

**CHAPTER TWO**  
**LITERATURE REVIEW**

## Introduction

Differing exercise modalities may have unique effects on exercise response variables. At similar exercise intensities various modalities of exercise have been shown to elicit differing  $\text{VO}_2$  responses (Zeni, Martin, Hoffman, & Clifford, 1990; Hetzler, Seip, Boutcher, Pierce, Snead, & Weltman, 1991). One exercise response variable that has gained attention recently is the slow component of  $\text{VO}_2$  ( $\text{VO}_{2\text{SC}}$ ). The SC of  $\text{VO}_2$  is separate from the initial exercise response, being initiated following a discrete interval after exercise onset and is responsible for “excess”  $\text{VO}_2$  consumption above that predicted for steady-state exercise. (Poole, 1994). This and other exercise response variables will be discussed in further detail in upcoming sections of this review.

The inclined stepper is a recent modality of exercise with a variation to the traditional stepper ergometers. However, data on the inclined stepper is limited to maximal exercise. Submaximal responses to the inclined stepper have yet to be identified.

For this study, exercise responses between the inclined stepper and treadmill were compared during heavy intensity (70% of  $\text{VO}_{2\text{peak}}$ ), constant-load exercise. During the submaximal exercise bouts, several response variables were evaluated. One of those being the  $\text{VO}_{2\text{SC}}$ . Although several mechanisms have been proposed to account for this  $\text{O}_2$  “excess”, the exact processes have yet to be identified. One of the proposed mechanisms is the increased  $\text{O}_2$  cost of lactate metabolism (Whipp & Wassermann, 1986). Due to the uniqueness of the inclined stepper, literature regarding the  $\text{VO}_{2\text{SC}}$  and subsequent changes in lactate is not currently available. For the most part, discussion is therefore limited to response to exercise testing on similar modalities of exercise. The focus of the upcoming literature review will be on maximal and submaximal responses to treadmill and stair climbing exercise with special attention given to the slow component of  $\text{VO}_2$  and blood lactate responses.

## Maximal Exercise Testing

It has been well established that the measurement of maximal oxygen consumption ( $\text{VO}_2$  peak) through open circuit spirometry is the “gold standard” through which an individual's cardiovascular fitness may be evaluated (American College of Sports Medicine, 1991). The direct measurement of  $\text{VO}_{2\text{peak}}$  is useful clinically in assessing a number of physiological parameters including functional capacity.

This study consisted of a baseline maximal exercise test on both the treadmill and inclined stepper to determine the appropriate workload for submaximal exercise. Maximal exercise testing can aid in determining a number of physiological parameters, the most important being the maximal amount of oxygen consumed by the subject (American College of Sports Medicine, 1991). Determination of  $\text{VO}_{2\text{max}}$  is essential for determining relative workloads for submaximal intensities.

When administering a maximal exercise test, several guidelines need to be followed to attain optimal exercise response values. One of these guidelines was examined by Buchfuhrer, Hansen, Robinson, Sue, Wasserman, and Whipp in 1983. From this study, it was determined that a maximal exercise test should last between 8 and 12 minutes. Tests lasting less than 8 minutes

may elicit lowered  $VO_{2peak}$  values. As well, exercise tests that last longer than 12 minutes may result in lowered  $VO_{2peak}$  values due to mental fatigue and lower back discomfort (Buchfuhrer et al., 1983).

During maximal exercise testing there are three common physiological responses that are used to evaluate effort. For this study, criterion for  $VO_{2peak}$  description was achieving at least two of the following three: 1) subjects maximal heart rate (HR) should reach at least 85% of age-predicted maximum, 2) maximum rating of perceived exertion (RPE) should be at least 17 on the Borg scale and 3) respiratory exchange ratio (RER) should reach at least 1.10 (ACSM, 1991).

### **Submaximal Exercise Testing**

In many cases, maximal exercise testing is not a feasible method for assessing  $VO_{2peak}$ . Such exercise testing not only requires a maximal effort, but specialized equipment and additional personnel are needed which can be costly. Submaximal tests were developed as a result. Not only are submaximal test cost effective, but they are highly practical in that they mimic a typical exercise session. While maximal tests allow for the direct measurement of  $VO_{2max}$ , submaximal tests can be used to estimate  $VO_{2max}$  (ACSM, 1991). An incremental exercise protocol is typically employed in order to estimate  $VO_{2max}$ . During each subsequent stage of exercise, HR response is measured. The test is stopped once the subject reaches a predetermined percentage of their age-predicted maximum. Heart rate can then be plotted against exercise intensity allowing for the estimate of  $VO_{2max}$ . (ACSM, 1991).

For this study, the maximal exercise test allowed for the direct measurement of  $VO_{2max}$ . Submaximal intensities were calculated using the maximal  $VO_2$  response. It was the purpose of this study to evaluate physiological variables of exercise under submaximal exercise conditions. To do this, the workload remained constant. A delta score is used to evaluate the drift in  $VO_2$  (SC). Heavy intensity constant-load exercise allows for the determination of  $VO_2SC$  by subtracting the  $VO_2$  at end-exercise from the third minute of exercise.

### **Stepper Testing**

The use of stair stepping for the evaluation of fitness has been utilized since the turn of the century. With the inception of the Master's Step Test in 1905, the use of stair climbing as a clinical tool became popularized. Other tests, such as the 3-Minute Step Test, were introduced as a means of evaluating fitness levels during submaximal effort. This test is conducted on a 12-inch high bench, with a stepping rate of 24 steps/min for the 3 minutes (ACSM, 1991). Following the test, the subjects is instructed to immediately sit down while heart rate is counted for 1 minute. Step tests have traditionally been used for submaximal testing because of their decreased oxygen consumption values compared to treadmill testing. As well, additional limitations of step tests include muscle fatigue in the legs and balance problems at higher stepping rates (Holland, Hoffman, Vincent, Mayers, & Caston, 1990).

While newer step-test protocols are available, their use has been limited with the advent of computerized step ergometers. These devices require arm/and or leg movements and usually provide the necessary technology for measurement and display of power variance. (Holland et al.,

1990). These step ergometers have been designed to simulate stair climbing offering a more feasible way of evaluating work capacity, especially for peak exercise.

Holland et al. (1990), tested college students using a step treadmill by StairMaster (SM) that simulates stair climbing. The SM 6000 incorporates a rotating set of stairs similar to an escalator. An incremental protocol equating MET values was used in the comparison of stair climbing vs treadmill exercise. Results of this study indicate that no significant differences were found for peak physiological responses between the stair climber and treadmill. Overall, mean  $VO_{2peak}$  data was higher for the SM than the treadmill. Similarly, during submaximal work rates (stage I and II) oxygen consumption and heart rates were higher for the stair climber. These results lead researchers to conclude that stair climbing ergometry is a viable alternative exercise modality for this population. Recent research, however, has demonstrated more discernible differences between stair stepping and treadmill exercise.

Zeni, Hoffman, and Clifford (1996), conducted research evaluating the energy expenditure of the treadmill compared to the stair stepper. The exercise test comprised 3 stages of 5 minutes at self-selected work rates corresponding to ratings of perceived exertion (RPE) values of 11 (fairly light), 13 (somewhat hard), and 15 (hard). The treadmill induced significantly higher rates of energy expenditure for fixed RPE values than the stair stepper.

A study published in 1995 by Gardner, Skinner, Bryant, and Smith evaluated the effect of stair climbing on the cardiovascular demand in claudication patients. Researchers acknowledge that for testing and rehabilitative purposes, exercise which elicits lower heart rate and blood pressure at a given metabolic intensity would be preferred for such patients over a more demanding task. Subjects exercised at approximately 75% of their maximal work rate from preceding incremental treadmill and stair climbing tests. This study found that lower heart rate and brachial blood pressure values were evident during stair climbing than treadmill walking. Researchers concluded that stair climbing is preferable to walking for claudication patients because a similar level of ischemia within the claudication limbs occurs at a lower cardiovascular demand.

Most recently, an unpublished study by Davis and Sipe (1995), investigated an inclined stepper and its  $VO_2$  response to maximal exercise as well as its test-retest-reliability. Using 28 college-aged subjects,  $VO_{2peak}$  values were found to be significantly (~15%) less for the inclined stepper compared to the treadmill. Also, results indicated that the stepper can be administered by researchers with the confidence knowing that oxygen uptake values will not differ significantly from day to day ( $r=0.91$ ).

From these studies, it is unclear whether the physiological demands obtained during constant-load and incremental exercise are similar for treadmill and stair climbing exercise.

### **Submaximal Protocol Design**

For constant-load work rates, steady state exercise has been shown by numerous studies to occur at approximately 80-110 seconds after the onset of exercise (Whipp, 1994). However, previous studies (Hagberg et al, 1978; Poole et al, 1994), have used the 5<sup>th</sup> minute of submaximal exercise as a starting point for the determination of  $VO_2$  change. By doing so, this assures

investigators that the drift in  $\text{VO}_2$  across this time period is due to the  $\text{VO}_2$  SC and not directly by the workload itself. According to Hagberg et al. (1978) changes seen after the 5<sup>th</sup> minute of constant-load exercise, therefore, can not be attributed to normal  $\text{VO}_2$  kinetics.

A workload chosen to elicit 70% of each subjects  $\text{VO}_{2\text{max}}$  on the treadmill and inclined stepper was selected for this study. A number of investigators (Poole, 1994; Whipp, 1994) have reported that  $\text{VO}_2$  continues to increase after the initial 3 minutes of exercise at work rates requiring more than 60% of  $\text{VO}_{2\text{max}}$ . Hagberg et al (1978) revealed that at constant-load work intensities of 65% and 80% of  $\text{VO}_{2\text{peak}}$ , a significant rise in  $\text{VO}_2$  occurred from the 5<sup>th</sup> to 20<sup>th</sup> minutes of exercise. For the 65% workload, 76% of the tests showed a significant change in  $\text{VO}_2$  compared to 85% for the tests at 80% of  $\text{VO}_{2\text{max}}$ . However, the magnitude of the rise at these two workloads was not significantly different and 19% of the subjects were not able to complete the 20 minutes for the 80%  $\text{VO}_{2\text{max}}$  workload. For this study, it was the goal of the investigator to provide a workload that would allow all subjects to complete the full 20 minutes yet still witness a drift in  $\text{VO}_2$ .

### **Slow Component of $\text{VO}_2$**

In the past decade the term slow component has become increasingly popular among exercise physiologists. The SC can be defined as the continual rise in  $\text{VO}_2$  following the third minute of exercise. During heavy constant-load exercise (i.e. above the lactate threshold), the slow component becomes evident. Exercise below the lactate threshold (LT) does not have an  $\text{O}_2$  “wasting” affect and is typified by a steady-state response. In extreme cases, the slow component may account to >1000 ml/min resulting in a compromised exercise tolerance. (Poole et al., 1991). During work rates above the LT the additional  $\text{O}_2$  uptake may elicit a  $\text{VO}_2$  max. The slow component can actually bring  $\text{VO}_2$  to the  $\text{VO}_{2\text{peak}}$  resulting in exhaustion thereafter (Whipp, 1994).

According to Barstow (1994) constant-load exercise of moderate intensity (i.e. below the lactate threshold) consists of the following phases of pulmonary gas exchange: Phase 1- representing the first 15-25 seconds of exercise where the rise in  $\text{VO}_2$  is thought to be due primarily to increased cardiac output; Phase 2- during which  $\text{VO}_2$  rises in an exponential fashion toward a steady state and Phase 3- the new steady state level of  $\text{O}_2$ . When the exercise intensity is heavy (above LT), phase three is no longer present. Above the LT,  $\text{VO}_2$  continues to climb and in some cases never reaches peak before exercise is terminated (Barstow, 1994).

Many mechanisms have been evaluated in order to identify the processes underlying the  $\text{VO}_2$  slow component. Factors such as catecholamines, lactate, recruitment of fast twitch muscle fibers, and rising muscle temperature have been proposed to be possible influences to  $\text{VO}_2\text{SC}$ . One mechanism that has gained interest among researchers is the contribution of peripheral factors (exercising limbs) to the slow component. Poole et al. (1994) evaluated the changes in leg and pulmonary  $\text{VO}_2$  during constant-load cycle ergometer exercise at a work rate above the LT. Results of the study indicated that greater than 80% of SC pulmonary  $\text{VO}_2$  arises from within the exercising limbs. Thus, leading researchers to believe that processes outside the exercising limbs

(i.e. core temperature changes, ventilatory, and cardiac work) do not contribute significantly to the slow component.

### **Lactate [HLa]**

A cardinal feature of the  $\text{VO}_2$  slow component is its relationship with the blood lactate profile (Poole, 1994). Constant-load exercise intensities below the LT result in a steady state  $\text{VO}_2$  profile whereas intensities above the LT are associated with “excess”  $\text{VO}_2$  consumption. The LT occurs when the accumulation of lactic acid exceeds the removal and resultant increases in blood lactate are found in the body.

At low exercise intensities (below 40% of the  $\text{VO}_{2\text{max}}$ ) there may be little or no change in the lactate concentrations. As exercise intensity increases, a point is reached at which an increase in the concentration of lactate in the blood becomes evident (Gollnick, Bayly, & Hodgson, 1986). It has been suggested by Gollnick et al. (1986) that lactate production occurs at all intensities of exercise and that the difference between its production and clearance determine whether or not there is an accumulation in the blood. The accumulation of blood above that of baseline values has been typified as the lactate threshold (Steed, Gaesser, & Weltman, 1994).

The lactate threshold is dependent on the individual and their fitness level. At the same exercise intensity trained individuals have a higher LT than the untrained and therefore, the onset of fatigue is delayed. By determining LT, work intensities below the LT can be established so as to avoid any drift in  $\text{VO}_2$  (SC) and subsequently increase the time to exhaustion. Roston, Whipp, Davis, Cunningham, Effros, and Wasserman (1987) demonstrated a correlation between end-exercise lactate levels and the increase in  $\text{VO}_2$  occurring after the 3<sup>rd</sup> minute of exercise. In this study, the investigators determined that as long as lactate was changing during exercise, so was the  $\text{VO}_2$ . Furthermore, if lactate reached a steady state at an elevated level, so did the  $\text{VO}_2$ . Similarly, both Casuburi, Storer, Ben Dov, and Wasserman (1987) and Poole, Ward, Gardner, and Whipp (1988), have shown that characteristics of SC appear to be related to the magnitude of the increase in blood lactate. It has also been shown that training reduces both blood lactate and the magnitude of SC (Casuburi et al., 1987), leading researchers to believe that a relationship exists between the two response variables.

Despite the frequently observed relationship between blood lactate and  $\text{VO}_2\text{SC}$ , evidence exists suggesting the relationship is not one of cause and effect (Poole, Barstow, Gaesser, Willis & Whipp, 1994). Poole et al. (1994) demonstrated that infusion of lactate (~5 mMol) into a working dog gastrocnemius did not significantly increase  $\text{VO}_2$ , establishing that some other mechanism may be at work.

Also, Womack, Davis, Blumer, Barrett, Weltman, and Gaesser (1995), studied the adaptation of the  $\text{VO}_2\text{SC}$  to endurance training. Specifically, the effect of an infusion of epinephrine [Epi] on SC was evaluated. This infusion of [Epi] following training allowed the researchers to partially assess whether blood lactate contributed to the reduction in  $\text{VO}_2\text{SC}$ . An increase in  $\text{VO}_2$  following an [Epi] infusion would suggest that blood lactate may be a contributor to the  $\text{VO}_2\text{SC}$ . Results showed that following training, the decreases in SC coincided with reduced end-exercise blood lactate values. However, the [Epi] infusion after training significantly

increased blood lactate without any change in  $\text{VO}_2$  during exercise. The researchers concluded that blood lactate adaptations are not responsible for the reduction of  $\text{VO}_2\text{SC}$  following training. According to Whipp (1994), it is unlikely that lactate per se is responsible for the “excess”  $\text{VO}_2$  commonly associated with heavy constant-load exercise.

More recently, mechanisms other than lactate have been proposed as a major influence to the slow component of  $\text{VO}_2$ . One potential mechanism that could explain  $\text{VO}_2\text{SC}$  is the recruitment of different fiber type patterns. Lower-efficiency fast twitch fibers demand a progressively greater  $\text{O}_2$  consumption than slow twitch fibers (Poole, Barstow et al., 1994). Exercise that predominantly recruits fast twitch fibers may therefore demand more oxygen thereby increasing  $\text{VO}_2\text{SC}$ . However, the exact magnitude that fiber type recruitment contributes to SC has yet to be determined. Given the strong association between blood lactate profiles and  $\text{VO}_2\text{SC}$ , it is plausible that some common underlying mechanism gives rise to both processes (Poole, 1994).

### **Summary**

Maximal exercise testing may be important in determining the peak response variables. However, constant-load exercise allows for the comparison of differing modalities of exercise. The recent advent of the inclined stepper has presented a new avenue of study. Research on the inclined stepper and the physiological responses to exercise is limited. The research available has been centered on similar stepping equipment. Results from such research dealing with physiological responses are mixed. Stair climbing has been shown to elicit lower, similar, and higher values during submaximal and peak exercise tests.

One measurement response variable that has gained recognition over the past decade is the slow component of  $\text{VO}_2$  kinetics. Researchers have shown that for exercise intensities that require work above the lactate threshold, the resultant “excess”  $\text{VO}_2$  can cause early onset fatigue. Therefore, evaluation of SC should be considered a useful indicator for comparing responses to differing modalities of exercise.

Additionally, the SC has been shown to coincide with increasing blood lactate levels. Research, though, has recently indicated that blood lactate may not be directly responsible for the concomitant increases in the slow component of  $\text{VO}_2$ . Furthermore, investigators believe that mechanisms such as an alteration in motor unit recruitment may play a role in the magnitude of SC.

