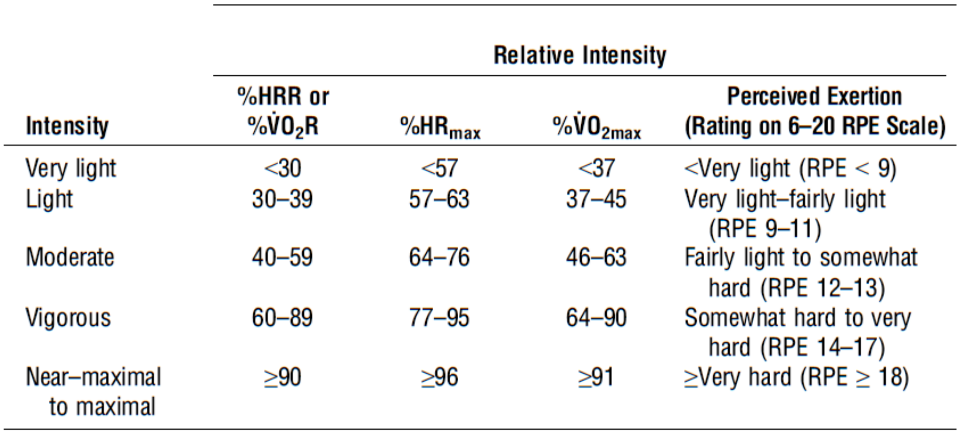
Monitoring heart rate and oxygen consumption. Measuring and monitoring heart rate is a common tool for both researchers and coaches to assess how hard a participant or athlete is working. Monitoring heart rate is important in various settings, such as exercise prescription, performance testing, or athletic training, to ensure that the individual is working at the appropriate intensity. Heart rate can be monitored different ways, with maximal heart rate (HRmax) having an important role in each method. The most accurate way to determine HRmax involves having an individual perform a task that incrementally increases intensity until a maximal effort is reached and heart rate no longer increases. While this method may be the most accurate it is not always appropriate to have an individual perform a maximal test, such as when evaluating a cardiac rehabilitation patient. In these situations, using formulas to predict an individual's HRmax is appropriate. Robergs and Landwehr (2002) provided a few equations, the first equation dates back to 1938 and was put forth by Sid Robinson, HRmax = 212 – 0.77 (age). The second formula, and most popular, HRmax = 220 – age was developed by Karvonen, although in an interview with Robergs and Landwehr in August 2000 Dr. Karvonen indicated that he never published original research for the formula. Inbar et al., (1994) developed a predictive formula based on 1424 healthy Isreali men ranging from 20 to 70 years old. The formula is HRmax = 205.8 – 0.685(age), with an error of 6.4 bpm and deemed as the most accurate formula by Robergs and Landwehr. While the formulas help provide an estimation of an individual's HRmax, Robergs and Landwehr stated that no formula provides acceptable accuracy of heart rate max prediction. While the formulas may not be perfect for HRmax prediction, even with a certain degree of error the formulas can still be useful.

Once an individual's HRmax is determined there are two popular methods used to gauge intensity of exercise. One method is using a percentage of HRmax (% HRmax) and the other method is developed by Karvonen, Kentala and Mustala (1957) and expresses work rate as a percentage of the range of pulse available. The range of pulse available refers to the beats per minute of the heart when the difference between HRmax and resting heart rate (RHR) is determined. This method was not uniquely defined, although Karvonen and Vuorimaa (1988) refer to it as working heart rate (HRwork), the formula has since been referred to as percentage of heart rate reserve (% HRR) or simply as the Karvonen method. One of the main issues regarding using % HRmax is that a person at rest has a nonzero heart rate (Swain & Leutholtz, 1996). The nonzero heart rate at rest becomes an issue with gauging intensity at the lower end of exercise intensity. For example, an individual with a HRmax of 200 bpm working at an intensity of 20% would involve a heart rate of 40 bpm, which is lower than most individual's RHR. To help correct the method of using % HRmax, Karvonen's method incorporated a nonzero heart rate by including an individual's RHR. Taking the difference between HRmax and RHR provides HRR, which is then used to determine training intensities. HRR will be multiplied by a percentage of exercise intensity and then added to RHR to determine a working heart rate. This method also allows for an individual to have a 0% intensity, as that would equate to resting values. For examples of HRR intensity levels and comparisons to percentage of maximal heart rate refer to Table 2 (American College of Sports Medicine, 1998). The intensity levels are named to relate to the intensity of the exercise, with moderate having a middle range of 40-59% HRR.

$$\text{Target HR} = [\%\ \text{exercise intensity} \times (\text{HRmax} - \text{HRrest})] + \text{HRrest}$$

Table 2

Heart Rate Reserve Training Zones



	Relative Intensity			
Intensity	%HRR or $\%\dot{V}O_2R$	$\%HR_{max}$	$\%\dot{V}O_{2max}$	Perceived Exertion (Rating on 6–20 RPE Scale)
Very light	<30	<57	<37	<Very light (RPE < 9)
Light	30–39	57–63	37–45	Very light–fairly light (RPE 9–11)
Moderate	40–59	64–76	46–63	Fairly light to somewhat hard (RPE 12–13)
Vigorous	60–89	77–95	64–90	Somewhat hard to very hard (RPE 14–17)
Near–maximal to maximal	≥90	≥96	≥91	≥Very hard (RPE ≥ 18)

Note. Adapted from Garber et al. (2011)

Oxygen consumption can also be used to measure the intensity of exercise. Heart rate and VO_2 are linearly related over a wide range of submaximal intensities (Achten & Jeukendrup, 2003), but some consideration needs to be taken when determining exercise intensities. Similar to monitoring heart rate, oxygen consumption has two common methods for determining exercise intensity. The first method is using a percentage of VO_2max (% VO_2max), but similar to % HRmax, the formula does not account for a nonzero value when at rest (Swain & Leitholtz, 1996). Another issue that was identified was that % HRmax and % VO_2max did not match, especially at lower intensities. Similar results were found between Londeree and Ames (1976) and Swain, Abernathy, Smith, Lee and Bunn (1994), where 74% and 76% of HRmax was equivalent to 60% of VO_2max, respectively. Swain and Leutholtz (1996) indicated that a small discrepancy between %HRR and %VO_2max resulted in a greater error in exercise intensity. The example provided by the researchers stated a 7 percentage point difference in the 35% HRR versus 42% %VO_2max translates to a 7/35 = 20% error in exercise intensity. To help minimize the error in exercise intensity another method was developed which applied the Karvonen method for HRR to incorporate oxygen consumption. Similar to HRR, oxygen consumption reserve (VO_2R) utilizes a nonzero value for resting oxygen consumption as well as a maximal value.

$$\text{Target } VO_2 = [\% \text{ exercise intensity X } (VO_2\text{max} – VO_2\text{rest})] + VO_2\text{rest}$$

Utilizing this method, Swain and Leutholtz (1996) and Swain, Leutholtz, King, Haas and Branch (1998) found that % HRR is more closely matched to percent of oxygen consumption reserve (% VO_2R), not to percent of VO_2max in an incremental bicycle ergometer test and running test, respectively. More recent research from Mendez-Villanueva, Landaluce, Garcia, Terrados and Bishop (2010) used surfers and found an inaccuracy between % HRR and % VO_2R during a prone arm-paddling exercise. The researchers also found that % HRR and % VO_2peak underestimated VO_2 as well. The results of the study contradict the results presented by Swain and Leutholtz and Swain et al., but this may be due to the participants used as well the type of exercise used, as the study utilized an upper-body exercise.

Although some discrepancies exist in the research, there is still some practical importance to the relationship between heart rate and oxygen consumption. While the comparison may not be perfect, using HRR can help a coach or athlete estimate VO_2 at different training intensities. Assuming HRR and VO_2R are similar during exercise, these measures could also be useful for recovery measurements. The use of HRR also has more of a practical application compared to VO_2R as determining oxygen consumption values requires sophisticated equipment and laboratory testing, while heart rate can be measured in the field.

Research Problem

Performing a warm-up is common practice in the world of athletics, as coaches and athletes believe that by doing so will help prepare the athlete both physically and mentally for training or competition. The primary role of the warm-up is to prime the body's cardiovascular, muscular and neural systems to meet the demands of a specific activity (Curry et al., 2009). There are numerous effects of performing a warm-up, categorized as both temperature related and non-temperature related. The temperature related effects include decreased viscous resistance of muscles and joints, greater release of oxygen from hemoglobin and myoglobin, speeding of metabolic reactions, increased nerve conduction rate and increased thermoregulatory strain (Bishop, 2003a). The non-temperature related effects include increased blood flow to muscles (shunting of blood to active muscles), elevation of oxygen consumption, postactivation potentiation and psychological effects (Bishop, 2003a). While there are numerous effects of performing a warm-up, the understanding of how warm-ups influence performance is still not completely understood.

In order to optimize the effectiveness of a warm-up, research has been conducted on the duration (Genovely & Stamford, 1982), intensity (Stewart & Sleivert, 1998), recovery time (Andzel & Gutin, 1976; Andzel, 1978; Andzel & Busuttil, 1982) and type of warm-up (Škof & Strojnik, 2007; Houmard, Johns, Smith, Wells, Kobe & McGoogan, 1991; Wittekind & Beneke, 2009). Each of these factors plays an important role in how effective performing a warm-up is on athletic performance. While it is understood that these variables influence one another, there is still debate regarding how to optimally improve performance by performing a warm-up. Confounding issues between warm-up intensity, duration and rest intervals become apparent when reviewing the literature. For example, research may indicate that a warm-up of a certain level of intensity proves to be most beneficial but this may be a result of the duration and the rest provided after the warm-up. An issue that becomes evident in regards to the rest period is whether the participants are remaining active or recover by standing still or sitting until the onset of testing. Many athletes will remain active even during recovery before competition, so to have participants perform a stationary or static recovery does not make practical sense.

For middle-distance and long-distance runners (intermediate-duration and long-duration) having an elevated baseline oxygen consumption and improved oxygen dissociation from hemoglobin and myoglobin may be beneficial for optimizing performance. The theory behind endurance athletes starting with elevated baseline oxygen consumption was explained by Andzel and Gutin (1976) and Gutin, Stewart, Lewis and Kruper (1976) and was referred to as the mobilization hypothesis. The mobilization hypothesis states that by starting with elevated baseline oxygen consumption, endurance athletes will rely less on anaerobic metabolism during the onset of exercise thus having a lower O_2 deficit and more anaerobic capacity at the end of an exercise. The athlete must perform a warm-up that allows for increased oxygen consumption but does not lead to fatigue, thus a period of rest is taken after the warm-up. How long a middle-distance and long-distance runner rests after completing the warm up is important, as elevated oxygen consumption is supposed to be a benefit of performing a warm-up but can return close to baseline measures within 90 to 120 seconds of rest (Andzel, 1978). With too much rest the athlete will return to baseline measures, yet with too little rest the athlete may not recover adequately resulting in a decrease in performance. Previous research (Andzel & Gutin, 1976; Andzel, 1978; Andzel & Busuttil, 1982; Andzel, 1982) used warm-ups at 50% VO_2max and found that compared to other rest intervals 30 seconds recovery generally provided the best performance. The warm-up intensity was based on a work rate at 140 beats per minute which was assumed to be approximately 50% VO_2max. The study by Andzel and Busuttil was the only study that used oxygen consumption as a measure but they used untrained participants. The results showed that performance following 90 seconds of rest was significantly worse than no warm-up and a warm-up with 30 seconds recovery, with no differences between no warm-up and 30 second rest. While a brief rest period between 30 and 60 seconds may be optimal for untrained participants, a time range for recovery does not indicate at what heart rate or level of oxygen consumption the participant should start at.

Previous research has outlined some limitations in the methodology when studying aerobic performance and rest intervals. Limitations that have been observed include type of testing, type of warm-up, duration and intensity of the warm-up, type of recovery and lastly the participants used in the studies (refer to Table 3). Limited research was found on warm-up recovery times with the most current dating back to 1982. With the results of various studies it is still unclear to athletes as to when an elevated heart rate and oxygen consumption will provide optimal performance in an endurance task. The focus on rest intervals has been based on the amount of time instead of biological factors the athlete could use in the field, such as heart rate. Since individual athletes warm-up for different durations and at different intensities, making a rest interval based on a specific time may not be appropriate for all athletes. Utilizing the principles of the Karvonen method on heart rate reserve, duration of recovery can be based on the individuals’ heart rate rather than on a time. Since warm-ups should be individualized, it is also necessary to individualize the amount of recovery to help ensure that the athlete performs optimally by eliciting the mobilization hypothesis. The purpose of this study is to examine how recovering to different percentages of heart rate reserve and oxygen consumption reserve after a warm-up affects running performance in distance runners.

Table 3

Aerobic Performance and Rest Intervals

Authors	Subjects	Warm-up	Performance Task	Design	Independent Variables	Dependent Variables	Results
Andzel & Gutin (1976)	12 female (physical education majors)	Bench stepping - 140 bpm ~ 3-5 min	Bench stepping - 9 min - 54 step/min - 1 min all out	1) No PE 2) PE+0 sec rest 3) PE+30 sec rest 4) PE+60 sec rest	- 30-sec intervals - Rest intervals	-Step-ups/ 30 sec -Heart Rate	- PE+30 & PE+60 significantly better than no PE - PE+0 no different from no PE - PE+60 significantly better than PE+0
Andzel (1978)	20 female (field hockey, swimming & basketball)	Treadmill - 140 bpm ~ 3-5 min	Treadmill - 5 mph and % grade to elicit 95-100% HR max	1) No PE 2) PE+30 sec rest 3) PE+60 sec rest 4) PE+90 sec rest 5) PE+120 sec rest (Standing rest)	- Rest intervals	- Total time PT - Heart rate	- PE+30 better than No PE, PE+90, PE+120 - PE+60 better than PE+90
Andzel (1982)	12 males (non-competitive runners)	Treadmill - 120 bpm - 140 bpm ~ no time	One-mile run on running course	1) No PE 2) PE 120 3) PE 140 (30 sec rest, 10 second walk to course)	- Warm-up intensity	- One-mile time - heart rate	- Duncan's range test found PE140 better than PE120 - PE120 and No PE had no difference
Andzel & Busuttil (1982)	8 females	Treadmill -140 bpm ~ no time	Treadmill run to exhaustion at 95-100% VO_2max (corresponding speed and slope)	1) No PE 2) PE+30 sec 3) PE+90 sec	- Rest intervals	- Run time - Heart rate - Oxygen consumption - Ventilation - Oxygen pulse	- No difference between No PE and PE+30 - PE+90 significantly worse than No PE and PE+30

Research Question

Since the warm-up athletes perform can be highly individualized in regards to duration and intensity, it is important for the individual athlete to understand at what point he or she is physiologically ready to perform. Thus, using a generic duration of time to suggest the athlete recovers before competing is not acceptable as individual athletes warm-up differently. While a general length of recovery time may not be the most appropriate for determining potential peak performance preparation, primary (heart rate) and secondary biological measures (oxygen consumption) may prove to be more useful. Therefore, there are two research questions to address. The first research question is; how does recovering to a moderate (~50% HRR) versus light (~35% HRR) intensity level after performing a warm-up influence subsequent performance on a 105% vVO_2max run to exhaustion test in trained middle and long-distance runners? The second question is; does VO_2, expressed as % VO_2R drop in parallel to the drop in HR, expressed as % HHR, when recovering to a moderate (~50% HRR) versus light (~35% HRR) intensity level among middle and long distance runners?

Hypothesis. The first hypothesis is that middle and long-distance runners will run longer during a run to exhaustion test when heart rate and oxygen consumption are elevated to a moderate (~50% HRR) compared to a light (~35% HRR) starting intensity level. The hypothesis suggests there is a limited range of elevated oxygen consumption that will benefit the participant based upon the mobilization hypothesis. Recovery from the warm-up to moderate (~50% HRR) will be within the 30-60 seconds range, which current literature indicated to be optimal. Recovery to light (~35% HRR) will have an extended recovery period, which may not benefit performance. With too much recovery, starting heart rate and rate of oxygen consumption will be too low, thus not providing an aid to performance. Similarly, if the rest is too short the athlete will not recover adequately and this may be detrimental to performance. The second hypothesis is that theoretically there should be no differences between the percentages of HRR and VO_2R at each intensity level, based on the findings of Swain and Leutholtz (1996) and Swain et al., (1998).

Methodology

Participants

The study was approved by the Lakehead University Research Ethics Board. Purposive and convenience sampling was used to recruit eighteen (nine male and nine female) trained middle and long-distance runners from the Lakehead University varsity track-and-field team and the Lakehead Athletics Club. Two of the participants (one male and one female) were excluded from results due to illness during testing, resulting in a final sample size of sixteen. All participants were considered trained runners, as they all had at least 2 years of training experience, competed in the last 6 months, and practiced 4-6 days a week at a volume of at least 50 kilometres per week.

Testing took place at the end of the varsity cross-country running season in the Fall of 2011, and nine of the sixteen participants had competed at the Ontario University Athletics championships the weekend before the start of testing. Participants were provided with a Participant Information Letter (Appendix A) prior to testing to inform them of the purpose of the study. Participants were also required to complete a Consent Form (Appendix B), a Physical Activity Readiness Questionnaire (PAR-Q) (Appendix C), a Maximal Exertion Testing Pre-participation Screening Questionnaire (Appendix D) and required to sign a Maximal Exercise Assessment Checklist (Appendix E). Additionally, participants were required to provide athletic background information on the Data Collection Sheet (Appendix F) indicating: birth date, years of experience, level of experience, kilometres per week, event times ranging from 800 m to 10 000 m, most current injury and recurring injuries (if any), height, mass, and body mass index. Descriptive measures are provided in Table 4.

Table 4

Descriptive Measures

Measures	Males	Females	All
Age (years)	21 ± 4	21 ± 1	21 ± 3
Height (m)	1.80 ± 0.10	1.67 ± 0.06	1.74 ± 0.11
Mass (kg)	69.8 ± 6.7	56.0 ± 4.8	62.9 ± 9.1
BMI (kg/m^2)	21.4 ± 1.3	20.2 ± 1.5	20.8 ± 1.5
1500-m Time (sec)	251 ± 8	289 ± 6	264 ± 20
3000-m Time (sec)	554 ± 20	629 ± 10	583 ± 41
VO$_2$max (ml/kg/min)	67.0 ± 7.8	56.4 ± 5.4	61.7 ± 8.5
Resting VO$_2$ (ml/kg/min)	4.1 ± 0.4	4.8 ± 1.1	4.5 ± 0.9
HRmax (bpm)	194 ± 10	193 ± 9	193 ± 9
Resting HR (bpm)	56 ± 8	64 ± 5	60 ± 8

Procedures

Participants completed all testing in the Exercise Physiology Laboratory (SB1025) in the C.J. Sanders Fieldhouse at Lakehead University. The testing consisted of three sessions, which occurred with approximately 48-hours between each and at approximately the same time of day. Intra-individual variation in running economy was minimized by wearing the same footwear, same clothing, and in a non-fatigued state (Morgan, Craib, Woodall et al., 1994; Morgan & Craib, 1992; Williams, Krahenbuhl, & Morgan, 1991). Each testing session was performed a day after an easy run or recovery day. Participants were asked to maintain a normal diet the days prior to testing and to treat preparation testing the same as preparing for a race. The first session involved a treadmill accommodation period and a VO$_2$max test. The second and third sessions were dedicated to testing run performance with an elevated baseline oxygen consumption. A control condition in which no warm-up was performed was not included in this investigation. This is because an athlete of this level would always perform a warm-up prior to training or competition.

Session 1: treadmill accommodation and VO$_2$max. Session 1 started by recording resting baseline measurements for oxygen consumption and heart rate. Resting baseline measurements for oxygen consumption and heart rate were recorded using the Cosmed Fitmate^{TM} PRO breath-by-breath metabolic cart by having the participant sit at rest for 3- to 5-minutes. The treadmill accommodation period was adapted from Morgan, Martin, Krahenbuhl and Baldini (1991). Male participants completed three 10-minute runs at 3.33 m/s (12 km/h), while females ran at 2.78 m/s (10 km/h), with 5-minute rest periods separating each run. The treadmill used for all testing was the Quinton Instruments Model 620 treadmill. The treadmill incline was set at 1% for all tests and warm-ups, as Jones and Doust (1996) found that for running economy testing at a grade of 1% most accurately reflects the energetic costs of over ground running. During the treadmill accommodation period participants were instructed and practiced how to properly get on and off the treadmill. No participants felt the need for further treadmill accommodation and all participants stated that they felt comfortable and stable on the treadmill.

Following the treadmill accommodation period, participants were provided with a 10-minute active recovery before completing an incremental run to volitional exhaustion to determine VO_2max. During the 10-minute recovery, participants were encouraged to perform any pre-race exercises or stretches needed to prepare for VO_2max testing. The Fitmate^{TM} PRO was used to record heart rate and oxygen consumption during the VO_2max test and running performance sessions. Heart rate data was collected using a Polar RS410 heart rate monitor band and was recorded directly to the Fitmate^{TM} PRO. In addition to oxygen consumption (ml/kg/min) and heart rate (bpm), the Fitmate^{TM} PRO recorded ventilation (l/min), oxygen consumption (ml/min), respiratory frequency (l/min), and fraction of oxygen expired (%). The Fitmate^{TM} PRO has an O_2 accuracy of 1 mBar (circa 0.03% O_2 at 760 mmHg PB), and < 2% flowmeter accuracy for flow and volume. Breath-by-breath analysis provides immediate results and measures for the entire duration of testing. The Fitmate^{TM} PRO was designed to measure oxygen consumption and energy expenditure using a turbine flowmeter attached to a Hans Rudolph V-mask to measure ventilation. The galvanic fuel cell oxygen sensor within the Fitmate^{TM} PRO analyzes the fraction of oxygen in expired gases (Nieman et al., 2006). Sensors in the machine measure humidity, temperature, and barometric pressure for use in internal calculations. Research has found that the device provides valid and reliable results. Lee, Bassett, Thompson and Fitzhugh (2009) stated that the Fitmate^{TM} provides reasonably good estimates of VO_2max, and that measuring submaximal VO_2, rather than predicting it from ACSM metabolic equations, improves the prediction of VO_2max. Nieman et al. (2006) found no significant differences between predicted submaximal VO_2 values from the Fitmate^{TM} PRO when compared to a maximal test using the Douglas Bag method. Measures of heart rate and oxygen consumption are assumed to be valid and reliable.

VO_2max testing. The protocol for determining VO_2max was adopted from Wittekind and Beneke (2009) having participants start testing at 10 km/h, with an increase in velocity of 1.4 km/h every 3-minutes. The protocol was modified for females participants by having them start at one stage lower (8.6 km/h). VO_2max testing used 1% grade throughout the entire test (see Table 5). This VO_2max test can be longer in duration, but the first few intervals (0 to 9-minutes) is relatively easy for the trained runners. The protocol is also useful for monitoring changes in oxygen consumption and ventilation to approximate anaerobic threshold. All participants were instructed and encouraged to run to exhaustion or until they did not want to continue.

Table 5

VO_2max Testing Protocol

Time (minutes)	Males Velocity (km/h) [mph]	Females Velocity (km/h) [mph]	Slope (%)
0-3	10.0 [6.2]	8.6 [5.3]	1
3-6	11.4 [7.1]	10.0 [6.2]	1
6-9	12.9 [8.0]	11.4 [7.1]	1
9-12	14.3 [8.9]	12.9 [8.0]	1
12-15	15.8 [9.8]	14.3 [8.9]	1
15-18	17.2 [10.7]	15.8 [9.8]	1
18-21	18.6 [11.6]	17.2 [10.7]	1
21-24	20.1 [12.5]	18.6 [11.6]	1
24-27	21.5 [13.4]	20.1 [12.5]	1

Metabolic data were recording using the Fitmate^{TM} PRO over the duration of the test. Three benefits of this VO_2max protocol include: an estimation of running economy at different velocities, an indication of anaerobic threshold, and a velocity at VO_2max (vVO_2max).

Sessions 2 and 3: running performance testing starting at 35% and 50% HRR. The second and third sessions involved having the participants complete a warm-up followed by a performance task. The warm-up performed by the participants was the same for each session and was structured to simulate a warm-up that a middle- or long-distance runner might perform prior to competition.

Warm-up and recovery. Following baseline measurements, participants completed a 15-minute warm-up run on the treadmill at a velocity that elicited 60% of HRR. A warm-up at 60% of VO_2max was utilized by Wittekind and Beneke (2009), which did not significantly elevate lactate beyond resting levels. The warm-up intensity for this study was based on HRR instead of VO_2max for reasons previously discussed. At the end of the 15-minute warm-up, participants had a 1-minute active rest before completing six 15-second strides on the treadmill with 1-minute active recovery between strides. The velocities for the strides were determined from the velocity at VO_2max (vVO_2max) during the VO_2max test session. The strides were performed at 95, 100 and 105% vVO_2max, with two strides being completed at each velocity. The active recovery between the 15-minute warm-up run and the strides had participants step off the testing treadmill and onto a recovery treadmill (Sensor Medics Horizon) set at a walking speed of 3 km/h. Wittekind and Beneke had participants perform a similar warm-up, but used six 15-second strides at 105% VO_2max with 1-minute standing rest between each stride and 5-minutes after the last stride. Performing the strides was considered to be the specific portion of the warm-up, as it allowed the participant to experience running at the testing velocity of 105% of VO_2max. After the last stride was completed, participants had an active recovery on the recovery treadmill until a heart rate was reached that corresponded with the appropriate starting work rate. Participants recovered until heart rate reached either 35 or 50% HRR before starting the performance test. The HRR values were chosen to have one measure that is closer to baseline and to have one high enough to elicit the mobilization hypothesis. The 35% HRR recovery time is assumed to be approximately 120-seconds, while the 50% HRR recovery time is expected to be between 30-seconds and 60-seconds. The two sessions were counter-balanced among the participants with half recovering to 35% and then 50% of HRR, and the other half recovering to 50% followed by 35%. Additionally, participants were randomly assigned to the protocols.

Performance task. The performance task required the participant to run at a constant speed that corresponded with 105% VO_2max to simulate middle distance running race pace (Wittekind & Beneke, 2009). This performance task was chosen because it required the participant to run to exhaustion, as well as utilizing both aerobic and anaerobic energy systems. The time to exhaustion was measured to the nearest second and testing was terminated when the participant indicated he or she was no longer able to continue and grasped the treadmill hand rails. The effort of the performance task should be similar between males and females, resulting in similar run to exhaustion times. Measurements from the Fitmate^{TM} PRO were recorded throughout the entire testing period, including heart rate.

Filtering of Oxygen Consumption Data

After recording the oxygen consumption data using the Fitmate^{TM} PRO, it was necessary to filter the data to remove the random noise from the signal. Currently, there are no universally accepted procedures for processing data acquired from breath-by-breath indirect calorimetry or from time averaged systems (Robergs, Dwyer & Astorino, 2010). There are number of methods which have been proposed to filter oxygen consumption data, such as time averages or a running average of breaths and digital filtering. Time averages are commonly used and an average of no longer than 30-seconds is recommended (Robergs et al, 2010). Alternatively, Robergs et al (2010) recommends using a 15-breath running average for breath-by-breath systems. Issues arise depending on the type of equipment that is used for research, for example, the Fitmate^{TM} PRO does not provide a true second to second measurement and number of breaths is measured as respiratory frequency in l/min. Data could be manipulated through digital filtering in order to interpolate missing values, but manipulating the data too much raises concerns as well.

A moving average deemed to be the appropriate method to reduce the noise in the raw data. A 9-point moving average was chosen to smooth the data without introducing systematic bias. The time scale of the raw data fluctuated and was inconsistent, making the 9-point moving average range from 10-seconds to 45-seconds. After the raw data had been filtered, VO_2max was determined as the highest value found during the final stage of VO_2max test or during the performance task. To determine the recovery VO_2, the lowest value found after the final stride and before performance task started was recorded.

Data Analysis

Descriptive statistics, including means and standard deviations, were calculated for all measures. Physiological responses (VO_2max, HRmax, RVO_2 and RHR) for VO_2max testing and the run to exhaustion tests were tested for Type 1 error using one-way repeated measures ANOVA. A scatter plot was used to display the recovery time and run to exhaustion time of each participant for both 35% and 50% heart rate recovery zones. 95% confidence limits for heart rate and recovery time were calculated for each recovery zone. A paired samples t-test was used to determine if there was a difference in the performance on the standardized treadmill test. The independent variable was recovery intensity (moderate vs. light) and the dependent variable was time to exhaustion on the treadmill test. In order to compare heart rate reserve and oxygen consumption reserve during recovery, the observed VO_2R (%) values at the start of the performance task were compared to the HRR values of 35% and 50% using one-sample χ^2 goodness-of-fit tests. Alpha was set at $p \leq 0.05$ for all analyses. Since multiple variables were compared for the repeated measures ANOVA, a Bonferroni adjustment was made for the α value. Therefore, the significance level for all statistical analyses was set at $p \leq 0.013$.

Results

Descriptive statistics (means and standard deviations) for run to exhaustion time, recovery time, heart rate reserve and observed oxygen consumption reserve are presented in Table 6. Comparisons were made among the two testing sessions and the VO_2max testing session to see if there were any differences in the physiological measures using one-way repeated measures ANOVA (Table 7). The results for VO_2max indicated that there were no significant differences among the three sessions, $F(2, 30) = .324$, $p = .726$. The results for HRmax, however, indicated that there was a significant difference, $F(2, 30) = 15.686$, $p = .000$. A Bonferroni post hoc test was used to determine where the differences are between the three sessions. The test found VO_2max testing heart rate was significantly higher from 35% HRR recovery trial but not the 50% HRR recovery trial, $p = .000$ and $p = .020$, respectively. There was, however, no significant difference between the HRR recovery trials, $p = .060$. Additionally, heart rates for session two and session three were compared regardless of recovery conditions using a paired samples t-test. Results indicated no significant difference between sessions, $t(15) = .46$, $p = .653$. There were no significant differences in resting VO_2 and resting heart rate between trials, $F(2, 30) = .815$, $p = .452$ and $F(2, 30) = 1.711$, $p = .198$, respectively.

Table 6

Descriptive Statistics for Run Time, Recovery Time, HR and VO_2

	35% Trial	50% Trial
REX Time (sec)	168 ± 49	178 ± 65
REC Time (sec)	137 ± 92	69 ± 20
HR (bpm)	107 ± 6	127 ± 6
VO_2 (ml/kg/min)	14.1 ± 6.4	19.1 ± 5.2

Note. REX Time = run to exhaustion time, REC Time = recovery time, HR = heart rate, and VO_2 = oxygen consumption.

Table 7

Physiological Measures

	VO_2max Testing	35% Trial	50% Trial
VO_2max (ml/kg/min)	61.7 ± 8.5	60.8 ± 9.0	61.5 ± 9.6
HRmax (bpm)	193 ± 9	188 ± 9	190 ± 9
RVO_2 (ml/kg/min)	4.5 ± 0.9	4.7 ± 0.9	4.8 ± 0.8
RHR (bpm)	60 ± 8	63 ± 8	62 ± 8

Note. VO_2max = maximal oxygen consumption, HRmax = maximal heart rate, RVO_2 = resting oxygen consumption and RHR = resting heart rate.

Table 8

95% Confidence Intervals for Recovery Time and Heart Rate Reserve

			95% Confidence Interval	
	Mean	Std. Error	Lower Bound	Upper Bound
35% - Recovery Time (sec)	137	23.35	87	187
50% - Recovery Time (sec)	69	4.35	59	78
35% HRR (bpm)	107	1.51	104	110
50% HRR (bpm)	127	1.58	124	130

A scatter plot provides a graphical representation of the run to exhaustion time and recovery time (Figure 11), and 95% confidence intervals for recovery time and heart rate reserve are provided in Table 8. When comparing the run times for the two performance tests, the results indicated that the participants ran approximately 10-seconds longer during the 50% HRR recovery trial compared to the 35% HRR recovery trial, but this difference was not statistically significant, t (15) = -1.016, p = .326. Eleven of the sixteen participants (four male and seven female) ran longer during the 50% HRR recovery trial compared to the 35% HRR recovery trial. Paired samples t-tests were also used to compare recovery time, recovery heart rate and recovery oxygen consumption between the 35% HRR recovery trial and 50% HRR recovery trial. Significant differences were found for recovery time (t (15) = 3.426, p = .004) with the 35% HRR recovery trial being significantly higher than the 50% HRR recovery trial. Recovery heart rate was significantly higher in the 50% HRR recovery trial (*t* (15) = -49.451, *p* = .000) and recovery oxygen consumption was also significantly higher in the 50% HRR recovery trial (*t* (15) = -2.978, *p* = .009).

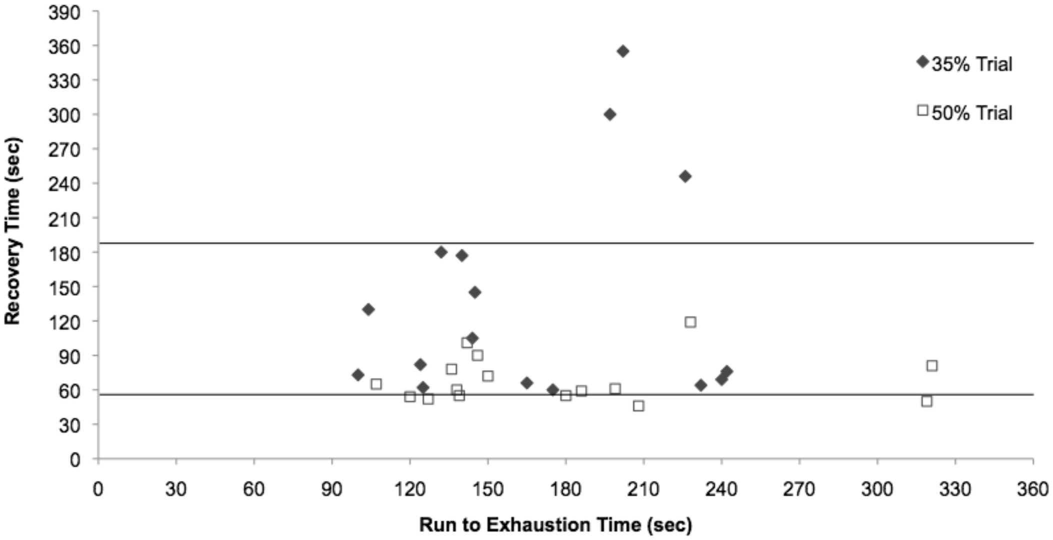


Figure 11. Run to exhaustion and recovery times. The figure illustrates the run to exhaustion times in relation to the participant's recovery time. The upper line represents the upper bound recovery time from the 35% trial and the lower line represents the lower bound recovery time from the 50% trial.

Further analysis was performed on run to exhaustion times to test for gender differences. A 2 x 2 repeated measures ANOVA was used to further investigate the differences in run to exhaustion time by comparing gender differences between the trials. The independent variables are gender (male and female) and run to exhaustion trial (35% trial and 50% trial), with the dependent variable being run to exhaustion time. Similar ANOVAs were performed for recovery time, recovery heart rate and recovery oxygen consumption as the dependent variables. Accordingly, alpha was adjusted to $p \leq 0.013$ to correct for the number of dependent variables. The results of the ANOVA were the same as the paired t-test having no significant difference between the 35% and 50% trial, *F* (1, 14) = .963, *p* = .343, but there was a significant difference between gender, *F* (1, 14) = 8.212, *p* = .012, (see Table 9). The ANOVA for run to exhaustion had no interaction effect, but main effects were found for both Factor A (gender) and Factor B (trial). Run to exhaustion time was higher for males, Factor A main effect. The 50% HRR recovery trial had a longer run time than the 35% HRR recovery trial, The Factor B main effect. A graphical representation of the difference in run to exhaustion time between trials and between genders can be seen in Figure 12. Since there was no treatment effect it is acceptable to pool males and females into one group.

Table 9

Analysis of Variance

	df	F	Sig.
Run Time	1	.963	.343
RunTime*Gender	1	.000	.915
Gender	1	8.212	.012
Recovery Time	1	11.068	.005
RecTime*Gender	1	.143	.711
Gender	1	1.293	.275
Recovery HR	1	2950.358	.000
RecHR*Gender	1	4.098	.062
Gender	1	2.029	.176
Recovery VO_2	1	8.311	.012
RecVO_2*Gender	1	.057	.814
Gender	1	31.218	.000

Table 10

Gender Comparison for Run Time, Recovery Time, HR and VO_2

	35% Trial		50% Trial	
	Male	Female	Male	Female
REX Time (sec)	200 ± 42	136 ± 32	210 ± 73	146 ± 36
REC Time (sec)	118 ± 97	156 ± 90	57 ± 11	80 ± 22
HR (bpm)	104 ± 7	109 ± 5	125 ± 7	129 ± 5
VO_2 (ml/kg/min)	18.1 ± 6.3	10.1 ± 3.2	22.7 ± 3.7	15.5 ± 3.8

Note. REX Time = run to exhaustion time, REC Time = recovery time, HR = heart rate, and VO_2 = oxygen consumption.

Table 11

Gender Comparison for Physiological Measures

	VO_2max Testing		35% Trial		50% Trial	
	Male	Female	Male	Female	Male	Female
VO_2max (ml/kg/min)	67.0 ± 7.8	56.4 ± 5.4	68.4 ± 3.3	53.2 ± 5.7	69.3 ± 4.6	53.7 ± 5.9
HRmax (bpm)	194 ± 10	193 ± 9	187 ± 9	189 ± 8	189 ± 10	192 ± 7
RVO_2 (ml/kg/min)	4.1 ± 0.4	4.8 ± 1.1	4.7 ± 1.0	4.7 ± 0.8	5.0 ± 1.2	4.7 ± 0.4
RHR (bpm)	56 ± 8	64 ± 5	59 ± 9	67 ± 7	60 ± 9	65 ± 5

Note. VO_2max = maximal oxygen consumption, HRmax = maximal heart rate, RVO_2 = resting oxygen consumption and RHR = resting heart rate.

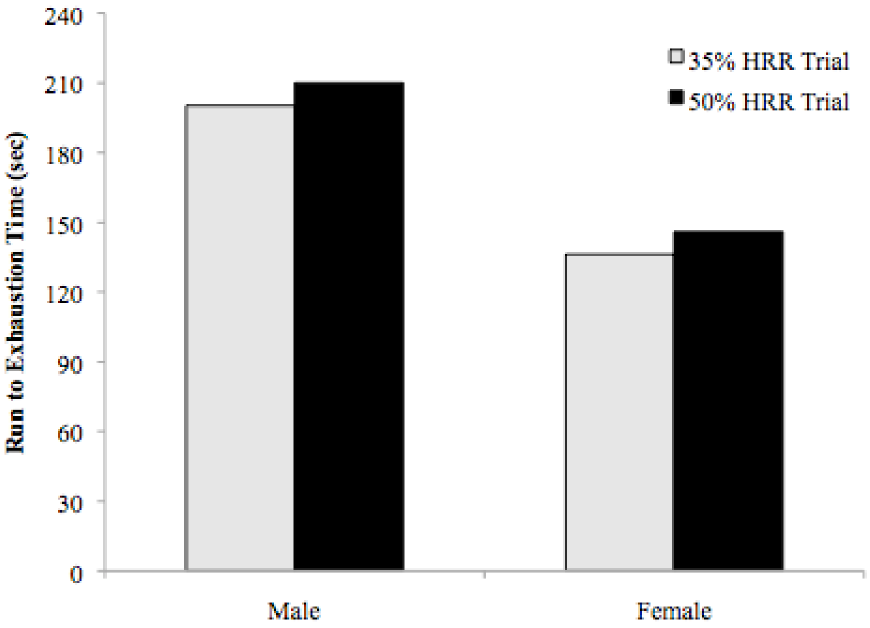


Figure 12. Gender differences in run to exhaustion time. The graph illustrates the differences between the run to exhaustion time for the 35% HRR recovery trial and 50% HRR recovery trial; as well as the difference between males and females.

Oxygen consumption for recovery was measured when the participant's heart rate reached 35% HRR and 50% HRR, the value was then converted into a percentage of VO_2R for comparison (Table 13). Participants oxygen consumption was approximately 16.4% VO_2R when recovered to 35% HRR, and oxygen consumption was approximately 25.5% when recovered to 50% HRR. Results from the one-sample χ^2 goodness-of-fit test indicated that there was a significant difference between HRR percentage and VO_2R percentage during recovery to both 35% and 50%, χ^2 (1, 16) = 5.11E-36 and χ^2 (1, 16) = 7.22E-38, respectively. VO_2R percentages were also significantly different during the warm-up (50% compared to 60%) for the 50% HRR recovery trial, χ^2 = (1, 16) = .000 (Table 14).

Table 12

Descriptive Statistics for Oxygen Consumption Reserve (%)

	35% HRR Recovery Trial	50% HRR Recovery Trial
Recovery (%)	16.4 ± 10.7	25.5 ± 9.0
Warm-up (%)	53.4 ±_7.2	50.1 ± 7.6

Table 13

Chi-Square Goodness-of-Fit

	All Participants
35% VO_2R	5.11E-36
50% VO_2R	7.22E-38
60% VO_2R – 35% Trial	.059
60% VO_2R – 50% Trial	.000

Discussion

Warm-ups are performed to prepare the body for the demands of a specific activity. A number of physiological changes, both temperature and non-temperature related, occur within the body in order to prepare the cardiovascular, muscular and neural systems. The basis of this research was on the non-temperature related effect of elevated baseline oxygen consumption, also referred to as the mobilization hypothesis (Andzel & Gutin, 1976). The purpose of this study was to test how recovering to different percentages of heart rate reserve and oxygen consumption reserve after a warm-up affected the subsequent performance in distance runners.

Participants did not run significantly different times between recovering to 35% HRR and 50% HRR, although it was hypothesized that recovering to 50% HRR would result in longer run to exhaustion times compared to 35% HRR. The results of the study indicate that the recovery heart rate and oxygen consumption, as well as recovery time, do not significantly change performance during a run to exhaustion. Resting and maximal values for heart rate and oxygen consumption were the same between HRR recovery trials, but the recovery heart rate and oxygen consumption were significantly higher for the 50% HRR recovery trial. Although the recovery heart rate and oxygen consumption were significantly different between trials, the observed oxygen consumption values were still significantly lower than the expected values.

Based on the statistical results of the study there is no clear evidence as to whether the mobilization hypothesis occurred or not. One explanation would be that the mobilization hypothesis did not occur when participants recovered to 50% HRR compared to 35% HRR. Stating the mobilization hypothesis did not occur could then be attributed to the VO_2R values being significantly lower than expected after recovery. The oxygen consumption may have been too close to baseline or at least not high enough to see a change in performance. An alternative explanation is that both recovery trials may have had a mobilized system but there were no significant differences between the trials. Since the procedures did not include a “no warm-up” trial or a trial with a recovery back to baseline it is difficult to state which explanation occurred. Although not a statistically significant difference, the 50% HRR recovery trial was 10-seconds longer than the 35% HRR recovery trial across participants, a performance improvement of approximately 6%. To help explain the results of this study to previous research it is required to look at both the warm-up and recovery time.

Warm-up

The warm-up used in this study was adapted from Wittekind and Beneke (2009), as the warm-up was appropriate for a laboratory setting but also a warm-up an athlete could perform before a race. There is a possibility that the warm-up is not an adequate warm-up to facilitate the mobilization hypothesis as Wittekind and Beneke found there were no significant differences in run to exhaustion performance when a similar warm-up was compared to a lighter warm-up and no warm-up. However, the warm-up had roughly an 8% improvement compared to no warm-up but was roughly 2% worse than the lighter warm-up. The warm-ups were followed by a 5-minute standing rest which may have also influenced possible benefits of the mobilization hypothesis.

In comparison, previous studies (Andzel, 1976; Andzel & Busuttil, 1982; Andzel & Gutin, 1976) had participant’s warm-up to 140 bpm, as this was associated with an intensity of approximately 50% VO_2max. Once the participant reached steady state at 140 bpm this intensity was held for 1-minute and then followed by the recovery duration. This type of warm-up likely would not be performed by many athletes and it also assumes that all participants are at the same relative intensity when at 140 bpm. Excluding the strides, the warm-up intensity was similar between this study and previous studies, with an average warm-up heart rate of 140 bpm. This study differed from previous studies by using HRR to determine warm-up intensity and it was found that heart rates ranged from 127 to 151 bpm for 60% HRR. Based on the results of previous research there may be benefits with recovering from a steady state effort as Wittekind and Beneke saw the best run to exhaustion time after performing 10-minute jog at 60% VO_2max.

Recovery Time

There was considerable variability in recovery times, not only between trials but also within each trial. The 35% HRR recovery trials averaged approximately 137-seconds, which may be too much recovery time to benefit performance (Andzel, 1978; Andzel & Busuttil, 1982). The recovery times within the trials ranged from 355-seconds to 60-seconds, resulting in a large standard deviation of 92-seconds. The 50% trials averaged approximately 69-seconds for recovery and is within the 30-second and 60-second recovery recommendations (Andzel 1978, Andzel & Busuttil, 1982; Andzel & Gutin, 1976). Compared to the 35% trials, the 50% trials had a much smaller range in recovery times ranging from 119-seconds to 46-seconds, resulting in a much smaller standard deviation of 20-seconds.

Recovery time recommendations were to be based on 95% confidence intervals to encompass the majority of the population and to remove outliers. Recommendations for recovery duration could be based on the statistical significance or the practical significance of the results. Since there was no significant differences in run to exhaustion times a broader recovery period could be recommended. The recovery period uses the lower bound value from the 50% HRR recovery trials and the upper bound value from the 35% HRR recovery trials, resulting in a range from 59-seconds to 187-seconds. Similarly, a heart rate range could take the lower bound value from the 35% HRR recovery trials and the upper bound value from the 50% HRR recovery trials ranging from 104 to 130 bpm. For practical significance recommendations for recovery time and heart rate may be based on the 50% HRR recovery trial, since there was roughly a 6% increase in performance with that trial. The recovery is more in line with previous research having participants recover for 59-seconds to 78-seconds and to a heart rate of 124 bpm to 130 bpm.

Heart Rate Reserve and Oxygen Consumption Reserve Comparison

The results of the study indicate that during recovery, heart rate may not be an accurate measure to estimate oxygen consumption. Ideally, oxygen consumption would have been the primary measure, as the mobilization hypothesis is based around oxygen consumption. However, due to limitations of the equipment, heart rate was deemed more appropriate as it was easier to track and measure. The level of oxygen consumption did not have a significant impact on performance, but this was measured as a secondary measure and analyzed post testing. Recovery was based on heart rate, with the assumption that using heart rate reserve would provide relatively the same oxygen consumption reserve values for relative intensity (Swain, Leutholtz & King, 1998; Swain & Leutholtz, 1997). The results found that participants started the run to exhaustion performance with a significantly lower percentage of oxygen consumption reserve when compared to heart rate reserve for both the 35% trial (16.4% VO_2R) and 50% trial (25.5% VO_2R). At the start of the performance task participants' oxygen consumption reserve was approximately half of the heart rate reserve. Since oxygen consumption reserve was so low at the start of the performance it is possible that the physiological processes described by the mobilization hypothesis did not occur, or was seen to a very limited extent in the 50% trial.

The differences in oxygen consumption reserve and heart rate reserve values may be attributed to the strides completed during the warm-up. During each stride there was a noticeable spike in both heart rate and oxygen consumption but due to the short duration of the stride oxygen consumption did not reflect the same level of intensity as heart rate. Heart rate and oxygen consumption have similar kinetics during recovery. There is a rapid decrease at the onset of recovery referred to as the fast component, followed by a more gradual decrease which is referred to as the slow component (Burnley, Doust, Carter & Jones, 2001). The fast component of recovery occurs within the first 2-minutes of decreased intensity and if participants did not reach 35% HRR within this time frame recovery was often prolonged. The slow component sees very gradual declines and can at times go down and rebound up slightly. The use of an active recovery does not assist in further decreases while recovering in the slow component. Seven of the sixteen participants had recoveries that were longer than 2-minutes during the 35% HRR recovery trial, while only one participant was close to reaching the slow component during the 50% HRR recovery trial (119-seconds). The variability seen within recovery times is partially a result of variability in recovery kinetics.

Gender Comparison

Although there were significant differences in run to exhaustion times between males and females, the overall results remained the same with no significant differences between 35% trial and 50% trial. The difference in run to exhaustion times may be explained by the differences in oxygen consumption values between males and females. For both trials males started at a higher percentage of VO_2R compared to females. When males recovered to 35% HRR, VO_2R was 22.6%, while females were at 10.9%. The results from the 50% HRR recovery trial were a little less between genders, with males at 29.9% and females at 21.1% but both were still far from the expected 50%. There may be a possibility that the physiological processes of the mobilization hypothesis were seen in males but not in females, as the results from the ANOVA indicated that there was no significant difference between male and female recovery times or for recovery heart rate. However, there was a significant difference found between genders for recovery oxygen consumption and males started performance at a higher baseline oxygen consumption than females.

Conclusion

Research on warm-ups and the effect of temperature on the body has been conducted since the early 1900's. While research has helped to increase our understanding of the physiological processes that occur during a warm-up, there is still research to be done on how to optimize performance through a warm-up. The study was designed to test the mobilization hypothesis by having participants start a performance task at different levels of elevated oxygen consumption. The mobilization hypothesis states that starting a performance with an elevated baseline oxygen consumption will improve performance by reducing the oxygen deficit at the beginning of the task, allowing for greater anaerobic capacity at the end of the task.

The 50% HRR recovery trial was hypothesized to have a longer run to exhaustion time compared to the 35% HRR recovery trial because the shorter recovery would allow for a higher elevated oxygen consumption. The results of the study indicated there was no significant difference in the run to exhaustion time when participants recovered to either 35% HRR or 50% HRR. The recovery time for the 50% HRR recovery trial was significantly shorter than the 35% HRR recovery trial, resulting in significantly higher oxygen consumption and heart rate values for the 50% HRR recovery trial. Oxygen consumption was significantly different between trials, additionally the observed VO_2R percentages were significantly different from the expected percentages. VO_2R percentages were expected to be similar to the HRR percentages, but during recovery the observed VO_2R values were 16.4% for the 35% HRR recovery trial and 25.5% for the 50% HRR recovery trial. The difference in HRR and VO_2R values were likely influenced by the high intensity of the strides during the warm-up. Since participants' oxygen consumption recovery was lower than expected there is a possibility that the physiological processes of the mobilization hypothesis were not witnessed because oxygen consumption was not elevated high enough. Alternatively, the slight increase in oxygen consumption did improve performance, but procedures did not include a no warm-up protocol for comparison.

Practical Applications

The difference in run to exhaustion time between recovery trials was not statistically significant, but there is some practical significance from the results. The performance task at 105% vVO_2max was meant to mimic a middle distance effort (1500-m to 3000-m). The majority of the participants ran longer during the 50% HRR recovery trial compared to the 35% HRR recovery trial, on average 10-seconds longer which is roughly a 6% improvement in performance. This result suggests that being able to run longer after a shorter recovery could translate to better performance during a race. Running 10-seconds longer in the performance task may not translate to running 10-seconds faster in the race, but any performance gain even if it is only 1-second or a stronger finishing kick should be considered valuable. Winning a race can come down to the final seconds of the event and having the ability to push a little harder or run a little longer at a maximal effort could make the difference between being on the podium and being in the crowd. Based on the practical significance of the results, recovery times based on the 50% HRR recovery trial would be recommended as it resulted in improved performance. Additionally, implementing a brief steady state run at the end of the warm-up could assist with elevating oxygen consumption through aerobic systems.

Limitations

- Time of testing: Participants just completed cross-country season, which could have athletes in peak or fatigued condition. Participants were only able to complete testing within a couple of weeks before regular training started again.
- Sample size: Limited to the number of athletes on the Lakehead University cross-country

team and Lakehead Athletic Club.

- Equipment: Cosmed Fitmate^{TM} PRO had no CO_2 analyzer, fixed respiratory quotient and time intervals of 15-seconds. There were some minor issues with masks fitting properly, heart rate probe connection and flowmeter functioning properly. The Quinton Instruments treadmill dates back to the 1960's and was the only treadmill available capable of the velocities required for testing. The velocity of the treadmill fluctuated when participants were getting on and off of the treadmill, but this was over with the installation of a digital speedometer.
- Procedures: The VO_2max testing protocol may have resulted in lower VO_2max since the VO2max results come from tests approximately 9- to 12-minutes in duration. The performance task was based on the results of VO_2max testing, using VO_2max, HRmax and vVO_2max, and this had the possibility of participants running under or over the desired effort depending on how the participant finished VO_2max testing
- Data filtering: No standardized way of filtering VO_2 data, influences both VO_2max and VO_2R values

Delimitations

The study was delimited to university-level middle- and long-distance runners. Additional endurance athletes, cross-country skiers, cyclists, and masters runners, could have been recruited to increase sample size but would not have been as focused. Only one specific warm-up protocol was employed and only two recovery protocols (based on HRR) were examined. Recovery was based on heart rate reserve not by time or oxygen consumption.

Recommendations for Future Research

Further research is required to understand the relationships between warm-up type, duration, intensity and recovery interval on running performance. Oxygen consumption should be used as the primary measure during recovery when studying the effects of the mobilization hypothesis. Heart rate reserve and oxygen consumption reserve are great methods to standardize and individualize warm-up intensity and recovery duration, but heart rate was not an appropriate method to infer oxygen consumption during recovery. Lastly, updating the equipment in the exercise physiology lab would be beneficial. A running performance treadmill with a harness and a more sophisticated metabolic cart with at CO_2 analyzer would be welcomed upgrades.

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Appendix A

Participant Information Letter

Lakehead University Letterhead School of Kinesiology

David Witiluk and Dr. Derek Kivi
(807) 472-9484
dwitiluk@lakeheadu.ca
Date

Dear Potential Participant,

You are invited to participate in a study "The effect of warm-ups and elevated oxygen consumption on running performance in trained distance runners," conducted by David Witiluk, a graduate student in the School of Kinesiology at Lakehead University, supervised by Dr. Derek Kivi. The purpose of this study is to examine how performing a running task starting at different percentages of heart rate reserve and oxygen consumption reserve influences performance. Heart rate reserve and oxygen consumption reserve are methods of monitoring intensity of an exercise by measuring either heart rate or oxygen consumption. You have been recruited to participate in the study because you are a distance runner competing at the university level.

Prior to participation, you will be required to complete the Physical Activity Readiness Questionnaire (PAR-Q) and sign a consent form. A treadmill accommodation session will be conducted prior to testing to instruct you with proper technique to step on and off the treadmill, as well to establish stable treadmill running mechanics. The accommodation session involves running on the treadmill at an easy pace (12 km/h for males and 10 km/h for females) for three 10-minute intervals, with 5-minute breaks between intervals. The accommodation session will provide you with a chance to become more comfortable with running on the treadmill. In addition, some basic descriptive measures including birth date, gender, height, weight, body mass index, resting heart rate, resting oxygen consumption, event focus, years of experience and kilometers per week will be recorded. Following the treadmill accommodation session, you will complete an incremental treadmill run to exhaustion to calculate your maximal oxygen uptake (VO_2max), velocity at VO_2max (vVO_2max), maximal heart rate (HRmax) and estimate anaerobic threshold. The VO_2max testing involves running 3-minute intervals at a grade of 1% with a starting velocity of 10 km/h for males and 8.56 km/h for females increasing by 1.44 km/h every 3-minutes until exhaustion. The first testing session will take approximately 1-hour to complete.

The next two sessions involve performing a standardized warm-up, followed by a running performance task. The warm-up will be 15-minutes and performed at a velocity that will illicit 60% of your individual heart rate reserve (HRR), followed by six consecutive 15-second strides of increasing intensity (2 x 95, 100, and 105% vVO_2max) with 1-minute active recovery between strides. Once the warm-up is completed you will step on to another slower moving treadmill and walk for an active recovery period. On separate test sessions you will recover until heart rate reserve reaches 35% and 50%, at which time you will begin the running performance task. The performance task involves a run to exhaustion at a velocity of 105% vVO_2max, which is approximately the intensity involved with middle-distance races. Once testing is completed you will be encouraged in completing a 15-minute cool down jog, either on the treadmill or outside. Performance testing sessions should take approximately 45-minutes to 1-hour to complete.

Participation in the study is entirely voluntary and you may refuse to participate or withdraw from the study at any time. You also may decline to answer any of the questions seen in the questionnaire. Potential risks in this study are similar to those that would be seen during running, and include possible muscle strains and ligament sprains. The testing involves running to exhaustion, which would be similar to competition and should not cause any muscle pain or soreness that you would not experience through regular training or competition. The potential benefits of the study are to better understand how much recovery and at which heart rate will help improve aerobic performance, as well as values for VO_2max and anaerobic threshold. The information will be valuable to both coaches and athletes as it may involve altering individual training programs to maximize athletic performance.

Full anonymity and confidentiality will be observed during the course of research and in the dissemination of the results. The participants will not be identified in this study in any way, and their names will not be recorded except upon the consent form, the PAR-Q questionnaire, and the Data Collection Form. Participants will be identified in the data files and the written report with a participant number.

Documentation including but not limited to consent forms and participant data will be collected and securely stored by the researcher and/or advisor during testing. After testing has been completed documentation will be securely stored in a locked cabinet within a locked office at the School of Kinesiology at Lakehead University for the period of no less than 5 years. Electronic documents will also be securely stored on a password-protected computer for the period of no less than 5 years.

It is the researcher's intention to apply for publication of the results of this study. The results will be available to the participants upon request in January 2012.

If you agree to participate in this study, please complete the attached consent form. If you have any questions, please feel free to contact me at 472-9484 or via email at dwitiluk@lakeheadu.ca. This research has been approved by the Lakehead University Research Ethics Board. If you have any questions related to the ethics of the research and would like to speak to someone outside of the research team, please contact Sue Wright at the Research Ethics Board at 343-8283 or swright@lakeheadu.ca.

Thank you for your cooperation.

Yours truly,

David Witiluk, MSc (c), HBK
☎ (807) 472-9484
💻 dwitiluk@lakeheadu.ca

Dr. Derek Kivi, Graduate Supervisor
☎ (807) 343-8645
💻 derek.kivi@lakeheadu.ca

Appendix B

Consent Form

Lakehead University Letterhead School of Kinesiology

David Witiluk and Dr. Derek Kivi
(807) 472-9484
dwitiluk@lakeheadu.ca

The effect of warm-ups and elevated oxygen consumption on running performance in trained collegiate distance runners

1. I, ____________________________ (PLEASE PRINT), agree to participate in this study on warm-ups and running performance. The purpose of this study is to examine how performing a running task starting at different percentages of heart rate reserve and oxygen consumption reserve influences performance. I have read and understand the information in the Participant Information Letter.
2. I understand that I will be required to attend a treadmill accommodation session with VO_2max testing and two testing sessions. I will also be required to provide some athletic background information and complete a PAR-Q prior to participation.
3. I understand that I will be completing an incremental treadmill running test to exhaustion to determine my VO_2max. I understand that I will also complete a warm-up described by the researcher before completing the running performance task. I am aware that information including height, weight, body mass index, birth date, sex, experience, heart rate, and oxygen consumption will all be recorded.
4. I understand that participation in this study is entirely voluntary, and I am able to withdraw from this study at anytime without penalty. I understand that all information that I provide will remain confidential. Data will be securely stored at Lakehead University for a period of 5 years.
5. I have been informed of the tests that I am required to perform in this study and I am aware that with all physical activity and sport, some risk of injury does exist. I understand that risks in participating in this study may include, but are not limited to, possible muscle strains and ligament sprains.
6. I am aware that the research findings will be made available in January 2012.

____

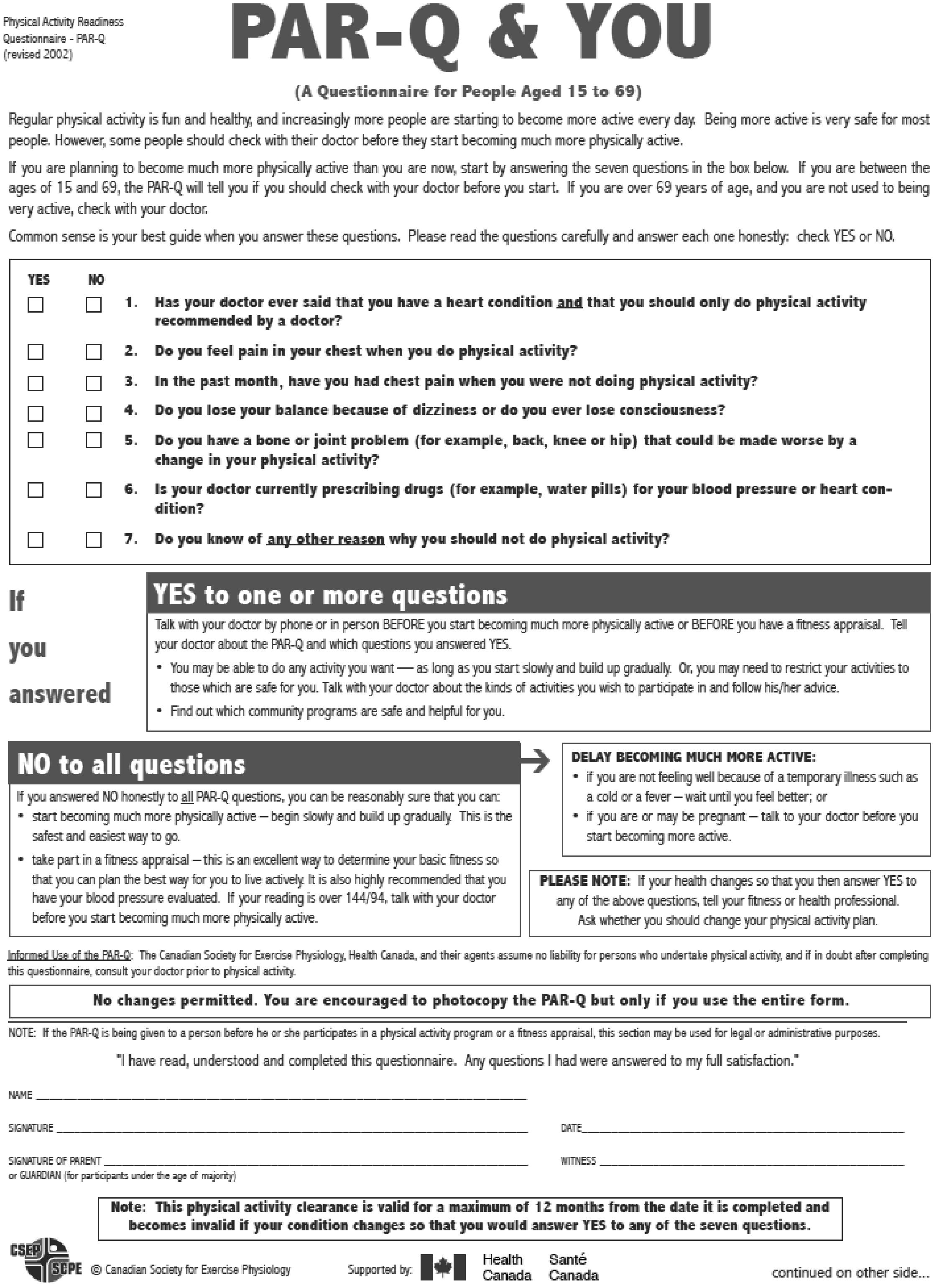
Signature of Participant Date (dd/mm/yyyy)

____

Signature of Witness Date (dd/mm/yyyy)

Appendix C

PAR-Q



Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

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

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

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

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

If you answered

YES to one or more questions

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

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

NO to all questions

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

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

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

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

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

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

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

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

NAME ____________________

SIGNATURE ____________________ DATE ____________________

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

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

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Appendix D

Maximal Exertion Testing Pre-participation Screening Questionnaire

School of Kinesiology, Lakehead University
Maximal Exertion Testing
Pre-participation Screening Questionnaire

The purpose of this form is to ensure that we provide the highest level of care when conducting maximum exertion testing by obtaining specific information regarding your overall health and fitness. This form is completed in addition to a standard ParQ.

Please read and complete this questionnaire carefully and return it to the researcher(s) prior to the start of the testing.

The information contained in this form is considered confidential and will only be used to pre-screen activity participants.

Personal Information

Name: ________________________________ DOB: ______________________ M /F

Height (cm): _________________________ Weight (kg): _______________________

Assess your health status by marking all the true statements.

History
Have you had:
_____ a heart attack
_____ heart surgery
_____ cardiac catheterization
_____ coronary angioplasty (PTCA)
_____ pacemaker/implantable cardiac device
_____ defibrillatory/rhythm disturbance
_____ heart valve disease
_____ heart failure
_____ heart transplantation
_____ congenital heart disease

If you marked any of these statements in this section, consult your physician or other appropriate health care provider before engaging in testing or exercise. You may need to use a facility with a **medically qualified staff**.

Symptoms:
_____ You experience chest discomfort with exertion
_____ You experience unreasonable breathlessness
_____ You experience dizziness, fainting, or blackouts
_____ You take heart medications

Other health issues:
_____ You have diabetes
_____ You have asthma or other lung disease

_____ You have burning or cramping sensation in your lower legs when walking short distances
_____ You have musculoskeletal problems that limit your physical activity
_____ You have concerns about the safety of exercise
_____ You take prescription medication(s)
_____ You are pregnant

Cardiovascular risk factors:
_____ You are a man older than 45 years
_____ You are a woman older than 55 years, have had a hysterectomy, or are postmenopausal
_____ You smoke, or quit smoking within the previous 6 months
_____ Your blood pressure is >140/90 mm Hg
_____ You do not know your blood pressure
_____ You take blood pressure medication
_____ Your blood cholesterol level is >200 mg/dL
_____ You do not know your cholesterol level
_____ You have a close blood relative who had a heart attack or heart surgery before age 55 (father or brother) or 65 (mother or sister)
_____ You are physically inactive (i.e., you get <30 minutes of physical activity on at least 3 days per week
_____ You are >20 pounds overweight

If you marked **2 or more** of the statements in this section, you should consult with your physician or other appropriate health care provider before engaging in testing or exercise. You might benefit from using a facility with a **professionally qualified exercise staff** to guide your exercise program.

_____ None of the above

You should be able to exercise or participate in testing safely and without consulting your physician or other appropriate health care provider in almost any facility.

Signature:________________________________

Date:_____________________

Adapted from the American College of Sports Medicine (ACSM) and American Heart Association (AHA). ACSM/AHA Joint Position Statement: Recommendations for cardiovascular screening, staffing, and emergency policies at health/fitness facilities. Med Sci Sports Exerc 1998: 1018; Guidelines for Exercise Testing and Prescription, 7th ed. Baltimore: Lippincott Williams & Wilkins, 2006:25.

Appendix E

Maximal Exercise Assessment Checklist

Maximal Exercise Assessment Checklist *(Nov. 2007 – updated Feb. 2011)*

(Complete for all Max. Assessments – in-class demonstrations, labs and research – file with ParQ)

Preparation	√
1. Protocol presented to the Risk Management Committee for review & recommendation (includes termination guidelines).	
2. Supervisor is recognized by the Risk Management Committee as having competence with maximal testing.	
3. Supervisor certified with Standard First Aid and CPR.	
4. Supervisor will be on-site for all max. assessment activity.	
5. Approved physician on-site for max. assessment with **high risk participants.**	
6. Equipment and facility prepared and inspected for safety of operation.	
7. Exercise protocol and termination guidelines discussed by the supervisor with all those involved in the actual assessment prior to commencing.	
Screening & Risk Stratification	
1. Par-Q & Screening Stratification Questionnaire reviewed and completed with low risk populations.	
2. Par-MedX completed by physician for moderate to high risk populations.	
3. All screening records to be maintained in the School of Kinesiology for seven years.	
Assessment	
1. Exercise protocol verbally reviewed with participant and posted in clear view.	
2. Exercise termination guidelines reviewed and posted in clear view.	
3. Informed consent signed by participant.	
4. Post exercise vital signs monitored and recorded.	
5. Completed screening tools and assessment records filed in the Kinesiology office.	
6. Incidents/accidents promptly addressed, report form completed and filed with the Kinesiology office.	

Name of Participant: ______________________________ **(print)**

______________________________ **(sign)**

Date of Assessment: ______________________________

Supervisor: ______________________________ **(print)**

______________________________ **(sign)**

Witness: ______________________________ **(print)**

______________________________ **(sign)**

Appendix F

Data Collection Sheet

Athletic Background

Name:		Birth date:	
Sex:	Height (cm):	Weight (kg):	BMI:
Years experience:	Level of experience:	Last competition:	
Practice/week:	Km/week:	Event Focus:	
Personal bests (800-10000m):			
Most current injury (recurring injuries):			

Accommodation and VO_2max Testing

Resting VO_2 (ml/kg/min):		Resting HR(bpm):	
VO_2max (ml/kg/min):		Heart rate max (bpm):	
VO_2R (ml/kg/min):		HRR (bpm):	
vVO2 (km/h):		Anaerobic threshold:	

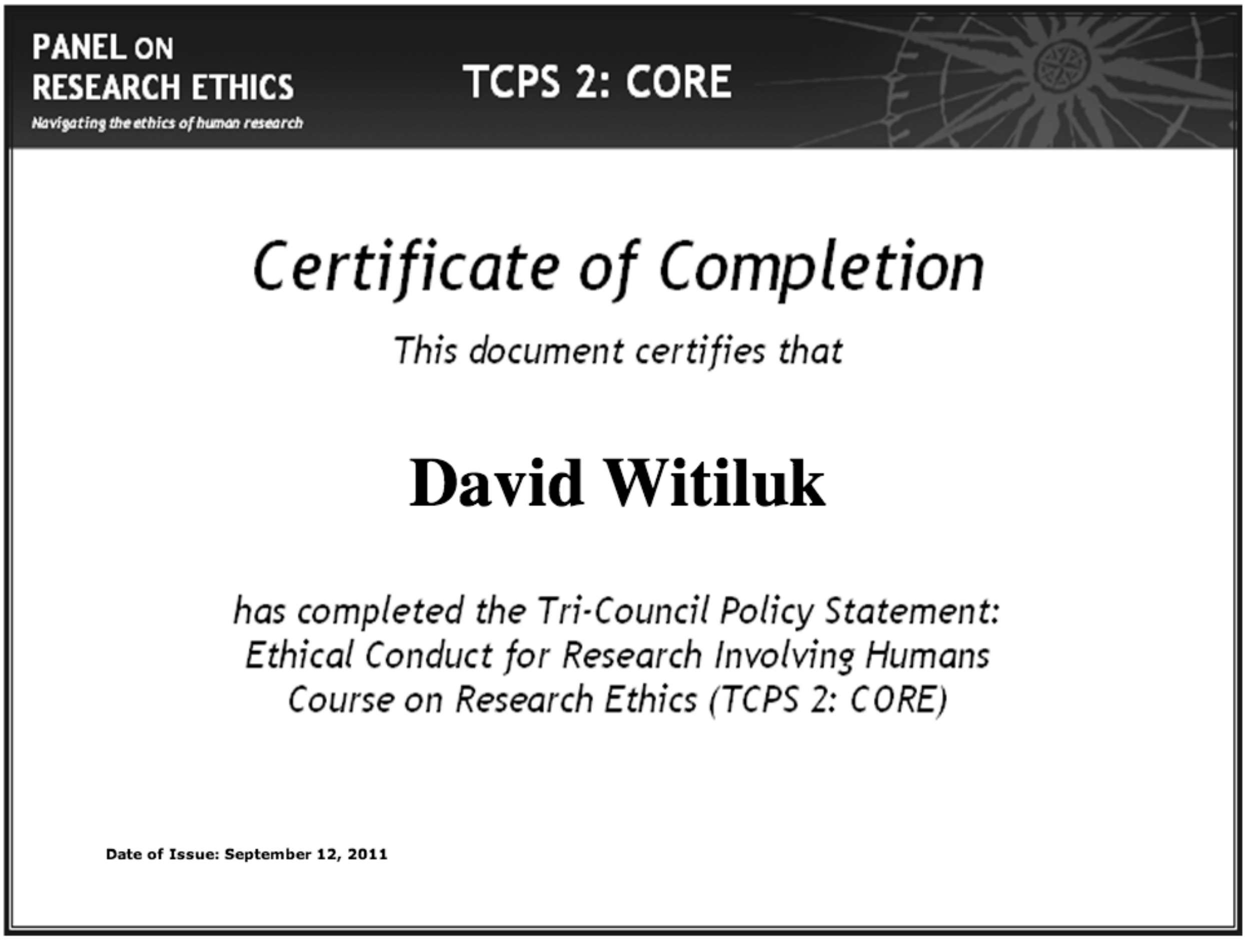
Performance Task

35% Session Date:		50% Session Date:	
35% HRR (bpm):		50% HRR (bpm):	
35% VO_2R (ml/kg/min):		50% VO_2R (ml/kg/min):	
Resting VO_2 (ml/kg/min):		Resting VO_2 (ml/kg/min):	
VO_2max (ml/kg/min):		VO_2max (ml/kg/min):	
Resting HR (bpm):		Resting HR (bpm):	
HRmax (bpm):		HRmax (bpm):	
Recovery time (sec):		Recovery time (sec):	
Run time (sec):		Run time (sec):	
105% vVO_2max (km/h):		Warm-up velocity (km/h):	

NOTES

Appendix G

Ethics Certificate



PANEL ON RESEARCH ETHICS

Navigating the ethics of human research

TCPS 2: CORE

Certificate of Completion

This document certifies that

David Witiluk

has completed the Tri-Council Policy Statement:
Ethical Conduct for Research Involving Humans
Course on Research Ethics (TCPS 2: CORE)

Date of Issue: September 12, 2011

Appendix H

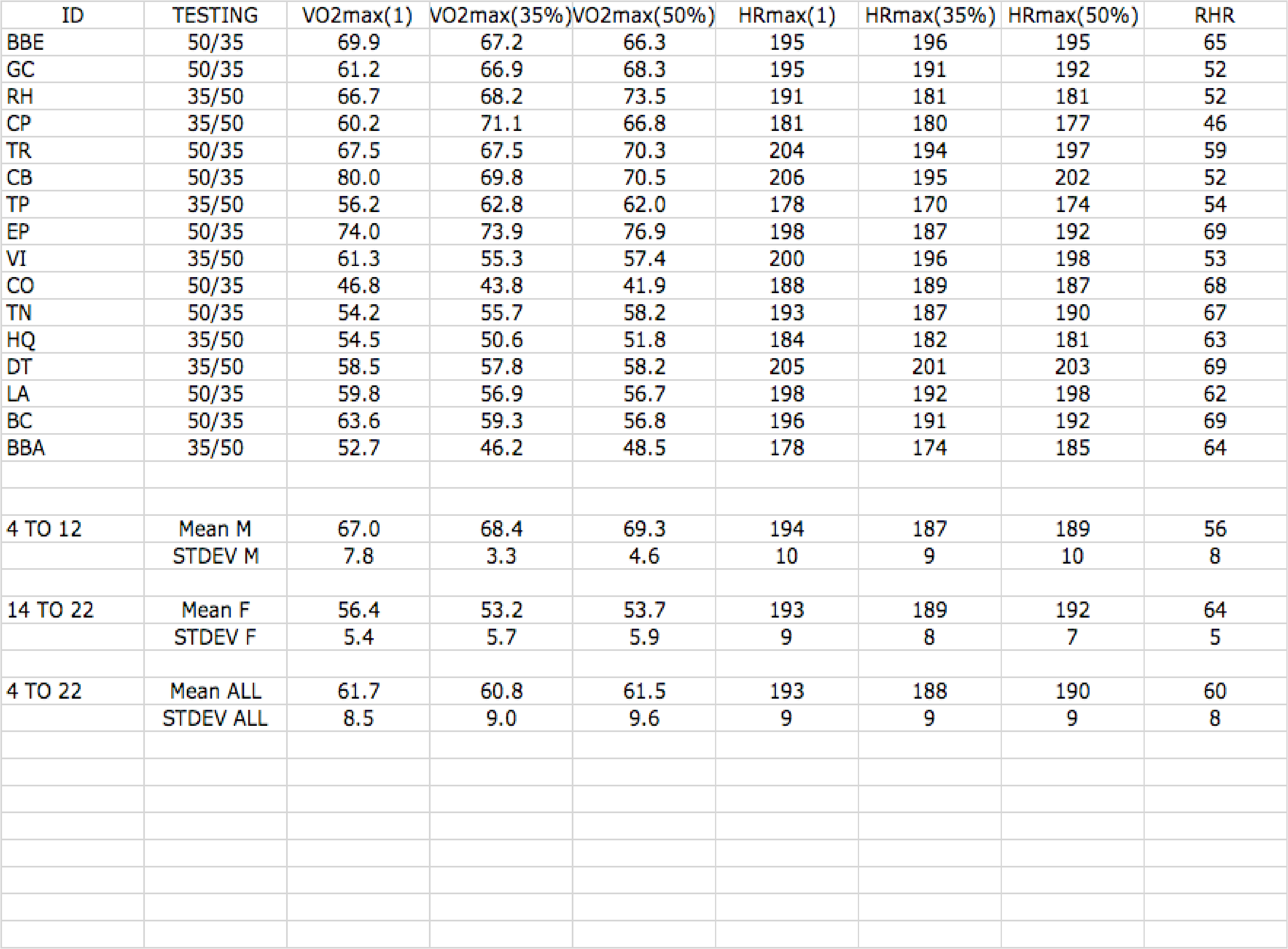
Descriptive Data

ID	Birthdate (YYYY/MM/DD)	Age(years)	Height (M)	Weight (kg)	BMI	Sex	Years/exp	Level Exp
BBE	1993/07/01	18	1.85	72.0	21.0	M	4	OFSAA/COLLEGIATE
GC	27/11/1992	18	1.98	78.0	19.8	M	5	OFSAA/COLLEGIATE
RH	1986/05/06	25	1.72	68.0	22.9	M	12	NATIONAL
TR	1991/05/03	20	1.78	71.0	22.4	M	8	OUA
CB	1991/04/19	20	1.88	74.3	21.0	M	7	OUA
CP	1989/09/28	22	1.83	67.1	20.1	M	8	OUA
TP	28/08/1983	28	1.76	72.4	23.3	M	9	OUA
EP	1993/01/20	18	1.64	55.4	20.7	M	5	OFSAA/COLLEGIATE
VI	13/01/1990	21	1.60	50.7	19.9	F	7	OUA
CO	23/02/1989	22	1.70	56.8	19.7	F	4	COLLEGIATE
TN	1989/10/15	22	1.74	60.8	20.1	F	7	OUA/CIS
HQ	1990/02/26	21	1.66	60.3	21.7	F	8	OUA
DT	1992/04/06	19	1.76	59.7	19.3	F	6	OUA
LA	1989/02/24	22	1.60	57.5	22.6	F	5	OUA
BC	1989/03/29	22	1.64	47.6	17.7	F	8	COLLEGIATE/PROV
BBA	1990/01/10	21	1.64	54.8	20.4	F	5	OUA
M 43-52	MEAN M	21	1.80	69.8	21.4		7	
	STDEV M	4	0.10	6.7	1.3		3	
F 53-62	MEAN F	21	1.67	56.0	20.2		6	
	STDEV F	1	0.06	4.8	1.5		1	
ALL 43-62	MEAN ALL	21	1.74	62.9	20.8		7	
	STDEV ALL	3	0.11	9.1	1.5		2	

prac/week	km/week	EventFocus	PB800(sec)	PB1500(sec)	PB3000(sec)	PB5000(min)	PB10000(min)
6	80	XC/800/1500	124	258	572		
6	85	800	119	247	554	18.05	
6	80	10000		248	523	15.77	32.98
6	80	300/1000/150	117	244	576		
6	100	1500	118	241	540		34.70
6	60	8000 XC	135	257	572	16.25	34.95
6	100	3000	122	249	535	16.02	33.90
6	60	3000		266	557		
7	65	600/800/1000	140			21.35	
6	50	600				19.77	
6	85	3000		284	618	18.90	
7	80	3000/5000	158	297	620	18.08	42.18
6	80	1500/3000	142	286	627	18.92	
7	80	3000/5000			639		
5	60	1500/3000	139	287	639	18.48	38.50
6	60	XC					
6	81		123	251	554	16.52	34.13
0	15		7	8	19	1.04	0.89
6	70		145	289	629	19.25	40.34
1	13		9	6	10	1.17	2.60
6	75		131	264	582	18.16	36.20
1	15		14	20	41	1.76	3.48

Appendix I

Raw Data



ID	TESTING	VO2max(1)	VO2max(35%)	VO2max(50%)	HRmax(1)	HRmax(35%)	HRmax(50%)	RHR
BBE	50/35	69.9	67.2	66.3	195	196	195	65
GC	50/35	61.2	66.9	68.3	195	191	192	52
RH	35/50	66.7	68.2	73.5	191	181	181	52
CP	35/50	60.2	71.1	66.8	181	180	177	46
TR	50/35	67.5	67.5	70.3	204	194	197	59
CB	50/35	80.0	69.8	70.5	206	195	202	52
TP	35/50	56.2	62.8	62.0	178	170	174	54
EP	50/35	74.0	73.9	76.9	198	187	192	69
VI	35/50	61.3	55.3	57.4	200	196	198	53
CO	50/35	46.8	43.8	41.9	188	189	187	68
TN	50/35	54.2	55.7	58.2	193	187	190	67
HQ	35/50	54.5	50.6	51.8	184	182	181	63
DT	35/50	58.5	57.8	58.2	205	201	203	69
LA	50/35	59.8	56.9	56.7	198	192	198	62
BC	50/35	63.6	59.3	56.8	196	191	192	69
BBA	35/50	52.7	46.2	48.5	178	174	185	64
4 TO 12	Mean M	67.0	68.4	69.3	194	187	189	56
	STDEV M	7.8	3.3	4.6	10	9	10	8
14 TO 22	Mean F	56.4	53.2	53.7	193	189	192	64
	STDEV F	5.4	5.7	5.9	9	8	7	5
4 TO 22	Mean ALL	61.7	60.8	61.5	193	188	190	60
	STDEV ALL	8.5	9.0	9.6	9	9	9	8

RHR(35%)	RHR(50%)	RVO2	RVO2(35%)	RVO2(50%)	vWarm-up	vVO2max	105%vVO2max
66	69	3.4	4.5	4.4	7.5	11.6	12.2
60	71	4.0	5.7	7.1	8.4	10.7	13.1
54	54	4.4	3.3	4.8	9.2	11.6	14.0
47	43	4.2	3.9	4.6	8.4	12.5	13.1
60	61	3.8	4.9	3.7	7.3	13.4	14.0
56	53	4.4	3.9	4.8	7.5	12.5	13.1
55	63	4.4	5.0	4.0	8.4	12.5	13.1
76	62	4.4	6.2	6.2	7.5	12.5	13.1
66	65	7.0	4.4	4.7	5.5	10.7	11.2
70	67	3.5	6.3	5.4	5.2	9.8	10.3
61	71	4.3	3.7	4.4	6.2	11.6	12.2
67	54	4.7	4.4	4.7	6.5	11.6	12.2
76	70	4.0	4.3	4.1	7.1	11.6	12.2
56	63	4.9	5.2	4.7	6.0	11.6	12.2
74	64	5.7	5.3	4.9	6.3	11.6	12.2
67	69	4.5	4.1	4.9	5.6	10.7	11.2
59	60	4.1	4.7	4.9	8.0	12.1	13.2
9	9	0.4	1.0	1.2	0.7	0.8	0.6
67	65	4.8	4.7	4.7	6.0	11.1	11.7
7	5	1.1	0.8	0.4	0.6	0.7	0.7
63	62	4.5	4.7	4.8	7.0	11.6	12.5
8	8	0.9	0.9	0.8	1.2	0.9	1.0

60%HRR	35%HRR	50%HRR	E60%VO2R	O60%VO2R35	A60%VO2R35	O60%VO2R50	A60%VO2R50	E35%VO2R
143	111	130	43.3	36.2	49.3	36.6	49.9	26.7
138	102	124	38.3	41.2	64.9	43.8	69.5	24.0
135	101	122	41.8	38.7	55.1	37.1	52.5	26.2
127	93	114	37.8	38.2	60.6	37.4	59.3	23.8
146	110	132	42.0	35.3	49.5	34.1	47.5	26.1
144	106	129	49.8	40.5	47.8	36.0	41.9	30.8
128	97	116	35.5	39.3	67.4	32.1	53.5	22.5
146	114	134	46.1	40.8	52.4	37.2	47.2	28.7
141	104	127	39.6	28.5	39.5	26.8	36.5	26.0
140	110	128	29.5	27.1	54.5	27.0	54.3	18.7
143	111	130	34.2	31.7	54.8	31.6	54.8	21.8
136	105	124	34.6	31.7	54.2	29.5	49.8	22.1
151	117	137	36.7	29.9	47.5	29.2	46.2	23.1
144	110	130	37.8	37.0	58.4	30.6	46.8	24.1
145	113	133	40.4	36.4	53.0	33.8	48.5	26.0
132	104	121	33.4	26.5	45.5	25.2	43.0	21.4
139	104	125	41.8	38.8	55.9	36.8	52.7	26.1
8	7	7	4.7	2.1	7.6	3.4	8.5	2.7
141	109	129	35.8	31.1	50.9	29.2	47.5	22.9
6	5	5	3.6	3.9	6.2	2.8	6.0	2.5
140	107	127	38.8	34.9	53.4	33.0	50.1	24.5
7	6	6	5.1	5.0	7.2	4.9	7.6	3.0

O35%VO2R	A35%VO2R	E50%VO2R	O50%VO2R	A50%VO2R	35%Run to ex	50%run to ex	35%rec	50%rec
18.9	23.4	36.6	20.5	25.7	242	319	76	50
9.5	9.6	32.6	25.1	36.9	226	321	246	81
26.0	34.7	35.5	18.3	22.3	240	180	69	55
17.4	23.6	32.2	27.2	41.1	232	208	64	46
9.2	8.4	35.7	18.7	23.4	197	186	300	59
21.3	22.5	42.2	26.6	29.5	175	199	60	61
25.1	40.0	30.3	19.9	30.0	165	127	66	52
17.6	19.0	39.2	25.3	30.1	125	139	62	55
7.0	0.0	34.1	12.5	10.2	202	228	355	119
7.7	9.8	25.1	16.5	29.9	145	142	145	101
9.6	10.6	29.2	13.0	17.5	140	146	177	90
6.9	4.5	29.6	24.4	39.6	104	120	130	54
8.1	7.5	31.3	13.9	18.1	144	150	105	72
15.0	18.4	32.3	14.0	16.7	100	107	73	65
13.7	13.8	34.7	14.5	15.2	132	136	180	78
12.4	16.3	28.6	14.8	21.3	124	138	82	60
18.1	22.6	35.5	22.7	29.9	200	210	118	57
6.3	10.9	3.9	3.7	6.5	42	73	97	11
10.0	10.1	30.6	15.5	21.1	136	146	156	80
3.2	6.1	3.1	3.8	9.4	32	36	90	22
14.1	16.4	33.1	19.1	25.5	168	178	137	69
6.4	10.7	4.3	5.2	9.0	49	65	92	20