The Effects of Constant vs. Interval Load Training 
At and about the First Ventilatory Threshold on 
Endurance Performance Indicators.

by

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A thesis submitted in conformity with the requirements for the 
degree of Master of Science 
Graduate Department of Physiology in the 
University of Toronto

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Thirteen sedentary subjects (five males and eight females) were randomly assigned to a constant load (CT) or interval load (IT) group. Exercise training corresponded to an intensity at or about the first ventilatory threshold ($T_{V_1}$). The CT group increased $\dot{V}O_2\max$ from 33.2 (+/- 3.5) ml·(kg·min)$^{-1}$ to 40.1 (+/- 4.3) ml·(kg·min)$^{-1}$, and $T_{V_1}$ from 19.2 (+/- 2.9) ml·(kg·min)$^{-1}$ to 24.7 (+/- 1.8) ml·(kg·min)$^{-1}$, after eight weeks. The CT group increased $\dot{V}O_2\max$ from 31.6 (+/- 8.9) ml·(kg·min)$^{-1}$ to 38.8 (+/- 7.3) ml·(kg·min)$^{-1}$, and $T_{V_1}$ from 17.7 (+/- 4.4) ml·(kg·min)$^{-1}$ to 22.8 (+/- 4.7) ml·(kg·min)$^{-1}$. These changes were significant. Between group differences for endurance performance improvements could not be detected after training, though there appeared to be a possible difference in the time course for adaptation, which could not be resolved with significance due to insufficient sample size. Conclusive statements regarding the effects of exercise training on the ‘breath sound check’ method of monitoring exercise intensity will require further research. The choice of CT vs. IT protocols in the training of sedentary persons will likely come down to subject preference.
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LIST OF ABBREVIATED TERMINOLOGY

- $\alpha$ - Probability of a making type-I error
- AT - Anaerobic Threshold
- $\beta$ - Probability of making a type-II error
- bpm - Beats per minute (measure of heart rate)
- CO$_2$ - Carbon dioxide
- CT - Constant load training
- CUSUM - Cumulative sum of the differences in ventilation data
- H$^+$ - Hydrogen ion
- HR - Heart rate
- HR$_{\text{max}}$ - Maximum heart rate
- IT - Interval load training
- K$^+$ - Potassium ion
- kg - Kilograms (mass)
- l - Litres (volume)
- MIF - Mean inspiratory flow
- Min - Minute (time)
- ml - Millilitres (volume)
- mmHg - pressure in millimeters of mercury
- mph - Miles per hour
- $N$ - Sample size of all groups inclusive
- $n$ - Number of subjects in an experimental group
- $N_R$ - Reynolds number
- O$_2$ - Oxygen
\[ \text{pH} \quad \text{- Measure of acidity or alkalinity} \\
\text{s} \quad \text{- Second (time)} \\
\text{SD} \quad \text{- Standard deviation of the mean} \\
\text{SE} \quad \text{- Standard error of the mean} \\
\text{t} \quad \text{Time} \\
\text{T}_1 \quad \text{Inspiratory time} \\
\text{T}_{L1} \quad \text{First lactate threshold} \\
\text{T}_{V1} \quad \text{First ventilatory threshold} \\
\dot{\text{V}}\text{CO}_2 \quad \text{Carbon dioxide production} \\
\dot{\text{V}}\text{O}_2 \quad \text{Oxygen consumption} \\
\dot{\text{V}}\text{O}_{2\text{max}} \quad \text{Maximum oxygen consumption or aerobic capacity} \\
\text{V}_T \quad \text{Tidal volume} \\
\text{y} \quad \text{Years of age} \\
\% \quad \text{Percent} \\
[H^+] \quad \text{Hydrogen ion concentration} \]
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CHAPTER 1 – INTRODUCTION

Ideally, an exercise training program should provide maximal adaptive benefit to the individual, for a given commitment of time, effort, and total work performed. For the sedentary person starting a training program, trying to ensure that maximal adaptive benefit is achieved may mean the difference between that individual continuing an active lifestyle, or abandoning it in view of a lack of results.

It seems clear from previous studies that sedentary persons benefit from exercise at relatively light intensities (40% VO_{2max}) just as much as they do from exercise at much higher intensities (80% VO_{2max}) (Londeree, 1977). Using constant or interval training protocols may also provide varying degrees of adaptive improvement on indicators of fitness (Thomas et al. 1984; Poole and Gaesser, 1985; Meyer et al., 1990; Gorostiaga et al., 1991). While most studies contrasting interval and constant load training have used workloads much higher than that corresponding to the anaerobic threshold, it is possible that constant and interval training protocols may offer different degrees of adaptive benefit at lighter workloads as well.

An integral part of ensuring the success of an exercise training program is the monitoring of workload. Traditionally, individuals have been taught to do this using heart rate or other measures, such as ratings of perceived exertion (RPE) and
energy expenditure. However, these techniques can be somewhat complicated and inaccurate if left for laypersons to implement. A recent study cited the ‘hear your breathing’ or ‘breath sound check’ method of targeting an effective training workload as an easy-to-use method of monitoring exercise in this range which could replace those other somewhat cumbersome methods (Goode et al., 1998).

It remains unclear what the effects of training are on the accuracy of the ‘hear your breathing’ technique, in terms of targeting workload. As training effects develop, target workloads increase and the repercussions of this on targeting a given workload through the use of ventilatory sounds warrants investigation.

**STUDY OBJECTIVES**

1) To compare constant vs. interval load training at an intensity corresponding to the first ventilatory threshold, for effectiveness in eliciting increases in maximum oxygen consumption and the first ventilatory threshold, as indicators of endurance fitness.

2) To investigate the effects of exercise training on mean inspiratory flow at the first ventilatory threshold, relating any such changes to the ‘hear your breathing’ method of monitoring exercise intensity.
(1.1) INTERVAL TRAINING

(1.1.1) Definition and Concept

The human body adapts in a multitude of ways to the stress of chronic or repetitive exercise. Changes in intramuscular, respiratory, cardiovascular and endocrine systems have all been studied and documented in some detail (Winder et al., 1979). The goal of coaching and exercise training is to utilize training programs that provide an exercise-induced stress, to which the body’s systems will optimally adapt. It has long been believed that interval training may provide a ‘better’ exercise induced stress during training, and in doing so elicit a greater degree of adaptation, when compared to constant load training.

The concept of interval training dates as far back as the 1930’s, when it was popularized among track and field athletes by Gerschler (Grey et al., 1993). Later in the early 1960’s, the early work of Astrand et al. (1960) and Christensen et al. (1960) set the foundations for much of the research on which interval training has been based (Daniels and Scardina, 1984). In papers published by both Astrand and Christensen, the term ‘intermittent’ work had been used to describe this type of exercise protocol, rather than the term ‘interval’ work. Since then, the two terms have been used almost interchangeably, with ‘interval training’ being more common among coaches and athletes.

Daniels and Scardina (1984) wrote a review article in which they put forth the opinion that there was, “a widespread misunderstanding as to exactly what is involved in interval training”. Their paper attempted to set clearer definitions for terms such as ‘interval training’, ‘intermittent training’ and ‘repetitive training’
which they felt were all frequently misused and misunderstood, most of all by the athletes who used the techniques.

While this paper by Daniels and Scardina has somewhat clear intentions, it doesn’t seem to accomplish the goal of clarifying why the terms ‘interval’, ‘intermittent’ and ‘repetition’ should represent clearly separate training methods. In fact the authors seem to unintentionally complicate the issue further by proposing that a new term, “\(\dot{V}O_2\text{max interval}\)” or “aerobic capacity” training be used to represent protocols which use interval type training geared towards \(\dot{V}O_2\text{max}\) and endurance improvements. The authors suggest that, “interval training is geared towards and dictated by a physiological variable - maximum oxygen consumption.”

On a positive note, the review article by Daniels and Scardina does clarify to some degree when one should use the terms ‘intermittent’, ‘interval’, and ‘repetition’ to describe training regimes. According to the authors, ‘intermittent work’ is a general term that describes a training protocol that uses exercise of various intensities, with varying work to rest ratios.

The term ‘interval training’, once synonymous with ‘intermittent work’, now seems to describe a particular type of intermittent work where the rest interval is normally shorter than or at most equal to the work interval that it follows. ‘Repetition training’, is another type of intermittent exercise and as the authors suggest, it should represent a protocol where the rest interval is long enough to permit near full recovery from the work interval exercise. The work interval in
repetition training is often short, kept to less than 3 minutes with a training intensity which exceeds that of the competitive effort.

Despite the reported misuse of the terminology one should use for a particular intermittent work protocol, it is generally accepted that intermittent load training is an effective method of targeting specific metabolic systems (Daniels and Scardina, 1984; MacDougall and Sale, 1981; Fox and Mathews, 1974). Whether you use the term intermittent, repetitive or interval to describe this type of training, the definition of Fox and Mathews (1974) applies equally well: “A series of repeated bouts of exercise alternated with periods of relief.” These work and rest intervals can be manipulated along with the training intensity in order to target the aerobic, anaerobic, phosphocreatine-ATP, or a combination of these energy systems. Depending on the sport or event an athlete is training for, an almost infinite combination of intensities and work to rest intervals can be applied.

Given the popularity of intermittent work training programs in athletics, one would expect there to be an abundance of literature as a guide to developing and implementing such protocols. This is however, far from the case. The only comprehensive text written on the subject of intermittent load training as it applies to sport or general fitness was published in 1974, and entitled, Interval Training: Conditioning for Sports and General Fitness. The authors of this small book were Fox and Mathews. To this day, well over twenty years later, no author has yet brought this topic up to date.

Fox and Mathews’ book begins with an introduction to the subject, then covers some of the physiological basis for interval training, and presents methods
for the construction and administration of interval training programs. Further, their book presents several examples of interval training programs using several sports as the target for such training. A later section covers the advantages of intermittent work in terms of heat production and water loss in hot climates, and gives methods for self-evaluation. No other book or article goes into such depth of discussion on the topic of intermittent work.

(1.1.2) Advantages of IT

(1.1.2.1) Reduced Fatigue

Perhaps the most well known advantage of interval training is that when rest periods are interspersed between periods of exercise, the total accumulated exercise time can be greatly increased over that which would be possible through one single continuous bout of exercise at the same intensity.

As an example, a motivated individual could likely train continuously at an intensity equal to his or her \( \dot{V}O_2 \)\textsubscript{max} for a period of about 10 minutes before becoming too fatigued to continue. If that same individual trained in an interval fashion, 2-3 minutes at an intensity equal to his or her \( \dot{V}O_2 \)\textsubscript{max} followed by a 2-3 minute recovery interval, they would be able to maintain this level of training for an hour or more before growing equally fatigued. Thus by using the interval training approach, the total training time at 100\% \( \dot{V}O_2 \)\textsubscript{max} can be increased to 30 minutes from the 10 minutes possible under a constant load training program (MacDougall and Sale, 1981). It should be noted that shorter work and rest intervals would produce even less fatigue, but would target the ATP-
phosphocreatine system instead of the anaerobic lactic and oxidative systems (Fox and Mathews, 1974).

The rest intervals employed in interval training partially prevent or reduce the build up of fatigue producing metabolites, and allow certain systems such as the ATP-phosphocreatine system to at least partially recover themselves. This permits a more intense effort in each and every work interval.

(1.1.2.2) Cardiovascular

It is well documented that the stroke volume of the heart reaches its maximal values during the recovery period after exercise (Ekblom and Hermansen, 1968). Many rest periods during an exercise session allow for peak stroke volumes to be attained multiple times as opposed to the single peak resulting from constant load training. It is well known that a higher stroke volume contributes to a greater overall capacity in the aerobic system (Fox and Mathews, 1974). Given that interval training provides multiple instances of peak level stress on stroke volume with each training session, it seems reasonable to say interval training stimulates increases in stroke volume to a greater degree over the weeks of the training program. In turn this increase in stroke volume provides increases in aerobic capacity (Fox and Mathews, 1974).
1.1.2.3 Rate of Change and Avoidance of Desensitization

The body senses the stresses of exercise through the myriad of receptors that serve to maintain posture, balance, and homeostasis of controlled physiological variables, such as pH and blood pressure. Examples of receptors believed to be responsible for sensing exercise stress are proprioceptors, muscle spindle receptors, metaboloreceptors, peripheral and central chemoreceptors (Wasserman et al., 1986).

A well-documented property of receptors, whether they sense touch, temperature change, movement, light intensity, sound intensity or [H'], is that of ‘adaptation’ or ‘desensitization’ (Ganong, 1995: 114). The rate, degree of, and mechanism behind this desensitization is specific to the type of receptor itself. In general, desensitization implies that when a maintained stimulus of constant intensity is applied to a receptor, the frequency of action potentials in its sensory nerve declines over time (Ganong, 1995; 114).

A non-constant stimulus, whether it is sinusoidal, step-wise or otherwise varying in nature will manage to avoid this phenomenon of desensitization. This strategy may be important in receptors that cannot afford to become desensitized under conditions of constant stimulus at a maintained level. Receptors such as the peripheral chemoreceptors need to be sensitive to slight changes in physiological variables that are generally held under tight control.

It has been demonstrated that the peripheral chemoreceptors, important in the regulation of breathing during exercise, are sensitive to the breath to breath fluctuations in arterial CO₂/[H'] (Band et al., 1978; Whipp and Davis, 1977). It
appears as though the rate of change of Paco2 is of more importance and has a more stimulating effect than the mean Paco2 over time. Band et al. (1980) demonstrated that between-breath fluctuations in arterial [H+] at the level of the peripheral chemoreceptors exist. Further, the authors demonstrated that at approximately 10 seconds after onset the onset of exercise) dpH/dt increases by 2.7 times, and this appears to be related to the increase in ventilation accompanying exercise (Band et al., 1980). This work supports the hypothesis of an exercise hyperpnea mechanism involving the rate dependent sensitivity of the peripheral chemoreceptors.

Investigators have repeatedly shown the peripheral chemoreceptors to be more sensitive to changes or fluctuations in arterial Pco2 compared to conditions of constant stimulus. Examples are the studies of Dutton and Permutt (1966) where it was demonstrated that intermittent fluctuations in arterial Pco2/[H+] cause increased discharge from the peripheral chemoreceptors when compared to constant levels of arterial Pco2/[H+].

It is probable that other receptors responsible for aiding in the perception of exercise onset and stress would display increased discharge under conditions of fluctuating intensity of stimulus, as the phenomenon of desensitization would be avoided.
(1.1.3) Previous Studies

A limited number of studies have been conducted which compare adaptations to interval vs. constant load training. Four 'recent' studies have been published, that conclude that there are definite advantages to interval training in terms of endurance performance indicators. One study by Thomas et al. (1984) concluded that, "interval training may benefit aerobic capacity more than continuous training in young adults who have moderately high initial fitness levels." A second study by Poole and Gaesser (1985) showed that interval training had a significantly greater effect at augmenting \( T_v \) compared to constant load training. Meyer et al. (1990) concluded that recovering coronary bypass patients benefited more in terms of improved cardiac function and exercise performance. Gorostiaga et al. (1991) demonstrated that interval training protocols produce higher increments in maximal oxygen uptake and maximal exercise capacity.

There are five other 'recent' studies which found conflicting results, indicating that interval training has no significant advantages over continuous training in terms of endurance performance indicators. In 1977, Eddy et al. demonstrated that, so long as workload per training session was equated between experimental groups, continuous and interval training elicited identical improvements in heart rate responses, blood lactate concentrations and \( \dot{V}O_2 \)max. Bhambhani and Singh (1985) concluded that, "continuous and interval load training were equally effective in improving \( \dot{V}O_2 \)max and submaximal ventilatory efficiency, regardless of initial fitness level, provided that the total amount of work completed was equalized." A third study by Overand et al. (1992) demonstrated
that neither low nor high power output interval training offers an advantage over continuous training of the same average power output in altering aerobic variables. Cunningham et al. (1979) compared CT and IT protocols in women, and found no significant differences between groups in terms of adaptation to endurance performance. However it should be noted that the authors suggest that the IT protocol seemed to have elicit greater peripheral cardiovascular adaptation.

Siconolfi et al. (1994) conducted a study to quantify the benefits of IT protocols in terms of effecting orthostatic tolerance during space flight. The authors found that IT and CT protocols were equally effective in maintaining VO₂max. However, it was discovered that IT protocols managed to minimize any increase in post flight orthostatic heart rate, suggesting a greater benefit in terms of cardiovascular conditioning.

It is important to note that all the previous studies have used a training intensity for both the interval and constant load training protocols which is far higher than those which would be utilized in this proposed study. There is one exception, in a study by Keith et al. (1992). This investigation used a lower training intensity, at or about the lactate threshold, and found no difference between interval and constant load training in terms of adaptations in endurance performance indicators. While this study used a training intensity similar to that in this proposed study, trained individuals were used as subjects (though none were 'elite' athletes). A meta analysis by Londeree (1997) indicates that while sedentary individuals respond to low and high intensity training in a similar manner, trained
subjects require a higher training intensity to stimulate physiological adaptation to exercise.

In addition, for the interval trained group, Keith's study used intervals of 7.5 minutes (each session 30 minutes) for a total of only two 'on' and two 'off' cycles during each session. Since the proposed present investigation predicts that the frequent rate of change fluctuations associated with interval training provide the advantage in adaptive change, this proposed study is significantly different in terms of both subject profile and experimental protocol.

Past investigations show there are some conflicting results in terms of the advantages of interval training. However, it is interesting, that previous studies demonstrate interval training to be at least as effective, if not more effective than continuous training in terms of adaptive responses of endurance performance indicators. No 'recent' (1977 and on) literature has been found where a continuous training protocol proved more effective than an interval training protocol.
(1.2) **The Ventilatory Threshold**

(1.2.1) **Relationship to Lactate and Anaerobic Thresholds**

The term ‘anaerobic threshold’ (AT), originated in a paper by Wasserman et al. in 1973, entitled “Anaerobic threshold and respiratory gas exchange during exercise”. In this paper, AT was defined as, “the level of work or O₂ consumption just below that at which metabolic acidosis and the associated changes in gas exchange occur”. This definition is based on the belief that exercise above a certain ‘rate’ elicits the increased use of anaerobic metabolism to power muscle contraction or prompts decreased rate of lactate removal, which in turn results in a build up of lactate, and a drop in blood pH.

Two methods are commonly used to measure AT. Monitoring either blood lactate, or ventilatory gases during an incremental exercise test, allows the determination of a lactate threshold or a ventilatory threshold, respectively.

Respiratory transition from rest to maximal exercise has been described using three models: (1) the single breakpoint model, (2) the double breakpoint model or three phase model, and (3) the exponential or continuous function model (Anderson and Rhodes, 1989). The discrepancies over which transition model best describes the physiological conditions of the body are complicated by mechanistic uncertainty.

Skinner and McLellan (1980) proposed a model wherein ventilation and lactate profiles display two threshold-like increase responses during an incremental load exercise test. In their paper, the authors recognize that both of these breakpoints have been referred to as the ‘anaerobic threshold’ in previous articles,
which used the single breakpoint model. The first ventilatory and lactate thresholds as described by Skinner and McLellan (1980) correspond to what is now commonly referred to as the 'anaerobic threshold' (Walsh and Bannister, 1988), though the authors suggested naming this threshold the 'aerobic threshold' to avoid confusion with the one occurring at higher workloads. The second threshold in lactate and ventilation occur at a higher workload, now being commonly referred to commonly as the respiratory compensation threshold (RCT) (Walsh and Bannister, 1988). The model proposed by Skinner and McLellan allows one to speak of a first ventilatory threshold, which corresponds to the anaerobic threshold, a commonly used indicator of fitness and performance potential (Loat and Rhodes, 1993). Use of the single breakpoint model places the ventilatory threshold at an intensity higher than that where the anaerobic threshold is believed to be indicated in exercise tests, and so provides a less than useful model for our purposes. This study will therefore use the model as proposed by Skinner and McLellan (1980), focusing on the first ventilatory threshold, and will use the abbreviation T\textsubscript{v1} to represent that workload. The first lactate threshold, usually coincident with T\textsubscript{v1}, will be abbreviated as T\textsubscript{L1}.

Although a thorough discussion of the so called 'anaerobic threshold' is beyond the scope and purpose of this section, a brief description of the relationship between T\textsubscript{v1} and T\textsubscript{L1} is warranted given the controversy over their relationship.

While it had been common to refer to T\textsubscript{L1} and T\textsubscript{v1} interchangeably as anaerobic thresholds, there is now ample evidence that T\textsubscript{L1} and T\textsubscript{v1} do not measure the same underlying mechanisms. While many still believe that T\textsubscript{v1} is a ventilatory
response to a rise in blood lactate, there is evidence that $T_{V1}$ is a phenomenon representing a much more complicated underlying mechanism in which lactate may play some role.

Neary et al. (1985) and Cecca et al. (1986) found no relationship between plasma lactate levels and a threshold like behaviour in ventilation. Poole and Gaesser (1985) showed that different exercise protocols elicited different degrees of adaptation in both $T_{L1}$ and $T_{V1}$, suggesting different underlying mechanisms. Giving further support to this argument, Poole and Gaesser (1985) published results showing that the time courses of adaptation of $T_{L1}$ and $T_{V1}$ to training were quite different. In their study, eight weeks under the same training protocol elicited increases in $T_{L1}$ which were 2.5 times greater than those experienced in $T_{V1}$.

An interesting study by Hagberg et al. (1983) showed that patients with McArdle's disease (those who lack the enzyme muscle phosphorylase, and thus do not have a glycolytic pathway, and do not produce lactate), displayed a threshold-like response in ventilation during ramp exercise similar to that of normal patients. This threshold occurred despite no rise in plasma $[H^+]$ and thus no drop in plasma pH. However, it is recognized that these patients may have developed an alternate ventilatory response mechanism to exercise due to their lack of blood acidosis. Anticipation of the pain of exercise, a symptom of McArdle's disease, may have caused stimulation of hyperventilation (Davis, 1985).

Previous work has also called into question the necessity of a lactate threshold in eliciting a ventilatory threshold. Matika and Duffin (1994) conducted two consecutive maximal exercise tests on a group of subjects. The subjects were
allowed to rest after the first test for a time period adequate to allow ventilation to return to levels well below $T_v$, but not long enough that blood lactate concentrations recovered below that corresponding to $T_L$. During the second incremental exercise test, a ventilatory threshold was displayed even though blood lactate concentrations showed no such threshold response.

Thus, given the information available, when one speaks of an 'anaerobic threshold', it should be specified whether it is a lactic anaerobic, or a ventilatory anaerobic threshold, as the two are not always coincident or likely one and the same (Poole and Gaesser, 1985).

(1.2.2) Mechanisms for $T_v$

There are numerous possible reasons that ventilation displays a threshold-like response in normal individuals during incremental exercise. One theory suggests that the carotid bodies are responsible for the ventilatory threshold. This is supported by the observation that subjects who have undergone carotid body resection do not display a $T_v$ (Wasserman et al., 1975). Carotid bodies do respond to other stimuli Besides $H^+$ and $CO_2$, such as catecholamines and $K^+$ ion concentrations (Walsh and Banister, 1988). Regardless of the mechanisms through which they act, the carotid bodies do appear to contribute significantly to the threshold-like ventilatory response to exercise in normal subjects. The precise role of the peripheral chemoreceptors is unclear however due to the apparent involvement of other mechanisms.
One of these other mechanisms involves the effect of body core temperature on ventilation. It is well documented that alterations in body core temperature can have effects on cardiorespiratory variables. Studies have shown that passive elevations in body core temperature produce effects on both breathing frequency and tidal volume equivalent to those observed during exercise (Martin et al., 1979). In addition, external cooling during exercise causes decreases in ventilatory and heart rates (Kruk et al., 1985). A raised body core temperature has been shown to increase the sensitivity of pulmonary stretch receptors, also believed to play some role in the generation of a ventilatory threshold (Walsh and Banister, 1988). All of these temperature effects seem to be rate sensitive, showing the greatest effect on ventilation while there is a rate of change, rather than during a steady state (Walsh and Banister, 1988). A previous study from our laboratory demonstrated that thermal and central chemoreceptor drives for ventilation have a multiplicative effect on ventilation, and further that thermal ventilatory stimuli have an independent additive component (Baker et al., 1996).

Another potential mechanism that may contribute to the display of a ventilatory threshold during incremental exercise involves the group III and IV afferents from skeletal muscle. These skeletal muscle afferent neurons are known to affect cardiorespiratory parameters during exercise, and their stimulation elicits a change in breathing pattern similar to the change at the ventilatory threshold. Approximately 35% and 55% of group III and IV afferents respectively are excited by several chemical stimuli, including some that display threshold-like concentration changes at the ‘anaerobic threshold’ (Mateika and Duffin, 1995).
Some of these chemicals are $H^+$, lactic acid, reduced $PO_2$, $K^+$, catecholamines and orthophosphate (Walsh and Banister, 1988). These skeletal neurogenic factors appear to have a substantial effect on ventilation during exercise, but the exact role in terms of eliciting a ventilatory threshold is not yet known.

It is worth noting that there are two major hypotheses regarding the stimulatory drives for not only ventilation, but also cardiovascular control during exercise. The first, being the ‘muscle chemoreflex’ model, proposes that stimuli such as those discussed in the previous paragraph, along with other peripheral feedback afferents drive the response of cardio-respiratory systems during exercise (Rowell et al., 1986). Secondly, the ‘central command’ model suggests that centrally generated motor signals from the cerebral cortex stimulate the cardio-respiratory response in parallel during exercise (Eldrige et al., 1985). Though both models have support in literature, the mechanisms controlling ventilation during exercise and their relationships remain unclear. There is likely a complex interaction between the two models, which is responsible for the control of ventilation during exercise and the display of a threshold-like response in ventilation during ramp exercise (Rowell et al., 1986).

(1.2.3) Applications of $Tv_1$

Regardless of its underlying mechanisms, the first ventilatory threshold has been used as an accurate non-invasive measure or approximation of an individual’s anaerobic threshold. It is now widely accepted that the individual anaerobic threshold is a more useful estimator of endurance performance than is $\dot{VO}_2\text{max}$.
the long time standard for prediction of endurance performance. Since the anaerobic threshold is an important, and increasingly used estimator of an individual’s ability to perform exercise (Loat and Rhodes, 1993), $\text{Tv}_1$ can be used to non-invasively estimate an individual’s performance capabilities, with greater accuracy than might be possible through the use of $\dot{\text{VO}}_2\text{max}$ tests alone.

In addition, for sedentary persons wishing to begin an exercise program to improve lifestyle and energy levels, the $\text{Tv}_1$ proves to be an ideal workload range for training. There is little risk of metabolite-induced exhaustion, and this workload provides stimulus for adaptation to exercise just as effectively as a higher workload where muscle fatigue and discomfort are a risk (Casaburi et al., 1995; Londeree, 1997.)

(1.2.4) Determination of $\text{Tv}_1$

By definition, $\text{Tv}_1$ corresponds to the first point of non-linear increase in ventilation during an incremental workload test. Regardless of the mechanisms eliciting the threshold-like response in ventilation, there are several methods of detecting where in the test the threshold occurred. Since $\text{Tv}_1$ is ‘picked-off’ graphs by observers, there tends to be a subjective component in determining exactly where $\text{Tv}_1$ is said to occur. To minimize this ‘guesswork’, several tools have been employed by investigators to aid in the determination of $\text{Tv}_1$ (Bischoff and Duffin, 1995; Ciaozzo et al., 1982).

Gas exchange measures commonly used in the detection of thresholds are ventilation, $\dot{\text{VCO}}_2$, $\dot{\text{VCO}}_2/\dot{\text{VO}}_2$ and $\dot{V}/\dot{\text{VO}}_2$ vs. time. Analyzing these values in
different ways allows resolution of the point where $T_v$ exists. Ciaozzo et al. (1982) suggested that $\dot{V}/\dot{V}O_2$ displayed the highest test-retest correlation and was the most reliable measure in the prediction of $T_v$. The authors also determined that ventilation and $\dot{V}CO_2$ were the most accurate means of resolving $T_v$ as a measure or representation of the anaerobic threshold. A study by Fukuba et al. (1988) verified the conclusions of Ciaozzo’s group. Due to equipment specifications of the gas analyzer used in this project (see Methods, section 2.6), ventilation, CUSUM, and $\dot{V}CO_2$ data were used to resolve $T_v$.

The following three sections outline the graphical analysis used for $T_v$ determination in this study. The methods section 2.6 further details the analysis of $\dot{V}O_2$ and HR graphs using the time corresponding to $T_v$ as obtained from the ventilation, $\dot{V}CO_2$ and CUSUM graphs.
(1.2.4.1) Ventilation vs. Time Graph

Fig. 1.2.1 represents a typical ventilation vs. time graph as obtained from an incremental load exercise test. \( T_{V1} \) is chosen as the point preceding the first non-linear increase in ventilation.

![Ventilation vs. Time Graph](image)

**Fig. 1.2.1** - A representative ventilation graph as obtained from incremental load exercise test data. The dashed line indicates where the first non-linear increase in ventilation can be seen to occur. The corresponding time as read off the x-axis is the point in the test where \( T_{V1} \) occurred.
(1.2.4.2) $\dot{V}CO_2$ vs. Time Graph

A disproportionate rise in $\dot{V}CO_2$ is known to accompany the non-linear increase in ventilation seen at $Tv_1$ (Anderson and Rhodes, 1989). This disproportionate increase can therefore be used to resolve $Tv_1$ from exercise test data. A representative $\dot{V}CO_2$ vs. time graph during an incremental workload exercise test is shown in Fig. 1.2.2.

![$\dot{V}CO_2$ vs. Time](image)

*Fig. 1.2.2 - A representative $\dot{V}CO_2$ graph obtained from an incremental load maximal exercise test. The dashed line indicates the first non-proportional increase in $\dot{V}CO_2$ during the test. This corresponds to $Tv_1$, and is used to determine the time where $Tv_1$ occurs, as read off of the x-axis (approx. 270 s).*
(1.2.4.3) CUSUM vs. Time Graph

The CUSUM (cumulative sum) method uses the observation that the variability in ventilation data begins to increase at $T_{V_1}$. Taking the absolute values of the differences between ventilation points in a ventilation graph and summing them in a cumulative manner gives a curve as shown in Fig. 1.2.3. At $T_{V_1}$, the CUSUM graph begins to rise at a disproportionate rate relative to the first region of the curve. This point of increase corresponds well to $T_{V_1}$ as determined through other methods, and can be used as an aid in the determination of $T_{V_1}$ (Bischoff and Duffin, 1995).

CUSUM Graph

![CUSUM Graph](image)

Fig. 1.2.3 - A typical CUSUM graph. The dashed line represents the first non-proportionate increase in the slope of the curve. The corresponding time, read off of the x-axis, is used to represent the point in the incremental load exercise test where $T_{V_1}$ occurred.
(1.3) SEDENTARY PERSONS

The definition of sedentary is less straightforward than one may imagine. Bernstein et al. (1999) attempted to formulate a precise definition of sedentarism. Based upon their definition, sedentary persons are those expending less than 10% of their daily energy expenditure on the performance of moderate and high intensity activities (at least 4 times their basal metabolic rate). Though intended to permit comparison across studies and populations, this definition requires a rather complicated assessment of lifestyle.

It is well understood that genetic potential has a great deal to do with both aerobic and anaerobic fitness, independent of lifestyle factors (Fagard et al., 1991). The use of fitness indicators, such as \( \dot{V}O_2 \text{max} \), to define sedentarism, creates the risk of wrongly classifying individuals as a result of differences in base genetic potential. An individual may have an above average \( \dot{V}O_2 \text{max} \) as a result of genetic factors and still be sedentary in terms of lifestyle. The opposite could also be true.

For the purpose of this study, a sedentary individual was defined as one not having been involved in a regular exercise activity/program for at least 3 months, and not having been involved in formal exercise training for at least 6 months.
(1.4) Breathing Sounds and Exercise

Recent work has established that exercising at an intensity where one begins to “hear their breathing”, will place that individual in a target workload range that approximates TV₁ (Goode et al., 1998). Normally, breathing sounds at rest are quiet and remain unnoticed. During exercise at higher intensities, breathing sounds become quite audible. Whether hearing one’s own breathing sounds occurs via the ossicular, air or bone conduction pathways, is relatively unimportant. What is important is that a change occurs which makes breathing sounds audible, and that this change occurs around TV₁.

It seems logical that the change in breathing that begins to cause breathing ‘noise’ is increased airflow in the upper respiratory tract. This could cause a shift from a laminar type flow towards a more turbulent flow pattern. Laminar flow could be described as a more structured, ‘smooth’ type of flow pattern, whereas turbulent flow is more disorderly. Fig. 1.4.1 shows a schematic representation of laminar and turbulent flow in a pipe representing the trachea.
Reynolds Number ($N_R$) predicts whether a given flow will be laminar or turbulent. It takes into account the momentum and viscous forces acting in a fluid under a given set of circumstances. At $N_R < 2000$, flow is generally laminar, while higher values such as those over 4000, represent turbulent flow patterns. The equation for $N_R$, and hence to predict flow pattern is
\[ N_R = \frac{D \cdot v \cdot \rho}{\mu} \]  
(Duffin, 1976; 151)

where, 

- \( D \) = diameter of 'tube'
- \( v \) = average velocity of the fluid
- \( \rho \) = density of the fluid
- \( \mu \) = dynamic viscosity of the fluid

Since the only thing likely to change to any great extent in this equation during exercise is the velocity of the air through the respiratory tract, it is this, which must affect the flow type exhibited during breathing. When ventilation increases to a certain point during exercise, the flow of air must reach a value where it drives \( N_R \) up to a level where turbulent flow would be predicted. At this point, breathing becomes 'noisy' and an individual can 'hear' their breathing. This point seems to correspond to \( T_{V1} \).

After individuals undergo a training effect, it is well known that \( T_{V1} \) rises and occurs at a higher \( \dot{VO}_2 \) (Poole and Gaesser, 1985). It seems reasonable to assume that the point where ventilatory sounds become audible during exercise wouldn't rise to this new workload, since the values of \( D, \rho \) and \( \mu \) would remain the same. Therefore, it is possible that monitoring your workload using breathing sounds will cause an underestimation of \( T_{V1} \) after a training effect occurs and \( T_{V1} \) has risen to a new value.
The average velocity of the air through the respiratory airways can be represented by mean inspiratory flow (MIF). MIF is equal to tidal volume divided by the inspiratory time. This gives a value with units in ml·s⁻¹.

\[ \text{MIF} = \frac{V_T}{T_i} \]

Establishing whether the MIF at \( T_{v1} \) changes after training could help determine the validity of using a breathing sound check to monitor exercise intensity after a training effect has been elicited.

It is recognized that training is known to reduce the ventilatory demand for any given workload during exercise. Thus, as the workload corresponding to the higher 'trained' \( T_{v1} \) will correspond to a higher intensity, the ventilatory demand at that higher intensity will have decreased. The interplay of these factors is unclear, and changes in MIF with training will be affected by both to some degree, the extent of which remains to be determined.

(1.5) HYPOTHESES

Given the theoretical advantages in interval vs. constant load training as discussed in section 1.1.2, it is hypothesized that the interval load group will experience larger increases in \( \dot{VO}_2\text{max} \) and \( T_{v1} \) as a result of their respective training programs. Additionally, it is hypothesized that mean inspiratory flow at \( T_{v1} \) will change and occur at a higher value. Therefore it is hypothesized that exercise training will affect the ability to target \( T_{v1} \) using breathing sounds.
(2.1) Subjects

(2.1.1) Sample Size

Experimental data from a comparable study by Gorostiaga et al. (1991) was used to predict the required number of subjects to detect a between-group difference in this study. The values of 0.05 and 0.8 represented $\alpha$ and $(1-\beta)$, respectively. An expected between-group difference of 2.2 ml·(kg·min)$^{-1}$, and an estimated standard deviation of 1.8 ml·(kg·min)$^{-1}$ were used to make predictions, as taken from Gorostiaga et al. (1991).

A computer statistical software package (SigmaStat, Jandel Scientific), determined that $N=12$ should be adequate for detecting the estimated between group differences.

(2.1.2) Recruitment

Volunteer subjects were recruited by means of advertisements placed around the University of Toronto’s St. George campus (see appendix III).
(2.1.3) Group Placement

Subjects were randomly placed in either the interval load training (IT) or constant load training (CT) group by order of entry into the study. Subjects were assigned a protocol in an alternating fashion to ensure random placement.

(2.2) EXPERIMENTAL PROTOCOL

(2.2.1) Overview

Subjects were first brought to the laboratory for a familiarization session. Here, they could see and ask questions about the exercise test and the equipment, as well as inquire about the pace setting, and exercise training program. A consent form approved for the study was read and signed by all subjects volunteering to participate (see appendix I). Volunteers also filled out two questionnaires. One, based upon the PAR-Q or 'physical activity readiness questionnaire', was utilized to ensure volunteers had no history of cardiac or stress related illness (Thomas et al., 1992). The second was a training history questionnaire (see appendix II).

A second visit to the lab was arranged to conduct an exercise test on the subject. This test allowed the collection of data, which was analyzed to determine baseline values, such as maximum oxygen uptake, first ventilatory threshold, heart rate and mean inspiratory flow at TV1.

The next meeting with the subject took place at the Field House track in the Athletic Centre on U of T's St. George campus. Pace setting and training of subjects took place on this indoor track. A polar HR monitor was used to set the
subjects’ walking/jogging pace at or about a HR coincident with the subjects HR at their Tv1, as determined through their exercise test. This walk /jog pace was employed for the first 4 weeks of training, after which a second ‘1/2 way’ exercise test was scheduled.

The training pace for the final 4 weeks of training was set to correspond to the HR at Tv1 as determined through the new data. This ‘re-setting’ of the subject’s exercise pace was to compensate for an expected training-induced increase in the individual’s Tv1 and ensure the subject was working at or about a pace corresponding to their new threshold. After eight weeks of training, the subject was asked to perform a final exercise test. The data from all three tests were then used to determine the extent of any changes in $\dot{VO}_2\text{max}$, Tv1, MIF, maximum HR and Tv1.

(2.2.2) Training

For the CT group, subjects were asked to walk or jog progressively faster until their HR rose to the target HR (at Tv1) as determined through their individual test. A polar HR monitor was used to track HR, while the pace of the walk or jog which elicited a HR corresponding to that at their Tv1, was determined aurally through the use of the digital metronome. The metronome was set at the same pace as the subject was walking or jogging. This pace was recorded and used to set the exercise intensity during training. The heart rate monitor was worn for the duration of the first training session to ensure that the set pace did elicit the target HR for the remainder of the session. After the half-way (4 week) exercise test, a
new target HR was established, and a new training pace was set for the subject to train at for the duration of the program (weeks 5-8).

For the IT group, the same general procedure was used, only this group worked in an interval fashion about their $T_{V_1}$, as opposed to a constant workload. Target HR's 15% above and 15% below the HR corresponding to $T_{V_1}$ were used for the high and low intensity intervals of the training program. The lower pace was set first at the track, followed by the higher pace. It was verified that these paces would elicit the targeted HR's for extended durations. While training, the IT group walked/jogged at the lower intensity pace for 2.5 minutes, followed by the higher intensity pace for 2.5 minutes. This cycle was repeated six times every session, for a total of 30 minutes. The use of the metronome to monitor pace meant that the workload could be increased or decreased accurately and relatively immediately, allowing a pseudo-square-wave interval training protocol while walking or jogging.

To ensure subjects didn’t alter stride length and change the workload over the training period, time for completion of one lap on the track was recorded and checked periodically throughout the program.

The total workload of the training sessions was thus kept equivalent across the IT and CT groups, while the actual training protocol differed. Both groups trained for 30 minutes per session, 3 times per week, for the 8 weeks the program lasted.
A schematic representation of the training protocols is shown below in fig. 2.2.1.

**Fig 2.2.1** - Schematic representation of CT and IT training protocols.

Workload is set based on the HR determined to correspond to $Tv_1$, and is monitored via walking/jogging pace using a digital metronome.
(2.3) EQUIPMENT

Subjects performed maximal exercise tests on a motorized treadmill (Quinton Instruments, model 18-49-B), capable of inclines of 0-40% and speeds up to 6 MPH. Ventilatory gases were collected from the mouth through a 2-way non-rebreathing valve, while the subject wore nose clips. Fresh room air was drawn in through the valve, and expired air flowed out through the valve into a wide-bore collection tube, connected to a Parkinson-Cowan dry gas meter. The expired gas was ‘mixed’ in this meter as its’ volume was measured. A sample of this mixed-expired gas was collected through a gas sample tube connected to a rapidly responding anaesthetic gas monitor (Bruel and Kjaer, model 1304). The anaesthetic gas monitor used a sample flow rate of 90 ml·min⁻¹, with CO₂ being analyzed via photoacoustic infrared spectroscopy and O₂ via magnetooacoustics. The O₂ resolution was 1% (vol.) with a range of 0-100%. CO₂ resolution was 0.1% (vol.) with a range of 0-10%. During the test, the subjects’ HR was monitored using a finger probe pulse oximeter (resolution of 1 bpm, accuracy of 2%), also connected to the anaesthetic gas monitor. The range of the pulse oximeter was 20-250 bpm.

Analog output from all monitoring equipment was passed through a 16-bit pulse code modulation adaptor (Vetter Digital, Model 3000A) and recorded on a VCR (JVC Hi-Fi Stereo VCR, model HR-D840U 500C) using standard VHS tapes for back-up purposes. This same analog output was passed in parallel through a National Instruments D/A converter (model AT-M10-16XE-50) in an Intel Pentium based PC, where specially written software (James Duffin, Labview, 34
version 5.1) analyzed the digital output and stored it in a standard format. Further analysis of the data was done using Excel 97 (Microsoft) and statistical software (SigmaPlot5, SPSS and SigmaStat, Jandel Scientific). A schematic representation of the exercise test set-up can be see on the next page, in fig 2.3.2.

On the track, a polar HR monitor (Nissen, model PU-801) was used in conjunction with a Seiko digital metronome (model DM-33), in order to set and monitor the subjects' walk/jogging pace.

The polar HR monitor and the pulse oximeter were compared several times for agreement, in terms of the heart rate readings that they displayed. Having a subject exercise while using both HR monitoring methods simultaneously allowed this comparison. The two means of monitoring HR were found to be consistently accurate to within 2 bpm.

Calibration of the CO₂ and O₂ reading was done before and after each exercise test, using a gas of known concentrations. These gas was passed through the anaesthetic monitor via the sampling tube, and a calibration procedure inherent to the monitor was initiated after setting temperature and barometric variables according to the day to day conditions. Further, it was ensured the gas monitor and computer software displayed equivalent values for O₂ and CO₂ pressures using room air and the same calibration gas as used in the monitor calibration sequence. Barometric pressure and temperature factors were also taken into account during this sequence and used by Labview to correct for volume effects.

The finger probe oximeter was calibrated against the ECG method of HR determination for accuracy. Having a subject exercise while using the oximeter
probe and the ECG lead set-up permitted this comparison. The HR was then calibrated in the computer software to ensure the HR on the computer and gas monitor agreed, with the Labview gains and offsets being adjusted where necessary. The gas meter was calibrated by passing a known volume of air through the meter (Hans Rudolph Inc. 1 litre calibration syringe, Model 5540), and calibrating the computer software to ensure the displayed volume equaled the volume being passed through the meter.
Exercise Test ‘Set-up’

Fig 2.3.2 - Schematic representation of the exercise test equipment
(2.4) The Exercise Test

To determine each subject’s $\dot{V}O_2\text{max}$, $Tv_1$, HR’s and MIF, three maximal exercise tests were performed: one at the beginning of the study, one half-way through the training program (4 weeks), and one at the end of the training program (8 weeks). All subjects were familiarized with the equipment, its’ function and the measurements being taken during the test. Treadmill exercise was used for the test, as this approximated the walk/jog training protocol.

For the test, subjects ‘warmed up’ at a walking pace for 3 minutes. The treadmill speed was then increased to 3 mph, and the subject was asked to indicate whether the speed should be increased or decreased to attain what they perceived to be a ‘brisk walk’. The speed was then adjusted up or down, depending on the subjects’ response. Any further adjustments were made at this point and the speed of the treadmill remained constant at this speed for the full duration of the test.

Subjects walked at this set pace for one minute, and then the test began ($t=0$). Subjects began exercise at a grade of 0%, with the incline (workload) being increased by 2% after the first minute and another 2% every minute until the subject reported that they had one minute of endurance left. At the end of that minute, the test ended and the treadmill was lowered to a 0% slope, with the speed gradually reduced to a calm walk. Subjects kept walking until their HR was below 120 bpm. This protocol was designed to bring the subject to exhaustion in 10 minutes, as this is reported to result in the highest values for $\dot{V}O_2\text{max}$, though time has little effect on $Tv_1$ (Wasserman et al., 1984). If the test ended prior to 9
minutes, or lasted longer than 15 minutes, the test was repeated a minimum of 48 hours later.

For the half-way and post-program tests, the treadmill was set to the same speed as used for the subject’s previous test, and adjusted upwards if necessary. The same test protocol was followed for all three tests on each subject.

(2.5) \( \dot{V}O_2 \text{MAX DETERMINATION} \)

\( \dot{V}O_2 \text{max} \) refers to the maximum \( O_2 \) utilization capacity of an individual’s aerobic system. This value is indicated as a plateau in the \( \dot{V}O_2 \) vs. workload (time) graph as obtained through an incremental load exercise test (see schematic diagram on next page, fig. 2.5.1).

In order for a subject to sustain a plateau in his or her \( O_2 \) consumption during an incremental workload, that individual must endure the accumulation of anaerobic byproducts and the discomfort and fatigue associated with exercise at this intensity. It is difficult to attain such a plateau in \( \dot{V}O_2 \) for obvious reasons. Subjects may state that they cannot go on once they reach the \( \dot{V}O_2 \) value, which if they were to go on, would end up being a plateau. Sedentary subjects, such as those used in this study, are especially unlikely to display a plateau in their \( \dot{V}O_2 \) graphs since they are unaccustomed to such demands on their bodies (Casaburi, 1994).
‘Peak-VO₂’ is a term used to describe the maximum VO₂ value attained during an incremental load exercise test, wherein a plateau was *not* indicated in the data. Under certain conditions, ‘Peak VO₂’ can be used to closely estimate what the subjects’ VO₂,max would have been had they been able to continue the test. This is because, provided the subject met certain criteria at the peak VO₂, this value would closely match the plateau value for the VO₂, had they managed to continue on in discomfort. It is widely accepted that a plateau in VO₂ is not a prerequisite in determining VO₂,max, so long as criteria based peak VO₂ values are achieved (Duncan et al., 1997).
The conditions for stating a peak $\dot{V}O_2$ as such are:

1. Respiratory exchange ratio (RER) $\geq 1.1$, and/or

2. $HR_{\text{max}} \geq 85\%$ of theoretical maximum HR (220-age)

In this study, $VO_{2\text{max}}$ will be used as a general term to represent either a peak $\dot{V}O_2$ or a strict $\dot{V}O_2\text{max}$ plateau. Should a subject have not at least attained a peak $\dot{V}O_2$ as described under the conditions above, their exercise test was repeated.

In this study, $\dot{V}O_2$ vs. time graphs were used to determine $\dot{V}O_{2\text{max}}$ from the test data. These $\dot{V}O_2$ graphs were fitted with regression lines in order that a statistically accurate value for $\dot{V}O_{2\text{max}}$ could be read from the graph at its' maximum point. In the event that a plateau was indicated, a 2-segment regression line was fitted to the data, otherwise a straight line was fitted through the appropriate data points.

![O2 Uptake](image_url)

**Fig 2.5.2 -** $\dot{V}O_2$ uptake data for subject CD. The fitted regression line allows the determination of $\dot{V}O_2$ occurring at any time during the test, most importantly, at $T_v$ and peak $\dot{V}O_2$. 

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(2.6) Determination of the First Ventilatory Threshold

In order to determine T_v1 from the test data, cumulative sum of differences (CUSUM), \( \dot{V}CO_2 \) and ventilation graphs were used. Though ideally, \( \dot{V}O_2 \) data would have been used as an aid in the determination of T_v1, the O_2 resolution of the anaesthetic gas monitor made such an aid impractical. The O_2 readings had an error of \( \pm 1\% \), whereas the CO_2 readings were accurate to \( \pm 0.1\% \). For this reason, only ventilation and \( \dot{V}CO_2 \) data were employed in the techniques used to resolve T_v1.

Two independent, trained and blind observers were used to determine T_v1 using the CUSUM, \( \dot{V}CO_2 \) and ventilation graphs for each test. Should the time at T_v1, as determined through all three graphs have coincided, this was taken as the T_v1 for the test. If the time (t) value from one graph disagreed, the value as obtained through the other two coinciding graphs was used as t at T_v1. In the event that all three graphs yielded somewhat different values, the average of the t value from the three graphs was used to represent t at T_v1. The values for T_v1 given by both observers were compared. If they differed, both observers re-checked their findings. If there was still disagreement, an average of the observers' time values was taken to represent t at T_v1.

The time value corresponding to T_v1 was used to determine the HR and the \( \dot{V}O_2 \) occurring at T_v1. This \( \dot{V}O_2 \) was used as the representative value for T_v1.
Fig. 2.6.1 – The $\dot{V}\text{CO}_2$, Cusum, ventilation, $\dot{V}\text{O}_2$ and heart rate graphs with a line indicating the time corresponding to $T_{v1}$ as determined by the top three graphs. HR and VO$_2$ at $T_{v1}$ are read from the regression lines in their respective...
(2.7) **Determination of Mean Inspiratory Flow (MIF)**

The data from the exercise tests were analyzed through another program (National Instruments, Labview) which determined values for ventilation, $\dot{V}O_2$, $\dot{V}CO_2$ and HR on a breath-by-breath basis. This type of analysis allowed the determination of tidal volume ($V_T$) and inspiratory time ($t_i$). From these data, MIF ($V_T/t_i$) could be calculated.

A graph of ventilation vs. time was used to verify the $T_{v1}$ obtained through the 1Ol analysis. Twenty-one data points were taken from the breath-by-breath data, ten immediately before, ten immediately after and including the point corresponding to the ventilatory threshold. These data were used to determine an average $V_T$ and $t_i$ for ventilation at $T_{v1}$, from which mean inspiratory flow at $T_{v1}$ was determined.

![Breath-by-Breath Ventilation](image)

*Fig 2.7.1 - Breath-by-breath analysis of ventilation during an incremental exercise test on subject CD. The dashed lines represent the 21 breath interval, across which a value for mean inspiratory flow was determined through the average values of $V_T$ and $t_i$.***
(2.8) Statistical Analysis

In order to determine the extent of changes in the variables HR (maximum and at Tv1), VO2 max, Tv1 and MIF at Tv1, statistical testing was conducted on data acquired from the pre-, mid- and post-training exercise tests.

First, Two Way Repeated Measures ANOVA testing was conducted on data in order to determine the overall effects of the treatment factors (training time and training protocol) on the aforementioned variables, as well as to determine the extent of interaction between training time (zero, four and eight weeks) and training protocol (constant or interval method). Simply stated, this design allowed for the testing of differences between the different levels of each treatment, as well as for the interactions between the treatment factors.

Should the ANOVA tests have yielded significant results (c ≤ 0.05), post-hoc testing was conducted through the use of Bonferroni t-tests. The Bonferroni t-test performs a pair-wise comparison using standard paired t-tests, and subsequently multiplies the resulting P-values by the number of comparisons that were made.

Where analysis of the CT and IT groups was done on an individual basis, this was conducted using One Way Repeated Measures ANOVA tests, followed by the use of Bonferroni t-tests to determine which levels of the factor of training time (zero, four and eight weeks) were significantly different.
(3) RESULTS

(3.1) SUBJECTS

Sixteen subjects (five males and eleven females) volunteered to participate in the study. Two subjects were removed from the study early in their participation due to non-compliance with the program. Fourteen subjects (five men and nine women) completed the entire study.

Subject GA was removed from the data analysis for treatment effects and between group differences. This decision was made after his results showed unusual changes in his \( \dot{V}O_2\)max data. Study supervisors determined that a change in his lifestyle just prior to his involvement in the study were likely responsible for the steady decrease in \( \dot{V}O_2\)max over the eight week training period. Subject GA is discussed and outlined further in appendix IV.

The remaining thirteen subjects were used in all data analysis for this study. Subjects divided into their experimental group (CT or IT), their age, sex, weight and initial fitness levels are shown below in tables 3.1.1 and 3.1.2.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Sex</th>
<th>Age</th>
<th>Weight</th>
<th>Training</th>
<th>( \dot{V}O_2)max</th>
<th>( Tv_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Protocol</td>
<td>(l\cdot min(^{-1}))</td>
<td>[ml(kg\cdot min)(^{-1})]</td>
</tr>
<tr>
<td>BG</td>
<td>m</td>
<td>50</td>
<td>63.2</td>
<td>CT</td>
<td>3.13</td>
<td>37.8</td>
</tr>
<tr>
<td>FH</td>
<td>f</td>
<td>30</td>
<td>79.0</td>
<td>CT</td>
<td>2.72</td>
<td>34.4</td>
</tr>
<tr>
<td>GS</td>
<td>f</td>
<td>44</td>
<td>75.0</td>
<td>CT</td>
<td>2.14</td>
<td>28.5</td>
</tr>
<tr>
<td>JS</td>
<td>f</td>
<td>29</td>
<td>70.8</td>
<td>CT</td>
<td>2.58</td>
<td>36.4</td>
</tr>
<tr>
<td>LV</td>
<td>f</td>
<td>32</td>
<td>76.5</td>
<td>CT</td>
<td>2.39</td>
<td>31.2</td>
</tr>
<tr>
<td>RB</td>
<td>f</td>
<td>22</td>
<td>70.4</td>
<td>CT</td>
<td>2.18</td>
<td>31.0</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.5</td>
<td>33.2</td>
</tr>
<tr>
<td><strong>SD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.4</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Table 3.1.1 – Summary of initial subject data for constant load training group.
In order to compare the subjects in the CT and IT groups for differences in initial fitness, age and weight, unpaired t-tests were performed on pre-program data. With $\alpha$ set at 0.05, this method of analysis yielded no significant between group differences for age, weight or initial fitness level in terms of $\dot{V}O_2\text{max}$ [ml/(kg·min)] or $Tv_1$ [ml/(kg·min)]. Statistical power for these t-tests (generally 0.050) was not great enough however to exclude the possibility of a type-II error, but empirical observation shows no great differences in initial mean values for these variables.

(3.2) Treatment Effects.

In order to analyze HR, $\dot{V}O_2\text{max}$, $Tv_1$ and MIF for effects of treatment factors (training time and protocol), two-way analysis of variance tests, with one repeated measure were performed on the data.
(3.2.1) HR at T\textsubscript{v1}

Analysis of heart rate at T\textsubscript{v1} showed that no significant changes occurred as a result of training time, or protocol (P=0.902 and P=0.561 respectively). This result was expected, as cardiovascular improvements would have counteracted training induced increases in workload at T\textsubscript{v1}. Statistical power for these findings was 0.05 in both cases, well below the desired (1-\(\beta\))=0.80.

(3.2.2) Maximum HR

No training induced changes in HR max were indicated in the data. The effects of training time on maximum HR showed a P value of 0.079. This was not significant at the pre-determined level of significance for this study (\(\alpha\)=0.05). Training protocol did not display any independent effects on maximum HR (P=0.271). The interaction between training time and protocol indicated a stronger effect (P=0.091), though this was not significant at \(\alpha\)=0.05. Power for statements regarding the effects of training time, protocol and interaction effects on HR max were, 0.335, 0.306 and 0.0797 respectively, leaving open the possibility of a type-II error.
(3.2.3) \( \dot{V}O_2 \text{max} \)

Subjects displayed significant improvements in \( \dot{V}O_2 \text{max} \) whether expressed in absolute or relative measures (\( P<0.001 \)). Neither training protocol nor interactions between training time and protocol contributed to these increases (\( P=0.852 \), and \( P=0.284 \) respectively). Power for the latter results was below the desired level of 0.80.

(3.2.4) \( T_v_1 \)

Subjects displayed significant improvements in \( T_v_1 \) as a result of training (\( P<0.001 \)). Neither training protocol nor interaction between training protocol and time contributed to this effect (\( P=0.500 \) and \( P=0.676 \) respectively). As in the results for \( \dot{V}O_2 \text{max} \), statistical power for negative statements regarding the effects of protocol and interaction were 0.05, below the desired level of 0.80.

(3.2.5) Mean Inspiratory Flow

Analysis of changes in MIF with training revealed no significant effects resulting from training time, protocol or their interaction (\( P=0.598 \), \( P=0.787 \) and \( P=0.963 \) respectively). Variance and small sample size limited power for these negative findings (0.05), allowing for the possibility of type-II error.
(3.3) POST-HOC ANALYSIS

(3.3.1) CT Group

Statistical analysis of the CT group using a One Way Repeated Measures ANOVA test (P<0.001) and subsequent Bonferroni t-tests, showed a significant increase in $\dot{V}O_2$max and $Tv_1$ between the pre- and post-program exercise tests (P<0.05) when expressed as either l·min$^{-1}$ or ml·(kg·min)$^{-1}$ values. However, this analysis determined that in the CT group, changes in neither $\dot{V}O_2$max nor $Tv_1$ were significant after four weeks of training (P>0.05).

Given the near significant reductions in HRmax through the Two Way ANOVA test, a post-hoc analysis of these data was also conducted, out of interest. A One Way Repeated Measures ANOVA test determined that heart rate at maximum values did not display any significant reduction in the CT group (P=0.104), although statistical power (0.292) was not great enough to exclude a possible type-II error.

A graphical summary of changes in $\dot{V}O_2$max, $Tv_1$, HR and MIF is shown in fig. 3.2.1. A summary of the data and % changes is given in table 3.2.1.
CT Group Treatment

Fig 3.2.1 - Pre-, mid- and post-program exercise test values for $\dot{V}O_2$max, $T_v$, HRmax and at $T_v$, and MIF at $T_v$. Values are group means with SE bars.
(3.3.2) IT Group

Statistical analysis of the IT group using a One Way Repeated Measures ANOVA test (P<0.001) and subsequent Bonferroni t-tests, showed there was a statistically significant increase in VO$_{2\text{max}}$ and TV$_1$ whether expressed in absolute or relative measures, after both 4 and 8 weeks of training (P<0.05). As in the CT group, post-hoc analysis of maximum HR data was conducted out of interest, given the near significance for changes due to training time as determined through the use of the Two Way ANOVA testing (P=0.079). A One Way Repeated Measures ANOVA test determined that heart rate at maximum values did not display any significant reduction in the IT group (P=0.129), although statistical power (0.243) was not great enough to exclude a possible type-II error.

A graphical summary of changes in HR, VO$_{2\text{max}}$, TV$_1$ and MIF for the IT group is shown in fig. 3.2.2. A summary of the data and % changes is given in table 3.2.1.
IT Group Treatment Effects

Fig 3.2.2 - Pre-, mid- and post-program exercise test values for \( \dot{V}O_2\text{max}, T_{V1}, \)
HRmax and at T\(_{V1}\), and MIF at T\(_{V1}\). Values are group means with
SE bars.
<table>
<thead>
<tr>
<th></th>
<th>CT Group (n=6)</th>
<th></th>
<th>IT Group (n=7)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre (±SD)</td>
<td>Mid (±SD)</td>
<td>% change</td>
</tr>
<tr>
<td>Body Weight</td>
<td>75.8 (2.0)</td>
<td>75.7 (5.8)</td>
<td>-0.1</td>
</tr>
<tr>
<td>( \dot{V}O_2 \max \ \text{(l/min)} )</td>
<td>2.52 (.15)</td>
<td>2.62 (0.16)</td>
<td>3.8 *</td>
</tr>
<tr>
<td>( \dot{V}O_2 \max \ \text{ml/(kg-min)}^{-1} )</td>
<td>33.2 (1.4)</td>
<td>34.6 (1.8)</td>
<td>4.1 *</td>
</tr>
<tr>
<td>( T_v ) (l/min$^{-1}$)</td>
<td>1.46 (.09)</td>
<td>1.63 (.08)</td>
<td>11.7 *</td>
</tr>
<tr>
<td>( T_v \text{ ml/(kg-min)}^{-1} )</td>
<td>19.2 (1.2)</td>
<td>21.5 (0.8)</td>
<td>11.8 *</td>
</tr>
<tr>
<td>HR at ( T_v ) (bpm)</td>
<td>135 (6.9)</td>
<td>135 (4.8)</td>
<td>0.4</td>
</tr>
<tr>
<td>HRmax (bpm)</td>
<td>179 (5.7)</td>
<td>175 (5.4)</td>
<td>-2.6</td>
</tr>
<tr>
<td>MIF (ml/s)</td>
<td>1762 (191)</td>
<td>1781 (337)</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Table 3.2.1 – A summary of treatment effects for CT and IT groups. Values are means (± SD). Asterisks beside percentages indicate significance at an \( \alpha \) level of 0.05.
(3.4) **Between Group Differences – CT vs. IT**

Though ANOVA testing indicated that there were no significant interactions between training time and training protocol, post-hoc analysis of between group differences for changes in \(\dot{V}O_{2\text{max}}\) were conducted, out of interest, using Bonferroni t-tests.

Graphically, the IT group displayed a slightly larger increase in \(\dot{V}O_{2\text{max}}\) [ml·(kg·min)\(^{-1}\)] after 4 weeks of training (see next page). After the 8-week training program was complete, any such graphically observed differences in training effect had disappeared. The between group difference in increases in \(\dot{V}O_{2\text{max}}\) at four weeks was determined to be statistically significant at \(P=0.073\) but not at the pre-determined level of significance in this study \((\alpha = 0.05)\). Lack of statistical power however, does not necessarily indicate that there wasn't a difference in training effect. Figure 3.3.1 shows the change in \(\dot{V}O_{2\text{max}}\) and \(T_{V_1}\) for the CT and IT groups over the 8-week training program as determined by pre-, mid-, and post-program tests.
Fig 3.3.1 - Changes in $\dot{V}O_2$max and $Tv_1$ for CT and IT groups.
(4.1) CRITIQUE OF METHODS AND RESULTS

(4.1.1) Subjects

(4.1.1.1) Gender

There were more female subjects in this study than male, and due to the random placement of subjects based on order of entry into the study, there were unequal numbers of men and women in experimental groups. The IT group had three male subjects, whereas the CT group had only one (another male subject, GA, was in the CT group but was removed from the study for the purpose of data analysis – see section 3.1). A study by Eddy et al. (1977) used men and women in a CT vs. IT comparison, where the groups trained at an intensity of 70% and 100% of \( \text{VO}_2\text{max} \), respectively, for four days per week. The authors concluded that the male and female subjects responded in an equivalent manner to the training, eliminating sex differences as a source of variance in data. A review by Lewis et al. (1986) and a study by Cunningham et al. (1979) also conclude that central and peripheral adaptations in the cardiovascular system under aerobic training programs are equivalent in men and women. Therefore it seems likely that sex differences were not of significant concern in this study.
(4.1.1.2) Sedentary Subjects

This study aimed to investigate the training response of a sedentary population to interval training. Problems in defining 'sedentary' were outlined in section 1.3. It is well known that initial fitness level as indicated by \( \text{VO}_2\text{max} \) is a major determinant of both the rate and magnitude of improvement in aerobic parameters (Casaburi, 1992; Bouchard et al., 1988; Eddy et al., 1977). The potential for improvement in cardiovascular fitness is greater for less active (or less 'fit') individuals, and decreases with the degree of conditioning already attained (Casaburi, 1992). In other words, the pre-training phenotype level of the individual is a major determinant of the degree of response to exercise training, and is a major factor underlying the variation seen in human response to exercise training (Bouchard et al., 1988).

The use of a careful screening process for admitting volunteers into the study, such as that described by Bernstein et al. (1999) would have been desirable, but was beyond the resources available for this project. This, because extensive analysis of lifestyle would have required the involvement more investigators or a much longer time-span for project completion. Having a less than rigorous definition of 'sedentary' allowed subjects with a variety of pre-program activity levels to participate in this study, and in this way may have increased variance in the adaptive response to the training protocols used.
(4.1.1.3) Genetic Components

Individuals are known to have differences in genetic potential for endurance fitness (Bouchard et al., 1999; Fagard et al., 1991). Such genetic differences also affect the adaptive ability of the individual, such that differing capacities for aerobic improvement are displayed under the same training protocol (Bouchard et al., 1999; Bouchard et al., 1992; Fagard et al., 1991). Bouchard and Lortie (1984) completed an extensive review article outlining the effects of genetic variability on human capacity for adaptation to exercise training. The authors listed three main indicators where genetic influence can be felt in endurance performance: (1) As genetic effects on traits correlated with endurance performance; (2) As a source of human variation in endurance performance independent of training; and (3) As it determines the extent of the sensitivity to training. Bouchard and Lortie (1984) described the total phenotypic variance in endurance performance through the use of the following equation:

\[ V_p = V_G + V_E + V_{G \times E} + e \]

where \( V_p \) represents the total variation observed in endurance performance, \( V_G \) represents the genetic component of variance, \( V_E \) represents the non-genetic factors involved in variance, \( V_{G \times E} \) represents the interaction between the genetic and environmental conditions, and \( e \) represents the random error component inherent in assessing endurance performance.

Using athletes in exercise training studies tends to limit the variability caused by differences in genetic potential (\( V_G \)), as athletes are generally members of the population who have expressed an innate ability for improvement through
training. Alternatively, the use of sedentary individuals causes base genetic potential ($V_O$) to be more variable between subjects and become a more pronounced factor adding to variance in data from studies such as this one.

However, systematic avoidance of sedentary subjects to control for genetic factors in variance imposes limitations on the applicability of results towards the general population. There is an apparent trade-off between limiting variability and maintaining applicability of results. Large-scale investigations with resources permitting the use of greater sample sizes (e.g., N=50) would allow sedentary subjects to be studied while reducing the concern of having to limit genetic variability in endurance performance factors. Given the aim of this study, increased variability due to genetic factors was unavoidable.

(4.1.2) Exercise Testing

(4.1.2.1) $\dot{V}O_2$max Determination

The use of sedentary subjects also had inherent problems when it came to conducting maximal exercise tests (Casaburi, 1992). These difficulties were previously described in section 2.6. Peak $\dot{V}O_2$'s were obtained and used to represent 40 out of the 42 $\dot{V}O_2$max values that provided data for this study. This is a reasonable and valid approach, as peak $O_2$ consumption has been accepted as an accurate estimation of maximum $O_2$ consumption, and achieving a plateau in $O_2$ uptake is not necessary in order to determine $\dot{V}O_2$max (Duncan et al., 1997; Noakes et al., 1988).
(4.1.2.2) \( T_{v1} \) Determination

Mathematical models and regression analysis can be performed and used in order to facilitate the determination of \( T_{v1} \) (Orr et al., 1982). Previous studies show that these methods are of limited value and do not provide any increase in the accuracy of threshold determination, beyond that provided by visual inspection techniques (Davis, 1985; Yeh et al., 1983).

This study used visual inspection of ventilation, CUSUM and \( \dot{VCO}_2 \) graphs to determine \( T_{v1} \) from exercise test data. A detailed description of the ventilation, \( \dot{VCO}_2 \) and CUSUM graphs was given in section 1.2.4, along with the approach taken in order to resolve \( T_{v1} \). These three methods have been previously described by researchers as being valid and reliable tools for resolving \( T_{v1} \) (Bischoff and Duffin, 1995; Fukuba et al., 1987; Ciazzo et al., 1982). The use of such tools in the determination of \( T_{v1} \) limited the subjective component involved in this task. Additionally, the use of two trained, blinded observers in determining the threshold from graphs removed the possibility of investigator bias in the act of collecting data.

(4.1.3) Training Protocol

The walk/jog method of training was chosen for three main reasons. First, it is a training method sedentary people can begin without buying equipment, and can be performed nearly anywhere, indoors or outdoors. Second, the walk/jog protocol allowed a near instantaneous increase or decrease in workload by
targeting a walk/jog pace through the use of the metronome. This allowed for a pseudo square-wave interval training protocol around $T_v_1$ that held CT and IT groups at an equivalent absolute workload. Third, the adaptations in working muscles were such that these adaptations would provide practical benefit to the subjects because walking is an activity that is useful in daily routines.

(4.2) ENDURANCE IMPROVEMENTS

(4.2.1) Treatment Effects

It is clear from the data that both CT and IT groups received significant training effects after four and eight weeks of training. Indicators of endurance fitness improved significantly for both experimental groups, whether expressed in absolute or relative measures. This result was expected, as a meta-analysis of previous studies by Londeree (1997) has shown that training at a workload corresponding to $T_v_1$ will elicit a significant training response in sedentary persons.

(4.2.2) Differences Between Groups

(4.2.2.1) Endurance Performance Indicators

There were no between group differences which could be resolved at $\alpha=0.05$. This result refutes the hypothesis that the theoretical advantages of interval training would elicit larger improvements in $\dot{V}O_2^{\text{max}}$ and $T_v_1$ as endurance performance indicators. However, data from this study graphically indicated that the IT group may have experienced a greater degree of adaptation in $\dot{V}O_2^{\text{max}}$ after four weeks (non-significant $P=0.078$), which was no longer
apparent after the end of the eight week program (P=0.876). Statistical power for the non-significant results was limited by variance and sample size, and was in the order of 0.335. This value fell below the desired (1-β)=0.80.

(4.2.2.2) Heart Rate

The effects of training time on maximum HR showed a P value of 0.079. Though this was not significant at the pre-determined level of significance for this study (α=0.05), it none-the-less shows a trend towards a reduction in maximum HR that may have been resolved with a larger sample size. The near significance in the reduction of maximum HR with training prompted post-hoc analysis of data. Changes in maximum HR (HR at VO2max) were not significant in either group when analyzed separately. Once again the statistical power for non-significant results was limited by the sample size and variance in the data, with (1-β)=0.050, below the desired value of 0.80.

Researchers have previously described IT protocols as having an advantage in stimulating cardiovascular adaptation (Siconolfi et al., 1994; Meyer et al., 1990; Fox and Matthews, 1974). Perhaps monitoring other indicators of cardiovascular adaptation, such as changes in stroke volume and a-v O2 differences, or the use of a larger sample size may have allowed resolution of the reported advantages of interval training on cardiovascular adaptation in this study. However, such advantages were not observed, as indicated by HR max.

Since both CT and IT groups increased their VO2max and TV1 significantly, while HR stayed the same, it is apparent that cardiovascular fitness increased for
both groups. Such results indicate that the subject’s cardiovascular systems adapted, becoming capable of delivering more \( O_2 \) to the active muscles while using fewer cardiac cycles to do so.

(4.2.2.3) Time-Course Differences in adaptation

From the results, it appears as though a difference in the time-course for adaptation may exist under CT and IT protocols. Although the CT and IT groups displayed nearly identical increases in \( Tv_1 \) and \( \dot{VO}_{2\text{max}} \) after the eight weeks of training was completed, the IT group seemed to have a greater rate of change for increases in \( \dot{VO}_{2\text{max}} \) compared to the CT group in the initial stage of the program. Though the between group difference for increases in \( \dot{VO}_{2\text{max}} \) at four weeks wasn’t significant (\( P=0.078 \)), the lack of statistical significance is likely a sample size problem, not a situation in which there is likely no difference. By this halfway point of the training program, the IT group had already attained 58% and 53% of their increases in \( Tv_1 \) and \( \dot{VO}_{2\text{max}} \) respectively. At the same point in the training program, the CT group had only managed to achieve 42% and 20% of their overall increases in \( Tv_1 \) and \( \dot{VO}_{2\text{max}} \) respectively.

As a result, statistical analysis of the CT and IT groups separately, demonstrated that the IT group displayed significant increases in \( Tv_1 \) and \( \dot{VO}_{2\text{max}} \) after four and eight weeks, whereas the IT group showed such significance increases after eight weeks, with no significance in the improvements after four weeks of training. These apparent differences prompted a review of results from
other CT vs. IT studies where mid-program exercise tests allowed an evaluation of
the time course for changes in $\dot{V}O_2\text{max}$.

(4.2.2.3.1) Comparison with Previous Results

A review of results from a study by Cunningham et al. (1979) showed similar
time course differences in adaptation to CT and IT protocols. Here, the CT group
trained at an intensity of 70-80% of $\dot{V}O_2\text{max}$, and the IT group trained at an
intensity corresponding to 90-100% of $\dot{V}O_2\text{max}$. Although there were no
significant between group differences in overall adaptation to the training program
in terms of $\dot{V}O_2\text{max}$, improvements in this indicator of aerobic fitness occurred
faster than in the IT group when compared to the CT group. The training program
used in their study was twelve weeks. The IT group attained 75% and 88% of the
overall increase in $\dot{V}O_2\text{max}$ after four and eight weeks of training, respectively. At
the same points in the study, the CT had attained only 37% and 67% of their
overall adaptation. Figure 4.2.1 shows a graphical representation of these
differences.
Bhambhani and Singh (1985) also conducted an exercise study where CT and IT protocols were compared and a mid-way test was performed. Two CT groups were used in their study, and trained at intensities of 10% and 50% of the ($\dot{\text{VO}}_2\text{max} - \text{T}_1$) difference above $\dot{\text{VO}}_2\text{max}$, while the IT group trained at an intensity corresponding to 100% of $\dot{\text{VO}}_2\text{max}$. The IT group in their study displayed a faster time course than either CT group, with increases in $\dot{\text{VO}}_2\text{max}$ being 89% complete after four of the eight weeks of study. The CT protocols elicited 84% and 64% of their respective changes in $\dot{\text{VO}}_2\text{max}$ at the same point in the program. This data is graphically represented in Fig. 4.2.2.
Bhambhani and Singh, 1985

![Graph showing % of overall change in VO2max](image)

**Fig. 4.2.2** – Results from a study by Bhambhani and Singh (1985) showing the % of overall increases in VO2max attained at times as indicated by the training program.

One exception to the trend seen in the two aforementioned studies exists in a study by Keith et al. (1992). Their study compared CT and IT protocols at an intensity corresponding to the anaerobic threshold. Subjects in their study were athletes and/or recreational fitness enthusiasts. The results from their study showed that the CT group gained 71% and 65% of their overall increases in VO2max and TV1 respectively after four weeks in an eight-week program. At the same point in the study, the IT group showed only 59% and 54% of their overall improvements in VO2max and TV1, respectively. These results are shown graphically in Fig. 4.2.3.
The conflicting results from Keith et al.'s 1992 study may have been due to the training protocol used. Keith et al. used 7.5-minute intervals for the IT group, allowing only 2 on-off transitions per 30-minute training period, a protocol which did not constitute interval training in its proper sense, as previously described. The differences and possible benefits of IT depend heavily upon the on-off transitions provided during the training period (Daniels and Scardina, 1984; Fox and Matthews, 1974). Providing the IT group with only two such transitions, defeats the purpose of an IT protocol.
Further, the study by Keith et al. (1992) used trained athletes and/or fitness enthusiasts for subjects, and the training intensity corresponded to the anaerobic threshold. It has already been clarified in section 1.2.1 that regardless of the mechanisms involved, the anaerobic threshold, as determined through ventilatory or lactic acid measures, corresponds to a relatively light to moderate exercise intensity (Loat and Rhodes, 1993; Anderson and Rhodes, 1989). It has also been well established that trained athletes require a higher intensity than that corresponding to $T_v$ in order to benefit from training (Londeree, 1997). Thus, given the fact that Keith's study used 7.5-minute intervals and trained athletes and/or fitness enthusiasts training at a light to moderate intensity, results are likely irrelevant to the findings of time-course differences for adaptation between CT and IT protocols, in the present study.

(4.2.3.2) Implications

A disparity in the time-course for adaptation in endurance performance indicators suggests that there may be differences in the way CT and IT protocols elicit adaptive change. These differences could be due to the intensity differences between protocols, although exercise intensity is one of the most controversial aspects of an exercise training program design (Casaburi, 1994). A review of literature by Wenger and Bell (1986) suggested that intensity is of key importance in stimulating adaptive change. Their conclusion was that regardless of initial fitness level, program length, exercise duration or frequency, intensity was the most important factor in determining adaptive response in the aerobic parameters.
Since the IT group was training at intensities transiently greater than those of the
CT group, this could have supplied an advantage in stimulating adaptation.

In addition, IT and CT protocols may elicit change via the central and
peripheral components of the cardiovascular system to different degrees and at
different rates, thereby accounting for the difference in the rate of improvement in
endurance performance under the two protocols. Information regarding such
differences is very limited, as few studies into the effects of CT and IT have been
conducted, and fewer where the mechanisms underlying such differences have been
investigated. Only two such studies could be found.

In the Cunningham et al. study (1979) both CT and IT groups improved
indicators of their aerobic endurance, with the IT group displaying a slight
advantage. The IT group demonstrated an increased a-v O₂ difference. The
investigators suggested that IT protocols are more effective in stimulating
adaptation in the peripheral system as a result of the increased stress that higher
intensity exercise provides.

Gorostiaga et al. (1991) also came to the same conclusion, that interval and
constant load training effect changes in muscle tissue metabolism through different
mechanisms. The CT group in their study was described as having a greater
increases in muscle oxidative capacity as indicated through increased
concentrations of the mitochondrial marker enzyme, citrate synthase. The IT group
was described as having an inconsistent increases in muscle glycolytic function. In
light of these differences, it should be noted that in Gorostiaga’s study, the IT
group displayed a significantly greater increase in \( \dot{V}O_{2\text{max}} \) when compared to that of the CT group, after 8 weeks of training.

(4.2.2.4) Protocol Preference

Observation during this study showed that all subjects found the workload to be somewhat challenging in the first and fifth week of the program, when they were just starting their training and when the workload had just been increased. The types of discomfort were described differently between the CT and IT groups. CT subjects complained of fatigue in the anterior regions of the left and right lower legs (in the region of the tibialis anterior) for about 3 sessions at their new workloads, after which this discomfort was no longer reported. IT subjects complained more of breathlessness and temperature related 'full body fatigue', which also disappeared with adaptation after approximately three sessions (one week) at the new workload.

Since CT and IT protocols may show no discernable differences in terms of improvement in overall endurance performance, subject preference may be the determining factor in terms of the method used for training.
(4.3) CHANGES IN MIF

Analysis of changes in MIF with training revealed no significant effects resulting from training time, protocol or their interaction (P=0.598, P=0.787 and P=0.963 respectively). An upward trend in MIF was observed in both groups over the eight weeks of training, however these changes were slight, and may have been purely a result of sampling variability. This result refutes the hypothesis that training would cause MIF at the first ventilatory threshold to increase, along with the rise in TV₁ to a higher absolute workload. Power for these negative findings was much lower than the desired (1-β)=0.80, and as such must be taken with caution.

As a result, definite conclusions regarding our hypothesis that exercise training would affect the long-term use of the ‘breath sound check’ as a tool for monitoring exercise intensity, cannot be made. Improvements for a future protocol aimed at determining the extent of training effects on the ‘breath sound check’ are possible and would be easily implemented with different equipment. A further discussion of possible mechanisms underlying the ‘breath sound check’, and exercise-induced changes that may affect its long term use, follow.

It is well known that exercise ventilation decreases for a given workload as a result of aerobic training (Casaburi, 1992; Casaburi et al., 1987). Adaptation to exercise training also causes TV₁ to occur at a higher absolute workload. Thus, the decrease in ventilation at this workload may well mean that the mean inspiratory flow is left virtually unchanged, as these two adaptations cancel one another out in terms of their effect on ventilation at TV₁.
In this study, mean inspiratory flow (MIF) was used to determine any changes which might have taken place with training, and which may have affected the point in incremental exercise when ventilation produced turbulent flow. Other investigators have shown that breathing sounds are of greatest intensity during the expiratory phase of the breathing cycle, becoming 36% greater than those produced during inspiration (Mahagnah and Gavriely, 1994; Charbonneau et al., 1983).

In this study, it was assumed that monitoring inspiratory flow would be adequate for making predictions regarding ventilatory flow during the expiratory phase. This assumption seems intuitively valid, since changes in inspiratory flow will be accompanied by changes in expiratory flow that are directionally equivalent and proportional in magnitude. Thus a lack of change in MIF at TV1 implies a lack of change in mean expiratory flow at TV1. The equipment used in this study allowed direct measurement of inspiratory time (ti), leaving expiratory time (to) to be determined via subtracting ti from the total time for a complete breath cycle. As a result to would have been an indirect measurement, including any pauses in the breath cycle. Use of equipment allowing direct measurement of to would provide a more relevant variable with which to work.

Another basic assumption that was made in drawing conclusions regarding breathing sounds, is that they emanate from the upper respiratory tract, comprised of airways that are not likely to change in diameter as a result of training. Researchers have shown that breathing sounds are of greatest intensity at the level of the trachea (Mahagnah and Gavriely, 1994; Charbonneau et al., 1988), and it
has previously been predicted that turbulence of airflow at this level is responsible for breathing sounds (Austrhein and Kraman, 1985). It therefore seems valid to use airflow changes as a means of monitoring changes that may affect turbulence in the airways at T_v1, as airflow (speed) is the only component of the equation for N_R that is likely to change in the trachea with habitual exercise in a healthy population.

This study analyzed mean inspiratory flow as opposed to peak flow. It is likely that the onset of ventilatory sounds in the trachea arise during peak flow velocities, not under a given mean flow. Monitoring peak flow may result in data with less variance and provide a more relevant variable with respect to the onset of breathing sounds during exercise. The equipment used in this study allowed measurement of expired volumes, but not flow rates. An experimental design incorporating an impeller-based flow meter would allow for such flow measurements, as well as the determination of both t_i and t_c.

Normalizing ventilation data would be a great advantage in reducing variance between subjects, as ventilation depends greatly on body size (Sherwood, 1993: 433). Using a variable such as vital capacity, known to correlate highly with ventilation, to normalize data may facilitate the resolution of any changes in peak flow resulting from habitual exercise.
(4.4) **Overall Conclusions**

The following conclusions were drawn from this study:

- CT and IT protocols with equivalent absolute workloads at an intensity corresponding to $T_v_1$ both resulted in significant adaptive improvement in endurance performance indicators for sedentary subjects.

- Between group differences for increases in $\dot{VO}_2_{max}$ and $T_v_1$ were absent, refuting our hypothesis that interval training would be more effective at increasing endurance performance indicators. Sample size limited statistical power, therefore caution must be used in interpreting these results.

- Definite conclusions regarding the effects of habitual exercise on MIF at the first ventilatory threshold cannot be made given the lack of statistical significance and power resulting from variance and limited sample size. Future work with equipment and protocol designed to resolve such changes is required.
Additionally:

The improvements displayed in endurance fitness indicators had noticeable benefits for these subjects. As a result of their training programs, they were able to exercise at higher maximal workloads. More importantly, increases in \( T_v \) suggest that their 'anaerobic threshold' had also increased due to better oxygen delivery and a larger capacity for oxidative metabolism in the trained muscle (Casaburi, 1994). This training effect allowed the subjects to perform physical activity at higher workloads for extended periods of time, without the fatigue and discomfort associated with build-up of anaerobic by-products. Activities such as climbing stairs, running to catch a bus, or walking the family dog will place less physiological stress on the body, and make such daily physical tasks seem less difficult. All of the subjects indicated that such beneficial effects were indeed experienced in their daily routines.
(4.5) Future Research

Further investigation into the time course difference for adaptation between CT and IT protocols could prove interesting. It may be that IT protocols would be more beneficial in the earliest stages of exercise programs, while in the long term switching to a CT protocol would promote maximal adaptation. It would also be interesting to determine whether such a disparity in time course for adaptation would be displayed in athletes training at high intensities. Investigation into the mechanistic differences between CT and IT and the adaptive changes that occur under these protocols may shed light on the benefits of either protocol. For example, CT and IT protocols may elicit adaptation in central and peripheral components of the cardiovascular system to different extents or at different rates, making one protocol more desirable under some circumstances (i.e., for recovering patients). Such mechanistic differences may indeed be present even in the absence of differences in overall increases in endurance performance.

A study directed towards resolving a time course difference for adaptation between CT and IT protocols would need a very specific protocol. This would include a longer training program (~16 weeks) with frequent exercise tests such that a half-life for training effects under CT and IT programs could be compared.

It would be interesting to design a study aimed at determining the mechanism behind the 'hear your breathing' technique. If turbulent airflow underlies the mechanism, then more refined methods of measuring the changes in airflow at TV1 with training would be useful. Monitoring peak airflow with an impeller-based
meter during incremental exercise tests, and normalizing ventilation data would provide a more accurate means of determining changes after training. In addition, comparing trained and untrained subjects using the 'hear your breathing' method for accuracy in the targeting of TV₁ would be a simple method of determining whether long-term training reduces the accuracy of this technique. Effects of adaptation to exercise may limit any long-term use of this technique, and such changes therefore warrant investigation.
Appendices

(I) Volunteer Consent Form

(II) Training History Questionnaire

(III) Subject Recruitment Flyer

(IV) Discussion of Subject GA

(V) Subject data (13 subjects)
CONSENT FORM

The purpose of this experiment is to evaluate the relative effectiveness of two different exercise training protocols on ventilatory threshold (VT). This experiment is being conducted through the Department of Physiology at the University of Toronto by Dr. R.C. Goode (Supervisor/principal investigator) and Mr. Harold Bell (M.Sc. student).

As a subject in this experiment, you will be randomly assigned to one of two experimental groups: (1) Training 3 times per week, 30 minutes per session at a constant work load corresponding to your own VT; or (2) Training 3 times per week, 30 minutes per session in an interval fashion: 2.5 minutes at 15% above your VT and 2.5 minutes at 15% below for 6 cycles. Both experimental groups will perform the same total amount of work in each 30 minute session, the difference being in the training method used. Both groups will use jogging as the method of exercise training.

The training program itself will last 8 weeks, while the entire study participation will last approximately 10 weeks, this including the preliminary interview, familiarization session, and final review of the results of your training program. Training sessions will be supervised by Mr. Bell, with heart rate being monitored to maintain a targeted work rate. In addition, for the interval training group, jogging 'pace' will be monitored and used to adjust work load during the sessions.

Initially, your VT (and \( V\text{O}_2\text{max} \)) will be determined in the lab on a motorized treadmill using a simple, non-invasive technique. During this test, a mouthpiece and nose clip will be worn to facilitate the collection of ventilatory gases. In addition, your heart rate and mechanical workload will be monitored throughout the test. The \( V\text{O}_2\text{max} \) tests will require an incremental load exercise output to the point of exhaustion. These tests will take place in the respiratory research lab at the beginning, end and 1/2 way through the training process. The 1/2 way test will be used to adjust training workload so that it closely approximates the individuals VT as it is expected to rise as a result of the training program. These 3 tests will last approximately 10 to 15 minutes. Subjects will be asked to abstain from eating, drinking caffeine-containing beverages and taking medication for 3 hours prior to the tests. Overall increases in your experimental group's fitness indices will be studied and compared to those of the other experimental group.

Metabolic by-products are produced during such an exercise test, which accumulate in the blood stream (i.e. lactic acid). As this by product accumulates, a feeling of nausea may occur which will later quickly subside. Other more remote potential risks include transient lightheadedness, fainting, blood pressure irregularities, chest pain, muscle cramping, and an extremely remote chance of heart attack (less than 1 in 100000 for men under 30, and less than 1 in 10000 for men 30 to 70 yrs. of age).

If you consent to this invitation to participate in this experiment, you will be asked to fill out a Physical Activity and Readiness Questionnaire (PAR-Q). This questionnaire is to ensure that you have no history of cardiac or stress related illness, and are indeed fit to participate in an
investigation of this nature. You will also be asked to fill in a small set of questions regarding your training history and your current level of physical activity. The answers will be strictly confidential and will only serve to assist in the analysis of the data collected. Subsequent to the start of the experiment, any relevant changes in health status (as per PAR-Q) should be reported as soon as possible to Mr. Bell or Dr. Goode.

Jogging is a common, practical method of training, and is easily used by sedentary individuals. Subjects may feel minor discomfort in the active muscles in the initial stages of training, as is common in any training program. This is a very short term effect, and is likely to have been experienced by and familiar to all subjects prior to their involvement, as a result of physical activity.

Overall risks due to this experiment are minimal. Normal, healthy individuals should readily be able to perform the exercise protocols with little risk to their health and well-being. The overall workload for your training sessions will be quite moderate. As already stated, no invasive techniques will be employed. It is expected that, as with any moderate exercise training program, this investigation will provide health related benefits to you, should you choose to participate. Through participating, you will have the opportunity to observe the results of your training program through the fitness testing process.

The results from your participation in this experiment will provide useful information which will expand our current knowledge regarding effectiveness of low intensity training on sedentary persons, and the advantages of interval vs. constant load training protocols. If you have any questions regarding any of the information on this form, please do not hesitate to ask the experimental representative before consenting to participate.

I have read and understand the above description of the proposed experiment, and consent to participate as a subject. I also realize that I am free to withdraw my consent at any time during the experiment, with no further obligation to the principal investigator or the Department.

_____________________________   _______________________________   _______________________________
NAME                                     SIGNATURE                                      DATE

Witness:  _______________________________   _______________________________
NAME                                     SIGNATURE

CONTACTS:

<table>
<thead>
<tr>
<th>Name</th>
<th>Phone Number</th>
<th>E-mail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harold Bell</td>
<td>(416) - 289 - 3598</td>
<td><a href="mailto:harold.bell@utoronto.ca">harold.bell@utoronto.ca</a></td>
</tr>
<tr>
<td>Dr. R. C. Goode</td>
<td>(416) - 978 - 6247</td>
<td><a href="mailto:robert.goode@utoronto.ca">robert.goode@utoronto.ca</a></td>
</tr>
</tbody>
</table>
Training History Questionnaire

Participant Identification:

Name: ________________________

Date: ________________________

Signature: ____________________

1. How many of the past 14 days have you done at least 20 minutes of exercise **hard** enough to make you breathe heavily and make your heart beat fast? (Hard exercise includes, for example, playing soccer, jogging fast dancing or bicycling etc.; include time in any instructional classes for such activities.)

   (a) None  (d) 6 to 8 days
   (b) 1 to 2 days  (e) 9 or more days
   (c) 3 to 5 days

2. If you answered b,c,d or e in the above, what type of activity was it?

   _______________________________________________________

3. How many of the past 14 days have you done at least 20 minutes of exercise that **was not** hard enough to make you breathe heavily and make your heart beat fast? (Light exercise includes, for example, playing baseball, walking or slow bicycling etc.; include time in any instructional classes for such activities.)

   (a) None  (d) 6 to 8 days
   (b) 1 to 2 days  (e) 9 or more days
   (c) 3 to 5 days

4. If you answered b,c,d or e to the above, what kind of activity was it?

   _______________________________________________________

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5. How would you rate your current level of physical activity on a scale of 1-5, where 1 is lowest and 5 is the highest activity level?

1 2 3 4 5

6. On the same scale type as above, please rate your level of physical activity in youth/adolescence?

1 2 3 4 5

Thanks, your co-operation is greatly appreciated!

INTERESTED IN A PERSONALIZED AND FULLY SUPERVISED EXERCISE TRAINING PROGRAM?

We are currently recruiting volunteers for a UofT study into the effects of low intensity exercise training on sedentary persons. Participants will receive a personalized exercise program that will correspond to their individual fitness level. Three descriptive fitness tests will enable volunteers to see their progress and better understand their own level of endurance fitness. Training sessions will take place 3 times per week for 30 minutes per session, with the entire training program lasting 8 weeks.

All persons 18-44 years of age and not currently involved in an exercise training program are welcome to participate. Just call Harold for more information at (416)-289-3598 (messages welcome), or e-mail me at harold.bell@utoronto.ca!
Discussion of Subject GA

Subject GA was placed in the CT group by virtue of his order of enrolment in the study. His data are listed below.

Age – 19

Gender – Male

<table>
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<th>Exercise Test</th>
<th>Body Weight (kg)</th>
<th>HR at TV1 (bpm)</th>
<th>VO2 at TV1 ml·(kg·min)(^{-1})</th>
<th>HRmax (bpm)</th>
<th>VO2max (ml/kg/min)</th>
<th>MIF (m/s)</th>
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<td>63.4</td>
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The first thing noticed in GA’s first exercise test data, was an unusually high VO2max of 65 ml/kg/min. Given our definition of sedentary used in this study (see Introduction, sec. 1.6), GA met entry requirements. However, his endurance indicators suggested a well developed training effect. GA informed study supervisors that he had been involved in cross-country running during high school, but hadn’t participated in any regular exercise activity in over nine months.

GA was trained under the assumption that his high endurance indicators were genetically influenced, and that training at his TV1 would benefit him since he wasn’t displaying a maintained training effect.

Once his test data was collected and analyzed, it was noticed that his VO2max was steadily declining over the training period, while his TV1 was
increasing, but only marginally. Since this was at odds with expectations and all other results in the study, GA was interviewed by study supervisors at the end of his program.

It was determined that GA had undergone a lifestyle change just prior to the start of the study, which may have affected his fitness. While GA had stated that he felt his lifestyle was sedentary, and that he wasn’t and hadn’t been exercising regularly for at least 3 months, this wasn’t as accurate as he thought.

GA revealed that he had been in the habit of inline skating for up to a couple of hours per day, every day during the school year, as this was his primary mode of transport around the city. Just prior to the study, he had reduced his daily activity, as end of year exams were being prepared for and written. He then moved back home from U of T residence to Oshawa, commuting several times each week for summer classes and this study. Since he wasn’t in the city, he no longer had the same duration or intensity of activity on a daily basis. GA didn’t realize that inline skating had given him a training effect, as this was in his mind just a way of getting about the city.

Since, (1) GA displayed such unusual results; (2) his recent lifestyle could explain his high endurance indicator values; and (3) his lifestyle change would explain his detraining in terms of $\dot{V}O_2\text{max}$, study supervisors decided to exclude GA from data analysis for treatment effects and between group differences.
### Subject Data

(1) Subject BG

**Age** - 59

**Gender** - male

**Training Protocol** - Constant load

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<td>2191</td>
<td>2390</td>
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</table>
Subject BG - Exercise Test # 1

O₂ Uptake

Heart Rate

Breath-by-Breath Ventilation

Time (s)
Subject BG - Exercise Test #2

**O₂ Uptake**

O₂ uptake over time (L/min).

**Heart Rate**

Heart rate over time (b/min).

**Breath-by-Breath Ventilation**

Ventilation (L/min.) over time (s).
(2) Subject CD

Age - 23

Gender – female

Training Protocol – Interval load

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<td>123</td>
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<td>173</td>
<td>174</td>
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<tr>
<td><strong>T\textsubscript{v_{1}} ml\cdot(kg\cdot min)\textsuperscript{-1}</strong></td>
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<td>19.1</td>
<td>20.6</td>
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<tr>
<td><strong>\dot{V}\textsubscript{O_{2max}} ml\cdot(kg\cdot min)\textsuperscript{-1}</strong></td>
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<tr>
<td><strong>MIF at T\textsubscript{v_{1}} (ml/s)</strong></td>
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<td>1216</td>
<td>1204</td>
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</table>
Subject CD - Exercise Test # 1

**O₂ Uptake**

- \( \dot{V}_{O₂} \) (L/min)
- Time (s)

**Heart Rate**

- Heart Rate (b/min)
- Time (s)

**Breath-by-Breath Ventilation**

- Ventilation BTPS (L/min)
- Time (s)
Subject CD - Exercise Test # 2

**O₂ Uptake**

- \( \dot{V}O_2 \) (L/min)
- Time (s)

**Heart Rate**

- Heart Rate (b/min)
- Time (s)

**Breath-by-Breath Ventilation**

- Ventilation (L/min)
- Time (s)
Subject CD - Exercise Test #3

O₂ Uptake

\[ \dot{V}_O^2 (L/min) \]

Heart Rate

Heart Rate (bpm)

Breath-by-Breath Ventilation

Ventilation BTPS (L/min)

Time (s)
(1) Subject FH

**Age** - 30

**Gender** – female

**Training Protocol** – constant load

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<td>180</td>
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<td><strong>VO₂max ml/(kg·min)^{-1}</strong></td>
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<td>1972</td>
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Subject FH - Exercise Test # 1

O₂ Uptake

Heart Rate

Gas Meter Steady-State

Time (s)
Subject FH - Exercise Test # 2

**O₂ Uptake**

![O₂ Uptake Graph]

**Heart Rate**

![Heart Rate Graph]

**Breath-by-Breath Ventilation**

![Breath-by-Breath Ventilation Graph]
Subject FH - Exercise Test # 3

**O₂ Uptake**

\[ \dot{V}O_2 \text{ (L/min)} \]

**Heart Rate**

\[ \text{Heart Rate (b/min)} \]

**Breath-by-Breath Ventilation**

\[ \text{Ventilation BTPS (L/min.)} \]

Time
(1) Subject GS

**Age** - 44

**Gender** – female

**Training Protocol** – Constant load

<table>
<thead>
<tr>
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<tr>
<td><strong>HR\textsubscript{max} (bpm)</strong></td>
<td>174</td>
<td>170</td>
<td>168</td>
</tr>
<tr>
<td><strong>T\textsubscript{v1} ml/(kg\cdot min)\textsuperscript{-1}</strong></td>
<td>15.9</td>
<td>18.9</td>
<td>26.0</td>
</tr>
<tr>
<td><strong>\dot{VO}_{2}\textsubscript{max} ml/(kg\cdot min)\textsuperscript{-1}</strong></td>
<td>28.5</td>
<td>30.8</td>
<td>38.5</td>
</tr>
<tr>
<td><strong>MIF at T\textsubscript{v1} (ml/s)</strong></td>
<td>1135</td>
<td>1483</td>
<td>1489</td>
</tr>
</tbody>
</table>
Subject GS - Exercise Test #1

O₂ Uptake

Heart Rate

Breath-by-Breath Ventilation

Ventilation BTPS (L/min.)
Subject GS - Exercise Test # 2

\[ \dot{V}_\text{O}_2 (\text{L/min}) \]

\[ 0.0 \rightarrow 3.0 \]

\[ 0 \rightarrow 600 \text{ (s)} \]

\[ \text{O}_2 \text{ Uptake} \]

\[ \text{Heart Rate} \]

\[ 0 \rightarrow 220 \text{ (b/min)} \]

\[ 0 \rightarrow 600 \text{ (s)} \]

\[ \text{Breath-by-Breath Ventilation} \]

\[ 0 \rightarrow 100 \text{ (L/min.)} \]

\[ 0 \rightarrow 600 \text{ (s)} \]

Time (s)
Subject GS - Exercise Test # 3

O₂ Uptake

Heart Rate

Breath-by-Breath Ventilation

Time (s)
(1) Subject JS

**Age** - 29

**Gender** – female

**Training Protocol** – Constant load

<table>
<thead>
<tr>
<th>Metric</th>
<th>PRE-</th>
<th>MID-</th>
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</thead>
<tbody>
<tr>
<td>Body Weight (kg)</td>
<td>70.8</td>
<td>70.4</td>
<td>70.5</td>
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<tr>
<td>HR at $T_{v_1}$ (bpm)</td>
<td>139</td>
<td>129</td>
<td>128</td>
</tr>
<tr>
<td>$HR_{max}$ (bpm)</td>
<td>183</td>
<td>179</td>
<td>177</td>
</tr>
<tr>
<td>$T_{v_1}$ ml/(kg·min)$^{-1}$</td>
<td>22.6</td>
<td>23.3</td>
<td>23.8</td>
</tr>
<tr>
<td>$\dot{VO}<em>{2</em>{max}}$ ml/(kg·min)$^{-1}$</td>
<td>36.4</td>
<td>39.1</td>
<td>40.7</td>
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<tr>
<td>MIF at $T_{v_1}$ (ml/s)</td>
<td>1843</td>
<td>1422</td>
<td>1629</td>
</tr>
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</table>
Subject JS - Exercise Test # 1

O2 Uptake

Heart Rate

Breath-by-Breath Ventilation

Time (s)
Subject JS - Exercise Test # 2

O₂ Uptake

\[ \dot{V}_O₂ \text{(L/min)} \]

Heart Rate

Heart Rate (b/min)

Breath-by-Breath Ventilation

Ventilation (L/min)

Time (s)
Subject JS - Exercise Test #3

O₂ Uptake

Heart Rate

Breath-by-Breath Ventilation

Time
(1) Subject LC

Age - 26

Gender - female

Training Protocol – Interval load

<table>
<thead>
<tr>
<th></th>
<th>PRE-</th>
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<th>POST-</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Body Weight (kg)</strong></td>
<td>95.5</td>
<td>94.0</td>
<td>94.0</td>
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<tr>
<td><strong>HR at TV₁ (bpm)</strong></td>
<td>120</td>
<td>133</td>
<td>125</td>
</tr>
<tr>
<td><strong>HRmax (bpm)</strong></td>
<td>159</td>
<td>165</td>
<td>158</td>
</tr>
<tr>
<td><strong>TV₁ ml·(kg·min)^{-1}</strong></td>
<td>15.7</td>
<td>17.1</td>
<td>19.3</td>
</tr>
<tr>
<td><strong>V̇O₂max ml·(kg·min)^{-1}</strong></td>
<td>24.5</td>
<td>27.6</td>
<td>33.0</td>
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<tr>
<td><strong>MIF at TV₁ (ml/s)</strong></td>
<td>2451</td>
<td>2198</td>
<td>2321</td>
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</table>
Subject LC - Exercise Test #1

O₂ Uptake

\[ \dot{V}_O_2 \text{(L/min)} \]

Heart Rate

Heart Rate (b/min)

Breath-by-Breath Ventilation

Ventilation BTPS (L/min.)

Time (s)
Subject LC - Exercise Test # 2

O2 Uptake

O2 Uptake (L/min)

Heart Rate

Heart Rate (b/min)

Breath-by-Breath Ventilation

Ventilation BTPS (L/min)

Time (s)
Subject LC - Exercise Test # 3

O₂ Uptake

Heart Rate

Breath-by-Breath Ventilation
(1) Subject LV

Age - 32

Gender – female

Training Protocol – Constant load

<table>
<thead>
<tr>
<th></th>
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<th>POST-</th>
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<tbody>
<tr>
<td>Body Weight (kg)</td>
<td>76.5</td>
<td>77.2</td>
<td>76.5</td>
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<tr>
<td>HR at $T_v_1$ (bpm)</td>
<td>154</td>
<td>146</td>
<td>153</td>
</tr>
<tr>
<td>HR$^{\text{max}}$ (bpm)</td>
<td>188</td>
<td>173</td>
<td>182</td>
</tr>
<tr>
<td>$T_v_1$ ml/(kg·min)$^{-1}$</td>
<td>21.6</td>
<td>22.7</td>
<td>27.7</td>
</tr>
<tr>
<td>$\dot{V}O_2^{\text{max}}$ ml/(kg·min)$^{-1}$</td>
<td>31.2</td>
<td>31.5</td>
<td>39.1</td>
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<tr>
<td>MIF at $T_v_1$ (ml/s)</td>
<td>1763</td>
<td>missing value</td>
<td>1889</td>
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</table>
Subject LV - Exercise Test # 1

O₂ Uptake

O₂ Uptake (L/min) vs. Time (s)

Heart Rate

Heart Rate (b/min) vs. Time (s)

Breath-by-Breath Ventilation

Ventilation (L/min) vs. Time (s)
Subject LV - Exercise Test # 2

O₂ Uptake

![O₂ Uptake Graph]

Heart Rate

![Heart Rate Graph]

* Breath-by-Breath Data - N/A
Subject LV - Exercise Test # 3

O_2 Uptake

Heart Rate

Breath-by-Breath Ventilation
(1) Subject MD

Age - 28

Gender – male

Training Protocol – Interval load

<table>
<thead>
<tr>
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<th>POST-</th>
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<tbody>
<tr>
<td><strong>Body Weight (kg)</strong></td>
<td>63.0</td>
<td>63.5</td>
<td>63.5</td>
</tr>
<tr>
<td><strong>HR at T_v1 (bpm)</strong></td>
<td>112</td>
<td>111</td>
<td>110</td>
</tr>
<tr>
<td><strong>HR_{max} (bpm)</strong></td>
<td>162</td>
<td>174</td>
<td>161</td>
</tr>
<tr>
<td><strong>T_v1 (ml·(kg·min)^{-1}</strong></td>
<td>18.0</td>
<td>18.0</td>
<td>21.6</td>
</tr>
<tr>
<td><strong>\dot{VO}<em>2</em>{max} (ml·(kg·min)^{-1}</strong></td>
<td>36.7</td>
<td>43.0</td>
<td>46.9</td>
</tr>
<tr>
<td><strong>MIF at T_v1 (ml/s)</strong></td>
<td>1272</td>
<td>1121</td>
<td>1129</td>
</tr>
</tbody>
</table>
Subject MD - Exercise Test # 1

\[ \dot{V}_O_2 \text{ (L/min)} \]

\[ O_2 \text{ Uptake} \]

\[ \text{Heart Rate} \]

\[ \text{Breath-by-Breath Ventilation} \]
Subject MD - Exercise Test # 2

O₂ Uptake

Heart Rate

Breath-by-Breath Ventilation
Subject MD - Exercise Test # 3

O₂ Uptake

\( \dot{V}O₂ \) (L/min)

Heart Rate

Heart Rate (b/min)

Breath-by-Breath Ventilation

Ventilation BTPS (L/min.)

Time (s)
(1) Subject PK

Age - 31

Gender – male

Training Protocol – Interval load

<table>
<thead>
<tr>
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<td><strong>Body Weight (kg)</strong></td>
<td>115.9</td>
<td>115.2</td>
<td>115.3</td>
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<tr>
<td><strong>HR at Tv1 (bpm)</strong></td>
<td>135</td>
<td>140</td>
<td>missing data</td>
</tr>
<tr>
<td><strong>HRmax (bpm)</strong></td>
<td>177</td>
<td>177</td>
<td>missing data</td>
</tr>
<tr>
<td><strong>Tv1, ml/(kg·min)^1</strong></td>
<td>15.1</td>
<td>18.6</td>
<td>20.7</td>
</tr>
<tr>
<td><strong>VO2max, ml/(kg·min)^1</strong></td>
<td>24.5</td>
<td>29.2</td>
<td>34.8</td>
</tr>
<tr>
<td><strong>MIF at Tv1 (ml/s)</strong></td>
<td>1906</td>
<td>2402</td>
<td>2314</td>
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</table>
Subject PK - Exercise Test # 1

**O₂ Uptake**

\[ \dot{V}_O₂ (L/min) \]

**Heart Rate**

\[ \text{Heart Rate (b/min)} \]

**Breath-by-Breath Ventilation**

\[ \text{Ventilation BTPS (L/min.)} \]
Subject PK - Exercise Test # 2

O₂ Uptake

Heart Rate

Gas Meter Steady-State
**Subject PK - Exercise Test # 3**

**O₂ Uptake**

**Heart Rate**

*Oximeter Probe Failure*

**Breath-by-Breath Ventilation**

*Time (s)*
(1) Subject RB

Age - 22

Gender – female

Training Protocol – Constant load

<table>
<thead>
<tr>
<th></th>
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<tr>
<td>Body Weight</td>
<td>70.4</td>
<td>68.2</td>
<td>65.9</td>
</tr>
<tr>
<td>(kg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HR at TV₁</td>
<td>144</td>
<td>150</td>
<td>152</td>
</tr>
<tr>
<td>(bpm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HRmax</td>
<td>193</td>
<td>195</td>
<td>194</td>
</tr>
<tr>
<td>(bpm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TV₁, ml/(kg·min)⁻¹</td>
<td>16.9</td>
<td>20.1</td>
<td>22.61</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VO₂max, ml/(kg·min)⁻¹</td>
<td>31.0</td>
<td>32.2</td>
<td>35.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIF at TV₁</td>
<td>1329</td>
<td>1039</td>
<td>1480</td>
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<tr>
<td>(ml/s)</td>
<td></td>
<td></td>
<td></td>
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</table>
Subject RB - Exercise Test # 1

**O₂ Uptake**

VO₂ (L/min)

**Heart Rate**

Heart Rate (b/min)

**Breath-by-Breath Ventilation**

Ventilation BTPS (L/min.)

Time (s)
Subject RB - Exercise Test #2

O₂ Uptake

\[ \dot{V}_O₂ (L/min) \]

Heart Rate

\[ \text{Heart Rate (b/min)} \]

Breath-by-Breath Ventilation

\[ \text{Ventilation BTPS (L/min.)} \]

Time (s)
Subject RB - Exercise Test #3

**O₂ Uptake**

\[ \dot{V}_O₂ (L/min) \]

Heart Rate

**Heart Rate (b/min)**

Breath-by-Breath Ventilation

**Ventilation BTPS (L/min)**

Time (s)
(1) Subject RC

**Age** - 45

**Gender** – female

**Training Protocol** – Interval load

<table>
<thead>
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<th>POST-</th>
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</thead>
<tbody>
<tr>
<td><strong>Body Weight (kg)</strong></td>
<td>45.5</td>
<td>45.5</td>
<td>45.5</td>
</tr>
<tr>
<td><strong>HR at T\textsubscript{v1} (bpm)</strong></td>
<td>118</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td><strong>HR\textsubscript{max} (bpm)</strong></td>
<td>156</td>
<td>154</td>
<td>150</td>
</tr>
<tr>
<td><strong>T\textsubscript{v1} ml-(kg\cdot min\textsuperscript{-1})</strong></td>
<td>11.2</td>
<td>14.7</td>
<td>18.7</td>
</tr>
<tr>
<td><strong>\dot{VO}_{2\text{max}} ml-(kg\cdot min\textsuperscript{-1})</strong></td>
<td>25.3</td>
<td>25.3</td>
<td>31.9</td>
</tr>
<tr>
<td><strong>MIF at T\textsubscript{v1} (ml/s)</strong></td>
<td>900</td>
<td>1247</td>
<td>1035</td>
</tr>
</tbody>
</table>
Subject RC - Exercise Test # 1

O₂ Uptake

Heart Rate

Breath-by-Breath Ventilation

Time (s)

Subject RC - Exercise Test # 1

O₂ Uptake

Heart Rate

Breath-by-Breath Ventilation

Time (s)
Subject RC - Exercise Test # 2

O_2 Uptake

\[ \dot{V}_O_2 \ (L/min) \]

Heart Rate

Heart Rate (b/min)

Breath-by-Breath Ventilation

Ventilation BTPS (L/min)

Time
Subject RC - Exercise Test # 3

**O₂ Uptake**

\[ V_{O₂} \text{ (L/min)} \]

**Heart Rate**

\[ \text{Heart Rate (b/min)} \]

**Breath-by-Breath Ventilation**

\[ \text{Ventilation BTPS (L/min.)} \]

**Time (s)**
(1) Subject SJ

Age - 20

Gender – female

Training Protocol – Interval trained

<table>
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<tr>
<td><strong>Body Weight (kg)</strong></td>
<td>52.2</td>
<td>52.8</td>
<td>52.4</td>
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<tr>
<td><strong>HR at TV₁ (bpm)</strong></td>
<td>142</td>
<td>145</td>
<td>144</td>
</tr>
<tr>
<td><strong>HRmax (bpm)</strong></td>
<td>172</td>
<td>172</td>
<td>170</td>
</tr>
<tr>
<td><strong>TV₁ ml·(kg·min)⁻¹</strong></td>
<td>19.7</td>
<td>24.8</td>
<td>26.0</td>
</tr>
<tr>
<td><strong>VO₂max ml·(kg·min)⁻¹</strong></td>
<td>33.9</td>
<td>36.9</td>
<td>36.5</td>
</tr>
<tr>
<td><strong>MIF at TV₁ (ml/s)</strong></td>
<td>1200</td>
<td>1409</td>
<td>1573</td>
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</table>
Subject SJ - Exercise Test # 1

O₂ Uptake

Heart Rate

Breath-by-Breath Ventilation

Time (s)
Subject SJ - Exercise Test # 2

**O₂ Uptake**

\[ \dot{V}O_2 \text{ (L/min)} \]

**Heart Rate**

Heart Rate (b/min)

**Breath-by-Breath Ventilation**

Ventilation (L/min)

Time (s)
Subject SJ - Exercise Test # 3

**O₂ Uptake**

\[ \dot{V}O_2 \text{ (L/min.)} \]

**Heart Rate**

\[ \text{Heart Rate (b/min.)} \]

**Breath-by-Breath Ventilation**

\[ \text{Ventilation BTPS (L/min.)} \]

Time (s)
(1) Subject SM

Age - 23
Gender - male

Training Protocol – Interval load

<table>
<thead>
<tr>
<th></th>
<th>PRE-</th>
<th>MID-</th>
<th>POST-</th>
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</thead>
<tbody>
<tr>
<td>Body Weight (kg)</td>
<td>84.5</td>
<td>84.5</td>
<td>84.0</td>
</tr>
<tr>
<td>HR at T\textsubscript{v1} (bpm)</td>
<td>147</td>
<td>149</td>
<td>147</td>
</tr>
<tr>
<td>HR\textsubscript{max} (bpm)</td>
<td>181</td>
<td>180</td>
<td>181</td>
</tr>
<tr>
<td>T\textsubscript{v1} ml\cdot(kg\cdotmin\textsuperscript{-1})</td>
<td>25.4</td>
<td>32.1</td>
<td>32.1</td>
</tr>
<tr>
<td>\dot{VO}_{2\textsubscript{max}} ml\cdot(kg\cdotmin\textsuperscript{-1})</td>
<td>48.8</td>
<td>49.8</td>
<td>51.2</td>
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<td>MIF at T\textsubscript{v1} (ml/s)</td>
<td>2325</td>
<td>2186</td>
<td>2785</td>
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</tbody>
</table>
Subject SM - Exercise Test # 1

O₂ Uptake

\[ \dot{V}_{O_2} \text{ (L/min)} \]

Heart Rate

Heart Rate (b/min)

Breath-by-Breath Ventilation

Ventilation BTPS (L/min.)

Time (s)
Subject SM - Exercise Test #2

**O₂ Uptake**

![Graph of O₂ Uptake over time.](image)

**Heart Rate**

![Graph of Heart Rate over time.](image)

**Breath-by-Breath Ventilation**

![Graph of Breath-by-Breath Ventilation over time.](image)
Subject SM - Exercise Test # 3

O$_2$ Uptake

Heart Rate

Breath-by-Breath Ventilation

Time (s)
References


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