# A COMPARISON OF TRAINING METHODS FOR ENHANCING CLIMBING PERFORMANCE

by

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Colin M. Davis

January 14, 2004

# TABLE OF CONTENTS

TABLE OF CONTENTS - CONTINUED

TABLE OF CONTENTS - CONTINUED

# LIST OF TABLES

## LIST OF TABLES - CONTINUED

LIST OF TABLES - CONTINUED

# LIST OF FIGURES

# ABSTRACT

Enhanced climbing performance may be achieved by applying systematic and documented principles to training for climbing. The purposes of this study were (a) to determine if improvements in climbing performance and related physiological variables would result from systematic training on a motorized climbing treadmill, and (b) to compare the effectiveness of two types of prescribed cardiovascular training programs on a motorized climbing treadmill: high-intensity interval training (HIT) and endurance training (ET). Climbing-related anthropometric variables, climbing performance, climbing-specific cardiorespiratory fitness, and climbing-related muscular strength and endurance were measured on 27 volunteers (13 males, 14 females) between the ages of 18 and 37 years, prior to and following six weeks of systematic physical training using a motorized climbing treadmill. Subjects were randomly assigned to training groups, which were similar with regard to gender and climbing experience. The ET program consisted of a single 20-minute bout of climbing at 65-80% of measured pre-test $\dot{V}O_{2peak}$ for each workout session,; the HIT program consisted of three 6-minute bouts of climbing at 80-95% of measured pre-test $\dot{V}O_{2peak}$, separated by three minutes of standing rest, for each workout session. Following training, climbing performance tended to be higher as a result of the HIT program compared to the ET program ($p = 0.069$), while climbing performance was significantly improved following training as a result of either program. Climbing-specific cardiorespiratory fitness did not differ between groups following training. With the exception of hand-grip strength, climbing-related muscular strength and endurance were significantly higher following training, with no differences observed between groups. Small yet significant improvements in climbing-related anthropometric variables were observed following training in both groups with no differences between groups. The results of this study show that six weeks of systematic physical training using a motorized climbing treadmill is capable of improving climbing performance, climbing-related strength and endurance, and climbing-related anthropometric variables. It was concluded that systematic training on a motorized climbing treadmill can be an effective method of increasing climbing-specific fitness and improving climbing performance.

# CHAPTER ONE

# INTRODUCTION

## Background

The sport of climbing is an increasingly popular form of recreation, with a growing number of participants and athletes. The diverse pursuits which make up the forms of the sport all require dedication from their participants and tend to evoke admiration from and inspiration in others. In general, the sport involves scaling steep terrain on a variety of media, such as large boulders, rock faces, cliffs, frozen waterfalls, or entire mountains. These environments produce different forms of climbing which are diverse enough to be considered unique pursuits in themselves; each form has specialists whose skill (or technical proficiency) at the expert- to elite-level does not necessarily transfer between disciplines. The majority of the difference between these forms of climbing is accounted for by the medium that is climbed, as this defines the methods and tools necessary for ascent, though other factors such as route length also distinguish these pursuits from each other (see Graydon, 1996, for a detailed comparison). By far, rock climbing is the most popular form of climbing (Outdoor Industry Association, 2002) and has become very accessible to the general population in the United States.

Rock climbing is characterized by specialization on rock; it originally developed as a means of skill practice for ascending sections of rock during mountaineering ascents (Jones, 1997; Watts, Clure, Hill, Humphries, & Lish, 1996). More recently, it has grown beyond the context of a component skill of alpine mountaineering into a sport in its own right (Watts, et al.; Williams, Taggart & Carruthers, 1978). Two modes of ascent are found in rock climbing: “aid climbing”, using sewn nylon ladders (known as aiders) in which to stand and ascend, and “free climbing”, in which upward progress is made solely by hand- and foot-holds on the rock face. Safety from falling is ensured in both cases by a belay system in which the climber is connected by a rope, through intermediate protection points, to his or her partner.

Recently, free climbing has evolved into two distinct forms, known as traditional climbing and sport climbing (Graydon, 1996; Jones, 1997). The differences are found in the way that the rope is secured to the rock; traditional climbing involves the use of irregularly shaped metal devices (termed “protection”) to fit cracks in the rock face, which are placed as the lead climber gains elevation (Long, 2002; Graydon, 1996). The protection is clipped with a snap-link, or carabiner, through which the rope is also clipped. Sport climbing is a refinement of the protection to a series of bolts and hangers, which have been previously anchored in drilled holes in the rock face (Graydon; Long; Booth, Hill, Marino & Gwinn, 1999). The hangers are clipped with carabiners, through which the rope is then clipped.

Sport climbing is a less technically demanding form of climbing, liberating the climber to focus almost exclusively on the gymnastics of difficult moves (Booth, Hill, Marino & Gwinn, 1999) instead of the art of placing protection. Of the two types of free climbing, it is undoubtedly the easier at which to develop proficiency due to the simplicity of the safety system. For this reason, it is has become very popular (Booth et al.; Billat, Palleja, Charlaix, Rizzardo, & Janel, 1995) and, in fact, enjoys a following of world-class competitors and participants (Mermier, Janot, Parker, & Swan, 2000). Though sport climbing receives relatively little attention in the popular news media of the United States, the majority of Western and many Eastern European nations derive national pride from the climbing performances of their athletes. The U.S. has a growing number of accomplished climbing athletes as well as an ever-growing population of amateur competitors. It is foreseeable that the U.S. could gain competitive advantage in the near future as advances in training science begin to identify effective techniques for maximizing climbing performance.

In addition to competition, climbing has a large and growing following in the recreational arena. According to the 2002 annual Outdoor Recreation Participation Study by the Outdoor Industry Association, 4.1% of the population of the US, or 8.8 million Americans, over the age of 16 years, participated in indoor or outdoor climbing activity in 2001 (Outdoor Industry Association, 2002). Across all forms of climbing surveyed (indoor, outdoor and ice climbing), these numbers represent a +16.7% increase in participation in climbing since 1998. In terms of participant days (any amount of time or number of times spent in the activity by an individual during a single day), across all forms of rock climbing, numbers rose 35% between 1994-5 and 2001 from 37.7 million participant days to 51.1 million (USFS, 2002).

Though high-level outdoor climbing is a pursuit of experts whose climbing standards involve long routes (often exceeding 1000 vertical feet) on natural cliffs of places such as Yosemite Valley or the Grand Teton, many climbers with appropriate experience and skill are pushing the limits of what can be accomplished by motivated yet sub-elite participants. These enthusiasts, comprising a similar demographic to that targeted by personal trainers, could also dramatically improve their performance by applying sound and systematic training strategies specific to climbing.

## Physical Training for Climbing

All climbing disciplines require strength, endurance, power and skill. Physical preparation for climbing requires increasing the volume and specificity of training as the peaking phase is approached. Since most climbers train unscientifically (Twight and Martin, 1999), it is hypothesized that enhanced climbing performance may be achieved by applying systematic and documented principles to training for climbing. These principles consist of frequency, intensity, duration and mode of training (Wilmore and Costill, 1994), and should be chosen with regard to the specific physical requirements of a particular climbing discipline.

Current training practices for rock climbing consist of any combination of resistance training, general cardiorespiratory power and endurance training (running, cycling, etc), climbing-specific forearm strength training (Horst, 2001) and indoor or outdoor climbing (Twight and Martin, 1999). However, the climbing component of training is underemphasized due to many factors; limitations of artificial indoor climbing walls include limited heights, lack of realism, the inconvenience of crowds, and training for static, isometric positions at the expense of climbing endurance. Outdoor climbing is limited by the location of appropriate climbing areas, weather, and the individual skill of the climber. In order for climbers to enhance the transference of training adaptations to climbing performance, it is necessary to increase the amount of sport-specific training as the peaking phase of a training program is approached.

Many technologies have been developed in the last decade that could potentially be applied to training for climbing, by increasing the sport-specific volume of training. Climbing ergometers, which now appear in many gyms, crudely simulate the large muscle group movements found in climbing. More sport-specific are indoor climbing walls, which have evolved from garage-walls covered with glued or bolted handholds to large, free-standing towers replete with bolted holds, sculpted features and textured surfaces, which require trained technicians to assemble (www.ep-usa.com). Better yet, in an effort to permit continuous climbing, new “scrolling” walls or climbing treadmills have been produced, such as the Brewer’s Ledge Treadwall ™ or The Rock ™ by Ascent Products, Inc. Climbing treadmills have the greatest sport-specific cardiovascular training potential, as some models (e.g. The Rock ™) allow variable speed and climbing angle (termed “grade”), which are controlled by a programmable on-board microcomputer. Workout intensity, duration and type are easily manipulated with these tools, giving climbing athletes the freedom to construct customized training programs appropriate to their individual fitness level and style of climbing.

The training options available on motorized climbing treadmills are numerous due to the great versatility inherent in their design. However, the activity of continuous climbing is very novel to most users. A literature review conducted in February, 2003 revealed no published training studies using motorized climbing treadmills. Thus the question of how exercise professionals or interested climbers may effectively use a systematic approach to physical training on motorized climbing treadmills remains unaddressed.

Motorized treadmill climbing may be considered to be continuous dynamic exercise. Workout sessions may be conducted at low, moderate or high intensities, similar to cycling and running. A major determinant of intensity in these activities is the pace or velocity of the athlete during the workout. In many forms of dynamic exercise, two different approaches to training may be found: endurance training, performed at low or moderate intensities for long durations; and high-intensity interval training, in which multiple bouts of exercise are performed at much higher intensities for shorter durations, separated by rest periods or intervals. It is unknown if these different types of training are appropriate for continuous motorized treadmill climbing, or if differences in physiological adaptation to training may exist between these two types of training.

## Statement of Purpose

The primary purpose of this study was to determine if improvements in climbing performance and related physiological variables would result from systematic training on a motorized climbing treadmill.

The secondary purpose was to compare the effectiveness of two types of prescribed cardiovascular training programs on a motorized climbing treadmill: high-intensity interval training (HIT) and endurance training (ET).

## Significance of the Study

The results from this study will help to identify appropriate strategies of training to enhance climbing performance using a motorized climbing treadmill for low-risk individuals of no, little, or moderate climbing experience.

## Hypotheses

The null hypothesis for the primary purpose of the study was that no improvements in climbing performance or associated physiological variables would result from the prescribed systematic training programs. The alternative hypothesis was that climbing performance, climbing-specific cardiorespiratory fitness, muscular strength, and muscular endurance would be improved as a result of systematic training on a motorized climbing treadmill.

### Primary Hypothesis

$\mathbf{H_0}$: $\mu(i)_{post} = \mu(i)_{pre}$

$\mathbf{H_a}$: $\mu(i)_{post} > \mu(i)_{pre}$

Where: $\mu(i)_{post}$ is the mean measured post-training value of variable i

$\mu(i)_{pre}$ is the mean measured pre-training value of variable i

for i=1 to 14 according to Table 1-1.

The null hypothesis for the secondary purpose of the study was that no difference in improvement in climbing performance and related physiological variables would be observed between the two training programs. The alternative hypothesis was that improvements in climbing performance and related physiological variables would be greater for the High-intensity Interval Training program than for the Endurance Training program.

### Secondary Hypothesis

**$H_0$**: $\Delta\mu(i)_{HIT} = \Delta\mu(i)_{ET}$

**$H_a$**: $\Delta\mu(i)_{HIT} > \Delta\mu(i)_{ET}$

Where: $\Delta\mu(i)_{HIT} = [\mu(i)_{post} - \mu(i)_{pre}]_{HIT}$

$\Delta\mu(i)_{ET} = [\mu(i)_{post} - \mu(i)_{pre}]_{ET}$

$\mu(i)_{post}$ is the mean measured post-training value of variable i

$\mu(i)_{pre}$ is the mean measured pre-training value of variable i

for i=1 to 14 according to Table 1-1.

Table 1-1. Dependent Variables Used to Define the Primary and Secondary Hypotheses.

| i | Dependent Variable | Abbreviation | i | Dependent Variable | Abbreviation |
|---|---|---|---|---|---|
| 1 | Incremental Overhang Test Time | IOTTIME | 8 | Ape-index | APE |
| 2 | $\dot{V}O_{2peak}$ Test Time | $\dot{V}O_2$ TIME | 9 | Right Hand-grip Strength | RGRIP |
| 3 | Right Forearm Circumference | RARM | 10 | Left Hand-grip Strength | LGRIP |
| 4 | Left Forearm Circumference | LARM | 11 | Latissimus Pull-down 1-Rep Max. | 1RM-LAT |
| 5 | Right Calf Circumference | RCALF | 12 | Time-to-exhaustion in the Bent-arm Hang Test | HANG |
| 6 | Left Calf Circumference | LCALF | 13 | $\dot{V}O_{2peak}$, Absolute | $\dot{V}O_2$ ABS |
| 7 | Armspan | ARMSPAN | 14 | $\dot{V}O_{2peak}$, Relative | $\dot{V}O_2$ REL |

## Limitations

1. Day to day fluctuations in heart rate could have an effect on the training intensity prescribed for climbing sessions.
2. The subjects' unfamiliarity with maximal treadmill climbing during the pre-test series could affect the training intensity prescribed for climbing sessions.
3. Maximal climbing treadmill tests may not challenge all subjects maximally.
4. Restrictions on the subjects' extracurricular activity levels may result in a de-training effect during the study period.
5. Six weeks of training may not be of long enough duration to cause a detectable magnitude of improvement in all subjects.
6. Biorhythmic factors may affect test results if testing is undertaken at dramatically different times of day.

## Delimitations

1. This study was delimited to adults between 18 to 39 years of age in the Bozeman, Montana area.
2. Due to health-related contraindications to maximal-intensity exercise, this study was delimited to "low risk" individuals as defined by ACSM's Guidelines for Exercise Testing and Prescription (p.26, 6th edition, 2000).
3. The prescribed training programs may not have been able to provide a great enough training stimulus to elite climbers. Therefore, this study was delimited to subjects with no competitive climbing experience.
4. Due to the potential of confounding extracurricular training, this study was delimited to subjects who were undertaking no other regular exercise programs.

## Operational Definitions

| | |
|---|---|
| Absolute $\dot{V}O_{2peak}$ | The measured value of $\dot{V}O_{2peak}$ expressed in $L \cdot min^{-1}$. |
| Climbing Performance | Time to exhaustion in climbing performance tests; equivalent to total number of handholds attained during stationary-wall climbing. |
| Endurance Training (ET) | Type of physical training program consisting of single climbing sessions of long duration and moderate intensity conducted at 60-85% measured pre-test $\dot{V}O_{2peak}$. |
| High-intensity Interval Training (HIT) | Type of physical training program consisting of multiple short-duration, high-intensity bouts of climbing separated by recovery intervals; conducted at 80-95% measured pre-test $\dot{V}O_{2peak}$ |
| Maximal Heart Rate ($HR_{max}$) | The highest heart rate recorded during a graded exercise test to volitional exhaustion |
| Maximal Oxygen Uptake ($\dot{V}O_{2max}$) | The highest rate of oxygen transport and use that can be attained by an individual during maximal physical exertion. |
| Peak Oxygen Uptake ($\dot{V}O_{2peak}$): | The highest rate of oxygen transport and use that can be measured in an individual during maximal physical exertion in a particular activity. |
| Relative $\dot{V}O_{2peak}$ | The measured value of $\dot{V}O_{2peak}$ expressed in $ml \cdot kg^{-1} \cdot min^{-1}$ (where kg equals total loaded mass of climber) |

# CHAPTER TWO

# REVIEW OF LITERATURE

## Climbing as an Emerging Athletic Discipline

The discipline of mountaineering originated in the European Alps in the mid-eighteenth century (Jones, 1997). "Alpinism" is derived from the French root 'alp'; originally synonymous with "mountaineering", the term has evolved to mean the art of climbing difficult routes in the mountains with a style that reflects minimalism and self-sufficiency (Twight and Martin, 1999). This style represents the forefront of mountaineering, and stands in contrast to the large expeditions of the last four to five decades. At the extreme, the standards of physical difficulty of alpine-style routes are now being pushed to the limits of human performance. Appropriate physical preparation may give a climber the advantage he or she needs to rise to the challenge of a world-class alpine climb. Increasing the specificity of training for these athletic performances has the potential to further advance the standards of this sport.

The term "climbing" refers to other disciplines than extreme alpinism alone, however. Rock climbing has grown over the last 30 years from a form of practice for mountaineering on local cliffs into a mature competitive sport of its' own (Jones, 1997; Watts, Clure, Humphries & Lish, 1996; Williams, Taggart & Carruthers, 1978), with a large and growing participant population (USFS, 2002; Outdoor Industry Association, 2002) and organized events (Watts, Newbury & Sulentic, 1996). These events are typically held on indoor artificial walls that simulate the hand- and foot-holds found on real rock surfaces. Many European countries derive national pride from the competition climbing performances of their athletes; this is a growing phenomenon in the U.S. as our climbing athletes gain national and international recognition. Enhancing the effectiveness of physical training may serve to advance the standards of athletic performance for rock climbing.

## Climbing Fundamentals

### Difficulty Ratings in Rock Climbing

There is presently no standard universal rating system by which the difficulty of all rock climbs is measured. Furthermore, the subjective nature of route ratings still results in frequent disputes as to a particular rating's accuracy (www.peakware.com, 2003). All ratings are subjective to the conditions encountered during the first ascent of a route, the climbing style employed by the first ascentionist, that individual’s impression of the difficulties encountered, and the opinions of other climbers subsequent to the first ascentionist. In addition, international standards of climbing differ, and utilize a wide variety of terminology to describe the difficulties of a route. Included here is a summary of the more common difficulty rating systems.

American Rating System: The American system is a “combination of the National Climbing Classification System (NCCS) and the Yosemite Decimal System (YDS). Often these ratings assume a form similar to the following: (V 5.6). The first part of this rating, expressed as a Roman Numeral, is the NCCS rating” (www.peakware.com, 2003). This rating is based on time to complete the climb, on factors related to escape and rescue options, and on technical rock difficulty. The NCCS ratings are defined according to Table 2-1.

Table 2-1. National Climbing Classification System Ratings.

| Difficulty Grade | Description |
|---|---|
| I | Route includes a technical portion (of any difficulty), which generally requires only a few short hours. |
| II | Route includes a technical portion (of any difficulty), which generally requires half a day. |
| III | Route includes a technical portion (of any difficulty), which generally requires a full day. |
| IV | Technical portion of the route generally requires a long day, and its most difficult pitch is rated at least 5.7. |
| V | Technical portion of the route generally requires 1.5 days, and its most difficult pitch is rated at least 5.8. |
| VI | Technical portion of the route requires two or more days, and typically includes difficult free climbing and/or aid climbing. |

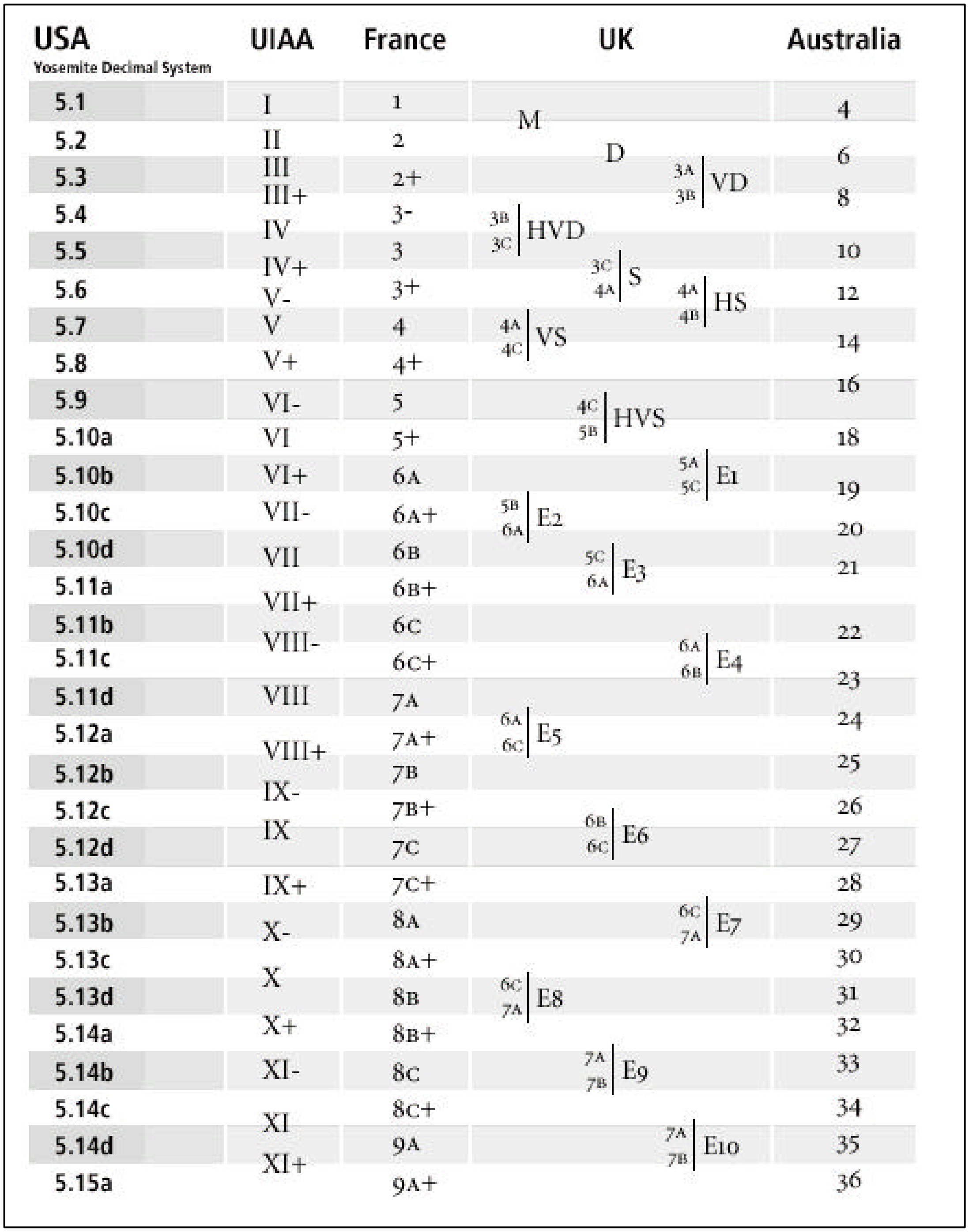
The second portion of the rating, expressed as an Arabic numeral, is the Yosemite Decimal System (YDS) rating, which is based upon techniques and equipment required for the route's most difficult technical pitch. The YDS ratings are defined according to Table 2-2.

Table 2-2. Yosemite Decimal System (YDS) climbing difficulty ratings.

| Difficulty Rating | Description: |
|---|---|
| Class 1 | Hiking, possibly light scrambling; requires little if any use of hands. |
| Class 2 | Scrambling, usually requiring use of hands. |
| Class 3 | Scrambling or simple climbing; requires extensive use of hands. A rope is recommended. |
| Class 4 | Steep climbing; requires a roped belay. |
| Class 5 | Serious technical climbing. Class 5 is broken down into the following detailed extensions: |
| 5.0 to 5.4 | Relatively secure climbing, with two hand and two footholds available for every move. |
| 5.5 to 5.6 | Two hand and two footholds are available for every move, though they may be less prominent; requires rock climbing techniques such as hand jamming. |
| 5.7 to 5.8 | One or two of the hand or footholds are missing on at least one of the moves. |
| 5.9 | At least one pitch requires movement when only one hold is available. |
| 5.10 and above | Movement on steep terrain with no apparent hand or footholds. These routes require superb rock climbing skills |
| Class 6 | Routes requiring the use of technical aid for ascent. |

Comparison of International Rating Systems: Many difficulty rating systems exist internationally, specific to regions, countries or particular international standards. No exact equivalency between rating systems exists (Graydon, 1996), though general comparisons may be drawn. Table 2-3 shows a comparison of the systems used in the United States, France, the United Kingdom and Australia, as well as the international standard of the UIAA (Union Internationale des Associations D’Alpinisme).

Table 2-3. Comparison of difficulty rating systems in rock climbing used in the United States, France, the United Kingdom and Australia, and the UIAA standard rating system.



| USA<br>Yosemite Decimal System | UIAA | France | UK | Australia |
|---|---|---|---|---|
| 5.1 | I | 1 | M | 4 |
| 5.2 | II | 2 | D | 6 |
| 5.3 | III<br>III+ | 2+ | 3A<br>3B VD | |
| 5.4 | IV | 3- | 3B<br>3C HVD | 8 |
| 5.5 | IV+ | 3 | | 10 |
| 5.6 | V- | 3+ | 3C<br>4A S<br>4A<br>4B HS | 12 |
| 5.7 | V | 4 | 4A<br>4C VS | 14 |
| 5.8 | V+ | 4+ | | |
| 5.9 | VI- | 5 | 4C<br>5B HVS | 16 |
| 5.10a | VI | 5+ | | 18 |
| 5.10b | VI+ | 6A | 5A<br>5C E1 | 19 |
| 5.10c | VII- | 6A+ | 5B<br>6A E2 | 20 |
| 5.10d | VII | 6B | | 21 |
| 5.11a | VII+ | 6B+ | 5C<br>6A E3 | |
| 5.11b | VIII- | 6C | | 22 |
| 5.11c | | 6C+ | 6A<br>6B E4 | |
| 5.11d | VIII | 7A | | 23 |
| 5.12a | VIII+ | 7A+ | 6A<br>6C E5 | 24 |
| 5.12b | IX- | 7B | | 25 |
| 5.12c | IX | 7B+ | | 26 |
| 5.12d | | 7C | 6B<br>6C E6 | 27 |
| 5.13a | IX+ | 7C+ | | 28 |
| 5.13b | X- | 8A | 6C<br>7A E7 | 29 |
| 5.13c | X | 8A+ | | 30 |
| 5.13d | | 8B | 6C<br>7A E8 | 31 |
| 5.14a | X+ | 8B+ | | 32 |
| 5.14b | XI- | 8C | 7A<br>7B E9 | 33 |
| 5.14c | XI | 8C+ | | 34 |
| 5.14d | XI+ | 9A | 7A<br>7B E10 | 35 |
| 5.15a | | 9A+ | | 36 |

(source: SuperTopo.com, 2003)

## Types of Climbing: Traditional Climbing vs. Sport Climbing

In general, the term “climbing” may refer to a broad range of activities, all of which involve vertical ascent on a variety of media including rock, ice, snow or artificial rock surfaces. Typically, the term “climbing” used with no prefix designates the rock medium, while the other media are referred to specifically (e.g. “ice climbing”). While they share the aspect of vertical ascent, the skills and equipment may be very different between the various forms of climbing. For the purposes of this study, only rock and gym climbing are considered.

Rock climbing can be subdivided into two modes of ascent: “aid climbing”, using sewn nylon ladders (known as aiders) in which to stand and ascend, and “free climbing”, in which upward progress is made solely by hand- and foot-holds on the rock face. Aid climbing is a specialized and highly technical activity that combines physical strength and mental fortitude with an understanding of physics, gear and rope management techniques, and takes place on truly huge cliffs known as “big walls” – typically thousands of feet tall, and vertical-to-overhanging in steepness. Upward progress is achieved by placing or hammering pieces of gear known as cams and pitons, respectively, into cracks in the rock face, and attaching aiders to these (see Graydon, 1996, pp. 249-277 for a thorough explanation). While this sport is gaining popularity, it remains very elite; it is discussed here for the sole purpose of placing free climbing into context.

Free rock climbing (referred to hereafter simply as “rock climbing”) developed as a means of skill practice for ascending steep sections of rock during mountaineering ascents (Jones, 1997; Watts, Clure, Hill, Humphries, & Lish, 1996; Williams, Taggart & Carruthers, 1978). Beginning in the mid-1930's in Berkeley, California, climbers began to incorporate a roped belay system for the leader of a climbing party to ensure safety in the event of a fall. Though it may seem illogical now, the prior school of thought was typified by the "Golden Rule" that the leader must not fall – any use of a rope was to assure the safety of the weaker members of a mountaineering party. As steeper routes were attempted, it became necessary to ensure the safety of the leader as well. In this regard, the Berkeley climbers surpassed the standards of the European community, and took the lead in the development of the sport (Jones, 1997, pp. 127-137). As their confidence on steep rock grew, the Californians began to set new standards of mountaineering in the High Sierras, and eventually other mountain ranges throughout the world.

More recently, climbing has grown beyond the context of a component skill of alpine mountaineering, and has become a sport in its own right. Today, rock climbing has further evolved into two distinct forms, known as traditional climbing and sport climbing (Graydon, 1996; Jones, 1997), differing from each other in the way that the rope is secured to the rock. Traditional climbing involves the use of irregularly shaped metal devices termed protection, or "pro", to fit cracks in the rock face, which are placed as the climber gains elevation (Graydon; Long, 2002). It is referred to as traditional due to its' status as the original means of securing a leader's safety. Sport climbing is a refinement of the protection to a series of bolts and hangers, which have been previously anchored in drilled holes in the rock face (Graydon; Long). Debate continues regarding the ethical purity of this means of protection, but will be left for other venues than this review of literature.

Sport climbing is less technically demanding, in terms of complexity of the protection system, liberating the climber to focus almost exclusively on the gymnastics of difficult moves (Booth, Marino, Hill & Gwinn, 1999) instead of the art of placing protection.  Of the two types of free climbing, it is undoubtedly the easier at which to develop proficiency due to the simplicity of the safety system.  For this reason, it is has become very popular (Booth et al.; Billat, Palleja, Charlaix, Rizzardo & Janel, 1995) and, in fact, enjoys a following of world-class competitors and participants (Mermier, Janot, Parker & Swan, 2000).  The proliferation of climbing gyms featuring simulated rock surfaces, replete with bolts and hangers, has dramatically increased accessibility to this activity for the general population.  These gyms both simulate outdoor rock for those who wish to increase the climbing specificity of their training, and serve as an acceptable substitute for outdoor climbing to the point where "gym climbing" has an identity of its' own; indeed, many advanced "gym climbers" have never experienced real rock.

## Previous Climbing Research

### Psychological Characteristics of Climbers

Climbers are often perceived to constitute a sub-culture by non-climbers. Reasons for this are often related to the relative obscurity of the sport, unfamiliarity of non-climbers with esoteric techniques and equipment, and a media-reinforced perception of climbing as reckless and dangerous.  Climbers themselves tend to reinforce these perceptions purposefully, both in order to remain on the fringe of the mainstream for the sake of status, and in an effort to discourage increased use of limited climbing areas. Despite this, or possibly due to it (a question worthy of exploration!), the appeal of climbing is growing rapidly in the U.S. and many other countries. It is beyond the scope of this discussion to consider the reason for attitudes and beliefs of climbers, and the perceptions of climbing by non-climbers; however, it is worth mention that according to recent research, climbers established in this sub-culture exhibit some common psychological characteristics.

Research conducted in the late twentieth century into personality traits of climbers and psychological rewards of climbing is in accordance with this author's anecdotal experience as a climber and climbing instructor. Jackson (1967) and Hardman (1968) (in Hardy and Martindale, 1982) studied personality traits of climbers and suggested that they were more intelligent, aggressive, and self-sufficient than the general population, but that they also tended to be less conscientious and sophisticated as a population when compared to non-climbers. Goma (1991) investigated the relationship between personality traits and participation in high physical risk sports, finding that participants shared the characteristics of extraversion, emotional stability, conformity to social norms, and seeking thrill and experience by socialized means.

Williams, Taggart and Carruthers (1978) conducted a study to determine the nature of the psycho-physiological stress on beginning climbers receiving instruction, by administering a placebo or oxoprenolol (a beta-blocking agent) to subjects before climbing. Their results showed that maximum heart rates during climbing and plasma adrenaline concentrations following climbing were significantly lower following administration of the beta-blocker. They interpret this to suggest that climbing represents more of "an anxiety-type stress than a physical stress", and likely to increase "moral fiber" over "muscle fiber". However, they do not report the difficulty of the routes climbed, nor any physiological costs associated with climbing these routes.

Newer studies from the field of sports psychology have attempted to construct generalities regarding the psychological characteristics of climbing sports. LeFebvre (1980), evaluating sensations before, during, and after rock climbing, concluded that the prevailing feelings of beginner climbers were of an "energetic" attitude at the beginning, reduced vitality during climbing, and feelings of self-assurance, power and enjoyment after climbing. Looking at motivations for climbing, Ewert (1994) studied high-altitude mountaineers on Mount McKinley in Denali National Park, Alaska, and constructed a five-component model to explain risk-taking behavior, including exhilaration, excitement and accomplishment; risk-taking itself did not generate a high level of importance as a motivating variable. It is likely that motivation for such activities varies according to highly individual traits. Ewert suggested that participants in risk recreation sports report different patterns of motivation contingent on their levels of experience. Further research and innovative study design may elucidate more complex psychological factors that determine participation in climbing sports.

## Anthropometric, Strength, Endurance and Flexibility Characteristics of Climbers

According to limited research, elite climbers as a population possess some advantageous physical traits and particular adaptations to their sport that differ significantly from non-climbers. Described in detail below, these include smaller body stature (Watts, Newbury & Sulentic, 1996), greater lean body composition (Watts; Booth, Marino, Hill & Gwinn, 1999), and higher sport-specific muscular strength and muscular endurance (Watts, Martin & Durtschi, 1993; Grant, Hynes, Whitakker & Aitchison, 1996). No studies cited here draw conclusions regarding the importance of these traits and adaptations, nor address the question of whether these traits facilitate elite climbing skills or result from the years of practice required to attain elite skills. Longitudinal studies of talented young climbers may help answer this question.

Watts, Martin and Durtschi (1993) measured anthropometric variables on 39 World Cup Sport Climbing Competition semifinalists immediately prior to competition. They report that elite-level climbers tend to be of small to moderate stature, exhibit very low percent body fat, have moderate grip strength and a high strength-to-weight ratio when compared with population norms published elsewhere. In comparison to the values of athletes from other sports, they state that stature and height-to-weight ratios of elite climbers were similar to distance runners and marathoners, as well as ballet dancers, but not body builders or elite gymnasts. In comparison to these groups, the elite climbers measured by Watts et al. had greater ectomorphy (greater height-to-weight ratios) than the elite gymnasts they were compared to. In their discussion, the authors state that greater ectomorphy is likely to be an advantage in climbing by reducing the absolute workload of the activity. In another study comparing climbers with runners (both sprinters and distance-runners) and a sport non-active group, climbers were found to be statistically similar to sprinters and distance-runners for subcutaneous fat over the calf muscles as well as for whole-muscle cross-sectional area by magnetic resonance imaging (Strojnik, Apih & Dempsar, 1995). All three sport-active groups were, however, found to differ significantly from the sport non-active group. As an attempt to address the question of adaptation resulting from training, calf circumference was considered a crude analogy to whole-muscle area, and was measured prior to and after the training period in this investigation.

Shoulder girdle strength and endurance may be significant factors in predicting climbing ability (Watts, Martin & Durtschi, 1993; Grant, Hynes, Whittaker & Aitchison, 1996). Indeed, Grant et al. state that the pull-up and bent-arm hang tests clearly distinguished the elite climbers from recreational and non-climbers. No significant differences were found between recreational climbers and non-climbers. This is in agreement with Watts et al. In this characteristic as well, it is not known whether elite status is determined by greater shoulder girdle strength and endurance, or results from the training required to attain this status; thus it was included as a dependent measure in this investigation.

Hand and finger grip strength would seem to be greater among elite climbers than non-climbers, due to the demand of contact forces on the handholds necessary to maintain body position on a wall (Quaine, Martin & Blanchi, 1997). To a small degree, this has been found by Watts, Martin and Durtschi (1993) in World Cup semi-finalists.

However, they understate this finding, due to the fact that the difference between elite climbers and recreational or non-climbers was not dramatic when expressed in absolute strength values. The expectedly large difference between these groups only emerged once strength values were expressed relative to body mass. This is in agreement with Donnelly, Byrnes, Kearney & Fleck (1991) in Watts, Newbury & Sulentic (1996).

Flexibility, as an athletic performance-related characteristic, has questionable contribution to climbing skill. Hamstring flexibility, as measured by the sit-and-reach test, was reported by Grant, Hynes, Whittaker and Aitchison (1996) as not significantly different between elite, recreational and non-climbers, though elite climbers tended to have non-significantly greater values in this test. The authors acknowledge that the sit-and-reach test is not the most effective way to measure hamstring flexibility. Nevertheless, the score for all three groups were categorized as ‘average’ according to norm tables developed by Pollock, Wilmore and Fox (1984). Leg span, as a more climbing-specific measure of flexibility, was also measured by Grant et al. to quantify hip abductor flexibility. Significant differences were found between elite climbers and recreational and non-climbers. They postulate that this type of flexibility may be important to elite climbers for bridging or stemming movements with the legs. However, these movements constitute advanced climbing techniques (Long, 2002) and are likely to be used more often by elite climbers on difficult or very difficult routes; novice or intermediate climbers would be less likely to encounter the need for such movements when climbing at their respective levels. This may serve to explain some of the difference found by Grant et al., though that remains speculation and deserves rigorous examination.

## Kinematics of Rock Climbing

A number of studies have attempted to characterize the activity of rock climbing from a biomechanical perspective. Many of these are manuscripts and abstracts presented at the International Congresses on Science and Technology in Climbing and Mountaineering, the first of which was held in 1999 in Leeds, UK. Few studies specific to climbing have been published in the literature, leaving this field of inquiry open to investigation. Some key ideas of the works to date may show the usefulness of biomechanical analysis to enhancing climbing performance, and may encourage others to apply the approaches identified here to this goal.

Two-dimensional filming of climbers during competition performance is a popular technique for analyzing the movement patterns of elite-level climbers. It is undoubtedly a primary means of analyzing movements in many sports and physical activities, and has great potential to address questions concerning how climbing problems are solved by climbers of different ability level. For example, the question of whether subjects would all use the same climbing techniques for managing a competition route's difficulties was addressed (Kauer, Gebert & Werner, 1999). It was discovered that the paths of the climbers' center of gravity in the frontal and sagittal planes varied considerably between climbers, indicating that different biomechanical solutions exist for any single climbing problem. Expanding the dimensions of analysis, another study (Bursnall & Messenger, 1999) was undertaken to validate the use of the ProReflex 3D

Motion Analysis System as a performance measurement system. This preliminary study concluded that this system serves as a suitable tool for analysis of rock climbing. Multi-dimensional filming techniques have thus been validated for characterizing movement patterns in climbing, and have been used in introductory investigations into how climbing difficulties are solved. Great potential exists in this area for future research.

A second method utilized to examine the biomechanics of climbing required the use of a climbing frame designed to measure contact force at the hands and feet (Rougier, Billat, Merlin & Blanchi, 1991). The frame was subsequently used to examine a very simple climbing situation: the reorganization of forces following a shift in body position of a climber from a four-point stable to a three-point stable static position, by removing either a hand or foot (Quaine, Martin & Blanchi, 1997). This technique allowed the researchers to describe the functional role of the upper and lower limbs during rock climbing: the upper limbs serve to stabilize body position through contact forces, while the lower limbs support the body weight through vertical forces. Furthermore, the distance of the center of gravity from the supporting wall influences the contact force necessary to counteract backward (falling) momentum. Though these ideas may be intuitive to thoughtful climbers, they illustrate the descriptive power of force analysis techniques when applied to even isolated climbing problems. This technique has great potential to be applied to more complicated movement patterns during climbing and will require innovative equipment and study designs.

There has been one attempt to date to incorporate biomechanical analyses as a component of a multi-disciplinary approach to answering climbing-performance related questions. Prediction models of sport-climbing performance were developed by Slaugh, Hyder and Abendroth-Smith (1998). Using a two-dimensional motion analysis system to analyze movement patterns of elite male and female climbers, they quantified the peak velocity and acceleration of the center of gravity, angular trunk displacement, peak velocity and angular acceleration of the left wrist, and the timing of these variables. Multiple prediction models were derived for climbing performance, in terms of redpoint ability (a performance measure of climbing ability), one each for the male and female subjects on the following categories of variables: anthropometrics, strength variables, and kinematic variables. A composite model was generated for each gender, as well as an overall model; important variables for the overall composite model were found to be body composition, flexed-arm hang time, grip strength, peak angular acceleration of the left wrist, and timing of the vertical velocity of the center of gravity. Practical suggestions from this research for enhancing climbing performance include incorporating resistance training (both conventional and climbing-specific) tailored to gender, and technique training focusing on timing and speed of movement. Future multidisciplinary studies incorporating biomechanical analysis with physiological and anthropometric variables represent the frontier of *in-situ* climbing research, and will also require innovative equipment and research design.

## Physiological Demand of Rock Climbing

In the U.S. and other developed nations, there is an increased emphasis on boosting individual physical activity levels (ACSM, 2000; President’s Council on Physical Fitness and Sports, 2002; World Health Organization, 2002). Accordingly, in an effort to substantiate this activity as health-promoting, some researchers have endeavored to quantify the exertional intensities of rock climbing (e.g. Williams, Taggart & Carruthers, 1978; Janot, Steffen, Porcari & Maher, 2000). While the degree to which rock climbing may be considered to be health-enhancing varies between published research, there is general agreement that it requires physical exertion; the health-enhancing benefits likely rest upon the duration it is performed, though this has not been evaluated in the literature. An early study attempting to address the physiological intensity of indoor rock climbing found a mean energy cost of 6.7-9.3 $\text{kcal}\cdot\text{min}^{-1}$ for beginner and expert climbers while climbing at their respective standards, using a 2-channel oscillograph to measure oxygen consumption (Hardy and Martindale, 1982). This range of energy expenditure values places indoor climbing among the activities of brisk walking, cycling, swimming and tennis (Hardy and Martindale; Astrand and Rodahl, 1977). However, the climbers were constrained to horizontal traversing, not upward movement, on an indoor artificial climbing wall; it seems probable that higher energy expenditure values would have been found if subjects had climbed vertically. Due to this limitation, other researches have found it necessary to expand the understanding of the physiological costs and benefits of this activity. These are summarized below, categorized by the setting of the research.

Outdoor climbing: It is interesting to note that only one published study of rock climbing was found in a literature survey as of February, 2003 that attempted to characterize the physiological response to climbing on outdoor rock. Due to this lack of data, it is unfortunate that the work by Williams, Taggart and Carruthers (1978) did not quantify the energy cost of climbing the routes chosen for their study. However, this was not the objective of their research; as such, energy costs may only be inferred from the data reported concerning the heart rate response to this form of exercise. Their objective was to determine the "nature" of the activity of rock climbing; to this end, they interpret their data as suggestive that rock climbing is more psychological than physiological, and likely to increase "moral fiber over muscle fiber". However, a comparison of their data to published physiological norms suggests this was an erroneous conclusion. They report mean peak heart rate during climbing to be 166 ± 20.4 bpm for eleven male, fit subjects with a mean age of 31 years, following administration of a placebo. Following administration of a beta-blocking agent, the mean peak heart rate of these same subjects during climbing was reduced to 120 ± 10.2 bpm. In both cases, these heart rate values place outdoor climbing in the general category of higher-than-resting exertion (American Heart Association, 2003); yet the control group mean peak heart rate, for the age group identified, represents a range of 77-99% of age-predicted maximum heart rate! The question of how heart rate varies with energy expenditure during rock climbing will be addressed below; however, based on this data it seems reasonable to place outdoor rock climbing in the moderate to upper range of the target heart rate zone for cardiovascular fitness improvement (ACSM, 2000).

The lack of data relevant to outdoor rock climbing is remarkable and leaves many topics open to further research, especially those concerning energy expenditure at different grades of difficulty and steepness. Appropriate methods will need to address the environmental variability of outdoor rock climbing, such as weather and climatic conditions, elevation, rock composition and features, as well as specific details regarding the types of climbing moves employed. Information from such research is necessary to address other questions in climbing, such as whether certain types of climbing moves place a greater physiological demand on climbers than other types of moves, and whether outdoor climbing is physiologically similar or distinct from indoor, or “simulated” rock climbing.

Indoor climbing: Presumably due to the relative ease of data collection and control of potentially confounding variables, the vast majority of published research on energy expenditure and physiological costs associated with rock climbing have been performed on indoor artificial rock walls. These have the advantages of a controlled environment, easy access, enhanced safety and facilitation of physiological measurements. The obvious drawback to this type of research is that direct application of results to outdoor rock climbing is limited. However, many factors that differ between the indoor and outdoor environments are essentially superficial when extremes are discounted (such as extreme heat or cold, wind, and precipitation), allowing generalization of results from studies of indoor climbing to be extrapolated to outdoor climbing, within reason. It should be noted that all research reviewed here is specific to sport climbing, since traditional climbing (during which protection is placed in cracks in the rock surface as the climber ascends) only occurs outdoors.

The conclusions of Williams, Taggart and Carruthers (1978), who state that the psychological benefit of climbing seems greater than any physiological benefit, stand in contrast to those of Mermier, Robergs, McMinn and Heyward (1997), who state that rock climbing is a good activity for increasing cardiorespiratory fitness and muscular endurance. They report mean values of energy expenditure of 0.622 – 0.844 $kJ\cdot kg^{-1}\cdot min^{-1}$ (equivalent to 9 – 12.5 $kcal\cdot min^{-1}$ for their subjects) for easy (5.6) to difficult (5.11+) climbing routes. In terms of oxygen consumption, they report 20.7 – 24.9 $ml\cdot kg^{-1}\cdot min^{-1}$ for easy to difficult climbing. These values are higher than those reported Hardy and Martindale (1982), above, who constrained subjects to horizontal traversing; this supports the notion that upward vertical progress requires greater energy expenditure than horizontal progress. Watts, Daggett, Gallagher and Wilkins (2000) report mean average climbing oxygen consumption of very difficult (5.12) climbing as 24.7 $ml\cdot kg^{-1}\cdot min^{-1}$ (equivalent to 8.3 $kcal\cdot min^{-1}$), with mean peak values 31.9 $ml\cdot kg^{-1}\cdot min^{-1}$ (10.7 $kcal\cdot min^{-1}$). Thus depending upon the degree of difficulty, climbing on artificial walls such as those found in climbing gyms may elicit an energy expenditure between 8 – 12 $kcal\cdot min^{-1}$, or oxygen consumption between 20 – 32 $ml\cdot kg^{-1}\cdot min^{-1}$.

A unique approach was utilized to compare $\dot{V}O_{2max}$ from traditional dynamic exercise with that during climbing, by Billat, Palleja, Charlaix, Rizzardo and Janel (1995), through the development of a incrementally-graded pulling test to exhaustion on a latissimus pull-down bar. A maximal treadmill test served as the first measure of cardiorespiratory fitness, followed by the maximal pulling test. Subjects then climbed two routes graded 7b (a European difficulty rating roughly equivalent to YDS 5.11+) with expired gases collected via Douglas bag. They found route-climbing $\dot{V}O_2$ to be 45.6% and 111.7% of treadmill and pulling $\dot{V}O_{2max}$, respectively. No differences were found between routes. They conclude from this that oxidative metabolism plays a secondary role in rock climbing since oxygen uptake during climbing only represents a small fraction of treadmill $\dot{V}O_{2max}$ . In addition, the role played by oxidative metabolism seems to be related to steepness of the route: as steepness increases past vertical, the contribution of the oxidative system diminishes. Their study used only four subjects of homogenous ability, limiting the applicability of their results to a sport with a widely variable population; thus further research into the contribution of various energy systems to rock climbing performance is suggested. Questions remain as to the relative roles played by the anaerobic energy systems and the contribution of oxidative metabolism to rock climbing in a sample of subjects of heterogeneous ability level.

An important question for the application of standard heart rate-based exercise prescription techniques to rock climbing concerns the validity of the linear relationship between submaximal heart rate and $\dot{V}O_2$ . Due to the fact that this activity involves repeated bouts of isometric contractions, (Mermier, Robergs, McMinn & Heyward, 1997) and the predominant use of the smaller musculature of the forearms (Billat, Palleja, Charlaix, Rizzardo & Janel, 1995), the relationship between submaximal heart rate and $\dot{V}O_2$ is not linear for static climbing on indoor artificial rock walls; submaximal heart rate is higher for a given submaximal $\dot{V}O_2$ than for more dynamic exercises such as cycling or running (Billat; Mermier). Presumably, this is related to the cardiovascular response to isometric exercise, in which heart rate and mean arterial pressure increase as a result of peripheral chemical stimulation (termed metaboreflex) as well as central baroreflex during sustained isometric contraction; the magnitude of the response has been linked to the size of the contracting muscle and the contraction intensity (Iellamo, Massaro, Raimondi, Peruzzi & Legramante, 1999). The question of how this applies to dynamic treadmill climbing will be addressed below.

The factors discussed above reveal that research into oxygen consumption alone, whether directly or indirectly, cannot fully address the energetics of rock climbing. Moreover, this approach leaves unaddressed any questions related to the generation of and response to blood lactate. Fortunately, many studies have included blood lactate analysis as part of their experimental design, though the results and conclusions vary between these. Immediate post-climb blood lactate values have been found to be 1.64, 2.40, and 3.20 $\text{mmol}\cdot\text{l}^{-1}$ on easy (90º, 5.6), moderate (106º, 5.9), and difficult (151º, 5.11+) routes, respectively (Mermier, Robergs, McMinn & Heyward, 1997); 6.1 ± 1.4 $\text{mmol}\cdot\text{l}^{-1}$ on a difficult route rated 5.12 (Watts, Newbury & Sulentic, 1996); and 5.7 and 4.3 $\text{mmol}\cdot\text{l}^{-1}$ at three minutes post-climb on two difficult routes rated 7b (French system, equivalent to YDS ~5.11+) (Billat, Palleja, Charlaix, Rizzardo & Janel, 1995). See Table 2-4 for a tabular summary of these results.

Table 2-4. Summary of blood lactate concentrations during climbing by route difficulty and angle.

| $[La^+]$ (mmol·l) | Route Angle | Difficulty (YDS) | Difficulty (other rating scale) | Study |
|---|---|---|---|---|
| 1.64 | 90º | 5.6 | | Mermier et al., 1997 |
| 2.40 | 106º | 5.9 | | Mermier et al., 1997 |
| 3.20 | 151º | 5.11+ | | Mermier et al., 1997 |
| 4.3[1] | NR* | (5.11+)[2] | 7b, France | Billat et al., 1995 |
| 5.7[1] | NR* | (5.11+)[2] | 7b, France | Billat et al., 1995 |
| 6.1 ± 1.4 | NR* | 5.12 | | Watts et al., 1996 |

[1] Sampled at 3 minutes post-climb

[2] Estimated difficulty equivalent

* Not Reported

The higher lactate values (greater than 4 $\text{mmol}\cdot\text{l}^{-1}$) for the difficult routes represent climbing above the anaerobic threshold (Pansold and Zinner, 1994). Watts, Newbury & Sulentic (1996) state that blood lactate began to significantly accumulate when the climbing angle was increased to beyond vertical, and was dependent on climbing angle. However, the dramatic differences in blood lactate concentrations between studies are not explained by climbing angle alone; other possible factors include types of movements, size of handholds, duration of isometric contractions, time spent on the routes, and individual experience level as related to climbing efficiency. Despite the discrepancy, it may reasonably be stated that climbers need to possess a high tolerance for lactate accumulation in order to climb at advanced to elite levels. More importantly, it is probable that the relative contributions of the three energy systems (ATP-PC, glycolytic and oxidative) vary based on route steepness, though exactly how these vary remains to be determined conclusively. Nonetheless, sufficient evidence supports the use of this theory in the present study to constrain climbing steepness during training to 95° or less from the horizontal, in an attempt to target the oxidative metabolic system.

## Treadmill Climbing

A recent innovation in climbing-specific training tools is the climbing treadmill, which can generally be described as a continuously-cycling length of adjoined panels fitted with modular climbing holds for the hands and feet. Some variation exists in the construction and function of various makes and models, related to the mechanisms that drive the treadmill surface and control the grade or angle of the treadmill. One such instrument, known as the Treadwall (Brewer's Ledge, Inc., Boston, MA), is driven by the weight of the climber due to gravity. As upward progress is made by the climber, a release mechanism engages allowing the surface panels to shift downwards. Climbing speed is thus self-selected by the climber for this type of climbing, termed "continuous self-paced climbing" by Watts, Clure, Hill, Humphries and Lish (1995). A motorized version of climbing treadmill has recently been developed by a different manufacturer (The Rock™, Ascent Products, Inc., Bozeman, MT), in which the speed and grade are controlled by a computerized interface. This design allows for pre-programmed settings as well as manually chosen ones, with speeds ranging from 3.0 to 15.15 $m\cdot min^{-1}$ and grades ranging from 80° to 180°. Previous research concerning climbing treadmills has been exclusive to the former model; only one study has addressed the use of the latter model (Heil, Mundinger, Stadtlander & Tesoro, in review).

In an effort to characterize the physiological response to climbing at different angles, Watts and Drobish (1998) recorded and analyzed heart rate, oxygen uptake and blood lactate during climbing on the Brewer's Ledge Treadwall. They verified that heart rate increased with climbing angle, while $\dot{V}O_2$ did not vary significantly between angles. As noted for indoor climbing (above), blood lactate began to significantly increase as the angle exceeded vertical. Subjects had a lower overall $\dot{V}O_2$ during climbing on the treadmill than for the same steady-state heart rate during traditional treadmill running; the dependence of rock climbing on the smaller musculature of the forearms (Billat, Palleja, Charlaix, Rizzardo & Janel, 1995) supports this finding. However, no differences were found in blood lactate concentration or RPE between treadmill climbing and treadmill running at equivalent steady-state heart rates. In contrast to the more static form of climbing on a fixed surface, treadmill climbing on the Treadwall was reported to present a "very heavy" demand on the cardiovascular system, eliciting 8.4 – 9.0 METs regardless of angle.

Another study evaluating physiological response to continuous self-paced climbing on the Treadwall addressed climbing at different paces. Watts, Clure, Hill, Humphries and Lish (1995) designed a novel way to pace climbing subjects using three different music rhythms at slow, moderate and fast speeds, averaging 28.9, 32.3 and 40.3 $ft{\cdot}min^{-1}$ (8.8, 9.85 and 12.3 $m{\cdot}min^{-1}$, respectively). Heart rate for slow and moderate speeds (162 and 168 bpm) were not significantly different, but were significantly lower than the fast speeds (179 bpm). Oxygen consumption averaged 33.1, 37.2 and 43.3 $ml \cdot kg^{-1} \cdot min^{-1}$ for each speed, all significantly different. Energy expenditure was higher than that reported by Hardy and Martindale (1982) (11.3 – 14.8 $kcal \cdot min^{-1}$ vs. 6.7-9.3 $kcal \cdot min^{-1}$). From these data, treadmill climbing may be seen as a continuous dynamic activity of higher energy expenditure than static wall climbing.

A pilot study conducted prior to the present research indicates a linear relationship between heart rate and oxygen consumption for motorized treadmill climbing. Using the methods described by Swain, Abernathy, Smith, Lee and Bunn (1994), submaximal steady-state data from twelve incrementally-graded exercise tests to exhaustion on a motorized climbing treadmill (The Rock ™) were compiled to produce a regression equation of $\%HR_{max}$ on $\%\dot{V}O_{2max}$. The resulting equation was $\%HR_{max} = (0.6244 \pm 0.162)\ \%\dot{V}O_{2max} + (39.738 \pm 16.383)$, with $r = 0.984 \pm 0.018$. The independent variable and the y-intercept of the linear equation have a mean and standard deviation due to the fact that the method calls for averaging the individual regression equation parameters over all subjects. This equation is similar to the linear relationship reported for treadmill walking by Swain et al., and is interpreted to suggest that motorized treadmill climbing is a dynamic exercise that elicits a linear heart rate – $\dot{V}O_2$ relationship. A greater sample size is suggested in order to conclude this relationship with certainty.

## Commonly-Used Dependent Measures in Climbing Research

### Anthropometric measurements

Body height of climbers was measured without shoes during mid-inspiration to the nearest 0.5 cm using a stadiometer by Mermier, Janot, Parker and Swan (2000). Grant, Hynes, Whittaker and Aitchison (1996) used a similar method, instructing the subjects to keep the arms at their sides and their eyes fixed at a point level on the opposite wall. Watts, Martin and Durtschi (1993) measured height to the nearest centimeter using a metal measuring tape fixed to a wall.

Body mass was determined by Mermier, Janot, Parker and Swan (2000) to the nearest 0.1 kg with the subject in athletic apparel without shoes, on a digital electronic scale. Watts, Martin and Durtschi (1993) weighed their subjects without shoes using a calibrated portable electronic scale. Grant, Hynes, Whittaker and Aitchison (1996) recorded the mass of each subject without shoes to the nearest 0.1 kg using a beam balance. Height-to-weight ratio was determined by Watts, Martin and Durtschi (1993) as height divided by the cube root of body mass.

Arm span was measured by Mermier, Janot, Parker and Swan (2000) with the subjects' backs against a wall and the arms outstretched laterally at the height of the shoulders. Total distance from the tip of one middle finger to the tip of the other middle finger in cm was recorded. Grant, Hynes, Whittaker and Aitchison (1996) measured upper limb length on the right side of the body with a tape measure to the nearest 0.5 cm. The inferior border of the acromion process served as the proximal reference point; the distal end of the measurement, for practical purposes related to climbing, was the tip of the middle finger with the arm abducted to shoulder height and the forearm supinated. Ape index was calculated by dividing the arm span by the body height by Mermier, Janot, Parker & Swan (2000).

Leg length was determined by Mermier, Janot, Parker & Swan (2000) using a carpenter's level placed at the level of the groin while the subject was standing, and total distance from the top of the level to the ground was calculated to be the leg length. Grant, Hynes, Whittaker & Aitchison (1996) measured leg length with the subject supine and legs spread to approximately shoulder width. Measurements were taken from the anterior superior iliac spine to the apex of the medial malleolus. For practical climbing purposes, they extended this measurement to the tip of the big toe with the foot plantar flexed as much as possible.

Leg span was measured by Grant, Hynes, Whittaker & Aitchison (1996) with the subject flat in a supine position, with their feet as far apart as possible without bending the knees; measurements were made from medial calcaneus to medial calcaneus to the nearest 0.5 cm.

Body composition was determined via skinfold by Mermier, Janot, Parker & Swan (2000). Skinfold thickness was measured to the nearest 0.5 mm using a Lange caliper, on the subjects' right side using anatomical sites according to Jackson and Pollock (in Mermier et al.) three-site equations for both men and women. Equations developed by Siri (in Mermier et al.) and Heyward and Stolarczyk (in Mermier et al.) were used to convert body density to percent body fat for men and women, respectively. Watts, Martin and Durtschi (1993) used a Lange caliper with measurements taken to the nearest 0.5 mm, summing seven skinfold measurements to determine body density via the generalized equations of Jackson & Pollock. Percent body fat was estimated using the Brozek (in Watts et al.) technique for each subject. Grant, Hynes, Whittaker & Aitchison (1996) predicted percent body fat using four skinfold measurements with a Holtain caliper following Durnin & Womersly's method (in Grant et al.), with all skinfolds taken on the right side of the body while the subject stood upright.

Hand and arm volumes were determined by Watts, Martin & Durtschi (1993) via plethysmography with the arm in a vertically-oriented position on the dominant arm. Hand volume was determined through immersion of the hand to the level of the styloid processes of the radius and ulna. Hand-plus-arm volume was determined through immersion of the hand and forearm to the level of the distal edge of the medial epicondyle of the humerus. Arm volume was calculated by subtracting hand volume from hand-plus-arm volume.

### Flexibility Tests

As a measure of overall flexibility, Grant, Hynes, Whittaker & Aitchison (1996) employed the sit-and-reach test, but acknowledged its limitations for assessing climbing-specific flexibility. They placed more emphasis on hip flexibility, assessed as the ability of the subject to perform the high-step maneuver with the right leg: the subject stood facing a wall with their toes on a line 23 cm from the wall, placed their hands on the wall at shoulder height, and raised the right foot as high on the wall as possible. Mermier, Janot, Parker & Swan (2000) assessed range of motion of the shoulder joint with a bubble inclinometer for abduction and flexion. Hip abduction with external rotation was measured using a goniometer while the subject was seated, with the goniometer centered at the inguinal fold at the axis of rotation with the knee bent. Hip flexion was assessed with the bubble inclinometer.

## Muscular Strength and Endurance Tests

Hand grip strength was measured by Mermier, Janot, Parker & Swan (2000) using a hand dynamometer with the dominant hand only, with the dynamometer adjusted so that the middle phalanx lined up with the handle. Three trials were permitted, with the highest value recorded as grip strength. Grant, Hynes, Whittaker & Aitchison (1996) used a calibrated hand dynamometer, sized for each subject so that the second joint of the middle finger of the hand holding the dynamometer was bent at a 90° angle. Subjects stood upright with the arm extended downwards. The best score of three trials for each hand was recorded. Watts, Newbury & Sulentic (1996) used a hand dynamometer sized so that the handle was at the distal interphalangeal joint; these researchers averaged right and left handgrip strength values.

Pincer strength was measured with a pincer dynamometer using only the thumb and middle finger by Mermier, Janot, Parker & Swan (2000). Grant, Hynes, Whittaker & Aitchison (1996) used the same hand dynamometer as for the hand grip strength test, with the grip adjusted to 4.5 cm wide for all subjects, using the thumb and forefinger. In each study, three trials were performed, with the highest value recorded as pincer strength.

Finger strength was measured in a novel way by Grant, Hynes, Whittaker & Aitchison (1996) They designed a specialized apparatus that isolated the fingers for two tests, one measuring finger extension strength and the other measuring finger curl strength.

Muscular strength of the shoulder girdle was assessed by Grant, Hynes, Whittaker & Aitchison (1996) as the number of pull-ups performed on a “finger hang-board”, a training tool for climbers to increase sports-specific hand and forearm strength. The “jug holds”, or the largest holds on the hang-board, were used for this test.

Muscular endurance of the shoulder girdle was assessed by Grant, Hynes, Whittaker & Aitchison (1996) using the bent-arm hang test on a hang-board, using the jug holds. Pilot testing by these researchers suggested that the elbow joint angle of 90º was preferable for this measure of endurance, due to the extensive period of time that subjects could hold the more fully-flexed position. Grant, Hynes, Whittaker & Aitchison (1996) used a similar test, noting chin height in relation to the hang board. Both studies relied upon administrator judgment to determine the point of failure.

### Climbing-specific Physiological Tests

Submaximal Tests: In an effort to characterize the energy expenditure of climbing on a motorized climbing treadmill, Heil, Mundinger, Stadtlander & Tesoro (in review) tested subjects at self-selected “slow” and “fast” speeds at three treadmill grades of moderate (80º or 85º), vertical (90º), and steep (95º or 100º). The six test conditions were climbed for five minutes each, separated by two minutes of standing rest. Oxygen consumption was measured for each condition via open-circuit spirometry.

To study the physiological response to climbing at different angles on a gravity-driven climbing treadmill, Watts & Drobish (1998) instructed subjects to climb at a self-selected pace, typical of what they would use over similar outdoor terrain. Five four-minute bouts of climbing were conducted at angles of 80º, 86º, 91º, 96º, and 102º, with six minutes of rest between each bout. Oxygen consumption was measured via open-circuit spirometry.

The question of physiological response to climbing at different speeds on a gravity-driven climbing treadmill was addressed by Watts, Clure, Hill, Humpreys & Lish (1995). Subjects were instructed to climb for four minutes in rhythm to three music tempos of slow, moderate and fast, while oxygen consumption was measured. No treadmill grade information was provided by the authors for this protocol.

Various indoor artificial climbing walls have been utilized for physiological research. Due to the diverse nature of the routes employed for these studies, no attempt will be made here to generalize route length, steepness or obstacles. Degree of difficulty of the routes used for climbing research ranges from 5.6 (Janot, Steffen, Porcari & Maher, 2000; Hardy & Martindale, 1982; ) to 5.12 (Watts, Daggett, Gallagher & Wilkins, 2000; Watts, Newbury & Sulentic, 1996; Billat, Palleja, Charlaix, Rizzardo & Janel, 1995); this citation list is not exhaustive, and many routes of intermediate difficulty have had physiological research conducted on them.

Maximal Tests: A unique pulling $\dot{V}O_{2max}$ test was designed by Billat, Palleja, Charlaix, Rizzardo & Janel (1995) on a pull-down apparatus. Subjects sat on a bench and grasped a pull-down bar with an overhand grip. Increments of 2.5 kg were moved through one meter in one second, corresponding to 25 watts. Initial power output was 25 watts, followed by an increase of 25 watts every two minutes until exhaustion. Expired gases were collected via Douglas bag.

Pilot work conducted prior to this research for the purpose of measuring peak oxygen uptake during climbing has validated an incrementally-graded protocol to volitional exhaustion on a motorized climbing treadmill. Subjects climbed for two minutes at each stage, beginning at a speed of 20 $ft \cdot min^{-1}$ and a grade of 80º, increasing in speed and grade at each stage by 6 $ft \cdot min^{-1}$ and 2º until exhaustion. Oxygen consumption was measured via portable open-circuit spirometry.

## Cardiorespiratory Exercise Training

Training can be defined as the systematic and regular participation in exercise to enhance sports performance (Billat, 2001). A great deal of research has been conducted into methods of improving $\dot{V}O_{2max}$, from perspectives including but not limited to types of training programs, optimal training intensities, sport-specificity of training adaptations, and cross-training effects. Specific mechanisms of adaptation, while extensively documented, are beyond the scope of this review of literature; only brief mention of these will be made here. The discussion that follows is more specific to the training programs utilized in this study.

Training for endurance sport typically involves a combination of techniques that target the three primary determinants of endurance performance: $\dot{V}O_{2max}$, economy ($\dot{V}O_2$ at submaximal exercise intensities) and the lactate threshold (LT). Substantial evidence indicates that improved performance will result from improvements in one or more of these variables (Pate & Branch, 1992). Accordingly, training programs should be designed to target each of these factors in order to be most effective. In a population of individuals of heterogeneous fitness level, $\dot{V}O_{2max}$ is the most important predictor of endurance performance (Costill, 1967; Farrell, Wilmore, Coyle, Billing & Costill, 1979), and will be considered as such for this discussion.

In whole-body exercise such as running and cycling, it is generally accepted that $\dot{V}O_{2max}$ is limited by the rate at which oxygen can be supplied to the muscles, not by the rate at which oxygen may be absorbed and utilized by the muscles (Basset & Howley, 2000; Jones & Carter, 2000; Noakes, 1998; Saltin & Strange, 1992). This ties $\dot{V}O_{2max}$ to maximal cardiac output, which is a product of maximal stroke volume and maximal heart rate; since maximal heart rate tends to remain stable regardless of fitness level, $\dot{V}O_{2max}$ is most affected by an athlete's maximal stroke volume. Factors that contribute to increased stroke volume include left ventricular hypertrophy, increased myocardial contractility, and increased end-diastolic volume (Spina, 1999). During maximal exercise, these factors result in a greater $\dot{V}O_{2max}$; during submaximal exercise, they result in a lower heart rate at a given intensity compared to pre-training heart rate.

## Types of Cardiorespiratory Training Programs

Endurance Training: The classical method of training for endurance performance is through endurance training, of long duration and moderate intensity. This type of training results in "profound adaptations of the cardiorespiratory system that enhance the delivery of oxygen from the atmosphere to the mitochondria and enable a tighter regulation of muscle metabolism" (Jones & Carter, 2000).

Long duration, moderate intensity exercise training is typically used to provide a physiological foundation of fitness related to the volume of training necessary for a particular event. For example, regardless of $\dot{V}O_{2max}$, an athlete must be able to run for 2.5-4 hours, or roughly 26 miles, in order to complete a marathon. However, this type of training is capable of raising the $\dot{V}O_{2max}$ in subjects of modest fitness level (Jones & Carter, 2000). Thus endurance training is perhaps the most common form of training (Pate & Branch, 1992), both for its' capability of enhancing the $\dot{V}O_{2max}$ of all but very-highly-trained athletes, and for its' role in providing a foundation of training volume particular to endurance events.

In their historical paper on exercise prescription, Karvonen, Kentala & Mustala (1957) reported that a threshold intensity existed for the improvement of cardiorespiratory fitness. Their conclusions were based upon intensity as a percentage of the difference between maximal and resting heart rate (the Heart Rate Reserve (HRR) concept), which is related to $\dot{V}O_{2max}$ via cardiac output as discussed above; the threshold they reported was 70% HRR. In its' 1990 position stand, the American College of Sports Medicine, equating $\dot{V}O_{2max}$ with HRR (Swain & Franklin, 2002), revised this threshold downward to 50% HRR or $\dot{V}O_{2max}$ for most healthy adults, and to 40% of HRR or $\dot{V}O_{2max}$ for individuals with low levels of fitness. Clearly, the threshold intensity is dependent on initial fitness level; more importantly, training must be conducted above this threshold for noticeable improvement in cardiorespiratory fitness. The intensity of endurance training programs, as currently undertaken by competitive participants of endurance sports, is typically 60-70% of individual $\dot{V}O_{2max}$ (Pate & Branch, 1992). As $\dot{V}O_{2max}$ improves with training, some coaches adjust the training intensity upwards, as high as 80% of initial $\dot{V}O_{2max}$, in order to continue to provide a sufficient physiological stimulus (Hawley & Burke, 1998).

High-intensity Interval Training: Interval training involves multiple bouts of exercise at higher intensities than could be maintained by an athlete for durations comparable to those used for endurance training programs. Daniels & Scardina (1984) describe interval training as such:

> Researchers, coaches and athletes have a variety of concepts of interval training, the only point of agreement being that interval training involves alternating bouts of exercise and recovery. The idea that interval training can be identified by a specific intensity, duration, or number of exercise bouts or by the amount or type of recovery between bouts of exercise is not valid. Rather, interval training has come to mean any type of intermittent training which, with manipulation of the number, intensity and duration of work bouts and amounts of recovery, is used to produce a particular type of stress on the body. There is general agreement that rather specific guidelines are available which determine the amount and intensity of work and the amount of rest necessary to produce specific results, and it is suggested that types of training be identified based on the specific characteristics of each particular type of training rather than placing all types of intermittent training in an all-inclusive category called 'interval training'.

Many interval training programs are designed to challenge metabolic energy systems other than the oxidative system alone, which tends to be the system targeted by endurance training. Because the contribution to energy expenditure from the various metabolic energy sources differs as a function of exercise intensity and duration (Wilmore & Costill, 1999), manipulating these variables allows an athlete to target the different components of endurance performance. Some training goals relate to maximizing oxidative capacity, while others are centered upon maximizing the time that high levels of lactic acid may be tolerated by an individual. When the selected exercise intensities are greater than an individual's lactate threshold, the work period may not be performed continuously for its' entire duration; rather, recovery periods must be incorporated into the workout sessions. In general, two categories of intensity may be selected from: very-high intensity, usually at or above individual $\dot{V}O_{2max}$; and high-intensity, usually in the range of the individual lactate threshold.

In some forms of endurance sport, such as cycling, power output of an athlete may be directly measured. Exercise training may then be based upon the power output corresponding to $\dot{V}O_{2max}$, and prescribed as a percentage of that power output rather than as a percentage of $\dot{V}O_{2max}$. *Supramaximal* exercise occurs when the exercise intensity is greater than the intensity which elicits $\dot{V}O_{2max}$. An external method of quantification is essential for this type of training, since respiratory parameters at intensities above the maximal aerobic capacity are not altogether capable of quantifying the energy expenditure. This is due to the fact that the metabolic energy sources for supramaximal exercise are anaerobic glycolysis and the phosphagen system, which do not require oxygen and thus are not fully accounted for by measurement of respiratory gas exchange parameters. Though the maximal accumulated oxygen deficit (MAOD) may be used to estimate the contribution to external energy expenditure by the anaerobic system (Medbo, Mohn, Tabata, Bahr, Vaage & Sejersted, 1988; Scott, Roby, Lohman, Bunt, 1991; Moore & Murphy, 2003), this variable is very technical and not easily used for exercise prescription. However, many high-intensity interval training strategies utilize supramaximal intensities quantified by power output, and expressed in terms of $\dot{V}O_{2max}$ utilizing percentages greater than 100% (e.g. Weber & Schneider, 2001). As the power systems relied upon operate without an immediate oxygen supply, the duration that work bouts may be performed is typically very short, from 15 seconds to less than 2 minutes. Such sessions have been called *anaerobic interval* training (Billat, 2001). In order to place these types of training programs into a context with the training programs used in the present study, they will be referred to as "very-high-intensity training" (Pate & Branch, 1992). None of the training programs used in the present study were conducted at these intensities; they are mentioned solely for the purpose of providing a thorough review of the literature.

The style of training chosen for the High-intensity Interval Training program in the present study has been termed "moderate durationhigh-intensity training" (Pate & Branch, 1992) or *aerobic interval training* (Billat, 2001), and involves an intensity of exercise in the range of the athlete's lactate threshold. The exercise intensity corresponding to the increase in blood lactate above resting levels is a powerful predictor of athletic performance (Jones & Carter, 2000; Farrell, Wilmore, Coyle & Costill; 1979). Optimal improvements in $\dot{V}O_{2max}$ are thought to be induced by training at an intensity corresponding to 90-100% of $\dot{V}O_{2max}$ (Robinson, Robinson, Hume, & Hopkins, 1991; Billat, 2001). The physiological benefits are "probably associated with increasing the lactate threshold and/or adapting to long durations of exercise at the current LT" (Pate & Branch). In fact, aerobic interval training was shown to improve both $\dot{V}O_{2max}$ and lactate threshold in a study of runners, while endurance training improved only $\dot{V}O_{2max}$ in similar subjects (Carter, Jones & Doust, 1999). Franch, Madsen, Djurhuus & Pedersen (1998) confirmed that endurance training and long interval training (4 minutes per work bout) improved $\dot{V}O_{2max}$ significantly mores than short interval training (less than 1 minute per work bout).

## Cardiorespiratory Adaptations by Length of Training Program

Training programs may be created for the short to long term, depending on individual goals and preferences. The magnitude of the physiological response depends upon many factors, including the frequency, intensity and duration of training (Wenger & Bell, 1986) and the initial fitness level of the participant (ACSM 2000). Sports performance following training is dependent upon all of these, plus the specificity of training to that sport or event (Hawley and Burke, 1998). However, provided that the training variables listed above are correctly utilized for the promotion of adaptation (neither under- nor over-training), the length of the training program then influences the magnitude of the response.

The ideal duration of a systematic training program for the improvement of cardiorespiratory fitness, as gauged by $\dot{V}O_{2max}$, is not an absolute period of time. Instead, $\dot{V}O_{2max}$ increases in response to proper training techniques along a continuum, as physiological adaptation to progressive stress occurs. At some point following the initiation of training, the magnitude of the physiological adaptation becomes detectable; this threshold may differ primarily due to the training intensity as a percentage of $\dot{V}O_{2max}$, as well as the ability of an individual to recover from and adapt to the training load. The greatest improvements in $\dot{V}O_{2max}$ occur when the greatest challenge to aerobic capacity occurs (Wenger & Bell, 1986), when all other factors (frequency, duration, program length, and initial fitness level) are equal. However, the magnitude of improvement is greatest among less fit subjects, and diminishes as initial fitness level increases. Thus, longer training program durations may be required to result in detectable improvements in $\dot{V}O_{2max}$ as fitness level increases.

Recent training studies, comparing or evaluating types of training programs or evaluating specific modalities of training, range in duration from 3 weeks to over 12 weeks. As mentioned, the longer the duration of the training program, the greater the magnitude of improvement in cardiorespiratory fitness tends to be. Eventually a plateau will be encountered, beyond which the rate of improvement will diminish, specific to individual factors such as initial fitness level or genetic capacity. However, in all but very highly-trained athletes, there exists sufficient potential for improvement in $\dot{V}O_{2max}$ that properly designed training programs of 3-12 weeks in duration will result in a detectable increase. In fact, it has been proposed that the majority of improvement in $\dot{V}O_{2max}$ in response to moderate- to high-intensity cardiorespiratory training occurs in as little as three weeks (Jones & Carter, 2000), partly as a result of an early hypervolemia (increased blood volume) which will increase stroke volume during exercise. Given this suggestion, as well as a preponderance of studies in which the training program was six weeks in duration or less, the duration of the training phase of the present study was chosen to be six weeks in duration. Table 2-5 summarizes the studies used to support this choice.

Table 2-5. Summary of improvements in $\dot{V}O_{2max}$ by program length and training parameters from selected studies.

| | | $\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$) | | | Training Parameters | | | |
|---|---|---|---|---|---|---|---|---|
| Author | Program Length (weeks) | Pre-training | Post-training | % change | Frequency ($days \cdot wk^{-1}$) | Intensity | Duration | Modality |
| 1 | 6 | 53 ± 5 | 58 ± 3 | | 5 | 70% $VO_{2max}$ | 60 min | cycling |
| " | 6 | 48 ± 5 | 55 ± 6 | | 5 | 170% $VO_{2max}$ | 20s x 8 | " |
| 2 | 6 | | | +5.9 | 3 | 93% $HR_{max}$ | 20-30 min | running |
| " | 6 | | | +6.0 | 3 | 94% $HR_{max}$ | 20-30 min | " |
| " | 6 | | | +3.6 | 3 | 92% $HR_{max}$ | 20-30 min | " |
| 3 | 6 | | | +10 | 3-5 | LT | 20-30 min | running |
| 4 | 3 | | | +14 | 6 | | 40 min | running |
| " | 9 | | | +23 | 6 | | 40 min | " |
| 5 | 4 | 61.5 | 64.5 | | 3 | $V_{max}$ | 60-75% $T_{max}$ | running |

1 Tabata, Nishimura, Kouzaki, Hirai, Ogita, Miyachi & Yamamoto (1996)
2 Franch, Madsen, Djurhuus & Pedersen, (1998)
3 Jones, Carter & Dourst, (1999)
4 Hickson, Hagberg, Ehsani & Holloszy, (1981)
5 Smith, McNaughton & Marshall, (1999)

## Training for Rock Climbing Performance

Climbing ability can be significantly explained by the training component (of anthropometric, flexibility and training) regressed on redpoint ability, a measure of difficulty-based climbing performance (Mermier, Janot, Parker & Swan, 2000). Despite significant differences observed between elite and recreational or non-climbers in many studies previously cited for anthropometric measures, muscular strength and endurance factors are essential determinants of performance in climbing. As these are trainable, it seems reasonable that properly-constructed training programs may have the potential to enhance climbing ability.

Most climbers tend to train unscientifically (Twight and Martin, 1999), though increasing awareness of the benefit of systematic physical training among climbers is resulting in a reversal of this trend. Many sources for training advice are available to the motivated climber, ranging from monthly columns in climbing magazines to recently-published books by authors of various background and experience. The science of training for climbing is a recent area of applied physiological principles and rigorous investigation, and has yet to reach maturity; however, some general training guidelines exist for improving climbing performance.

Due to the importance of sport-specificity as a training parameter, and the fact that many forms of climbing currently exist, a wide variety of approaches to training exist. Twight and Martin (1999) suggest a thorough approach to training based on periodization; the initial weeks of each period begin with a conditioning phase of cardiorespiratory exercise and resistance training, followed by strength training and cardiovascular power training, with the final phase of the period devoted to muscular endurance training and cardiovascular endurance training. This training approach is directed toward alpinists, whose performance events may be 6,000-meter peaks with approach hikes of 20 miles or more, with backpacks approaching 80% of body weight. Soles (2002) provides a similarly-targeted training program, with a focus on explaining the exercises that tend to be more functionally-oriented toward rock climbing and mountaineering.

These approaches to training may require too much dedication for the recreational sport-climber, whose performance events may simply be difficult and gymnastic moves on local cliffs or indoor gyms.  Horst (2003) provides a climbing-specific training manual oriented more towards this type of climber, with descriptions of training techniques for the forearms, hands and fingers.  He recommends training tools such as finger boards for building muscle and tendon strength that may enhance a climber's performance using small hand-holds, on steep routes or for long duration.  Undoubtedly, for the climber interested in increasing his or her performance on sport climbs, this type of training is much more sport-specific.  It should be stated that this summary is not exhaustive; a reasonable selection of other training-oriented books, articles, videos and online resources exist for the interested reader or climber.

# CHAPTER THREE

# METHODS

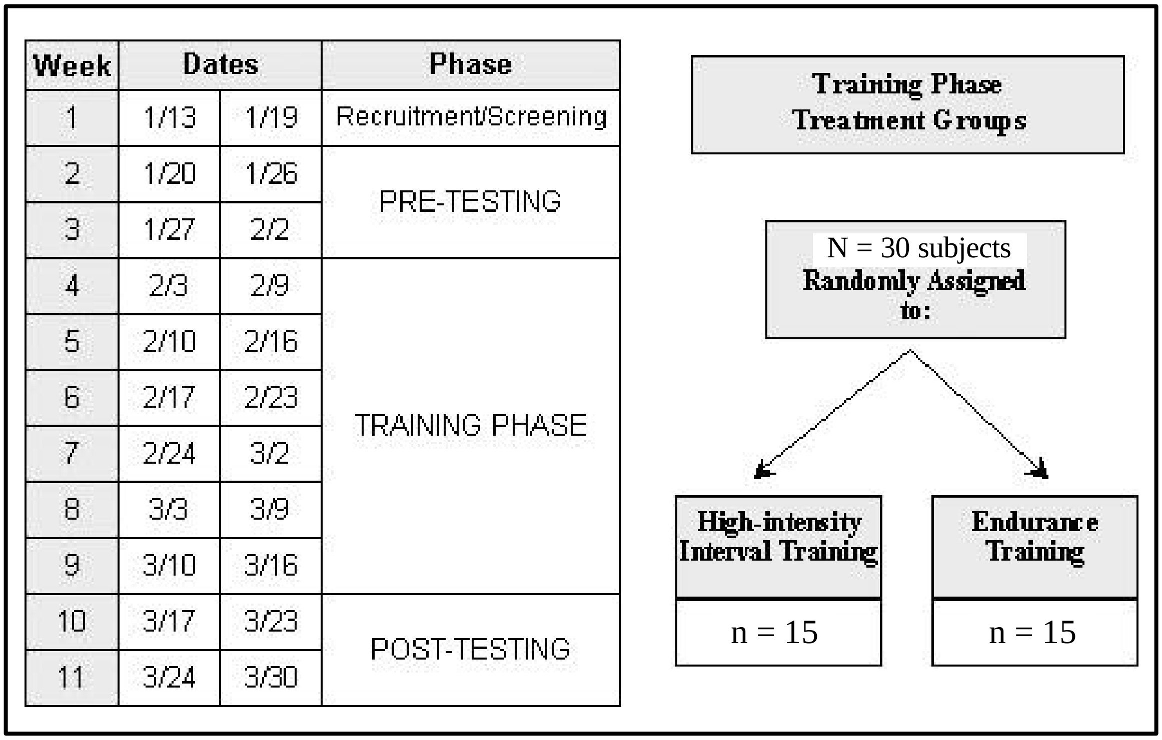
## Subjects

Thirty college-aged men and women were recruited from the Montana State University campus and surrounding community. Participants were required to be free from metabolic, cardiovascular or musculoskeletal disease, and were screened for contraindications to maximal exercise testing using a medical health history questionnaire. Furthermore, participants were required to be physically active, but not highly trained; previously sedentary subjects were excluded, as were very fit athletes and competition-level climbers. Due to potentially confounding results related to greater physical training volume, subjects who were undertaking additional training outside of this study were also excluded. Each subject signed an Informed Consent Document (Appendix A), which included a description of the testing and training procedures. These procedures were approved by the Institution Review Board of Montana State University.

## Experimental Design

A timeline for the experimental procedures and overview of the experimental design is shown in Figure 3-1. Following recruitment, pre-test measures were obtained over a two-week period. Subjects were then randomly assigned into one of two experimental groups: a high-intensity interval training group (HIT) and an endurance training group (ET). Six weeks of physical training then occurred according to the exercise prescription procedures described below for each experimental group. Post-testing occurred immediately after the conclusion of training, and covered a two-week period.

Figure 3-1. Overview of timeline and study design.



| Week | Dates | | Phase |
|---|---|---|---|
| 1 | 1/13 | 1/19 | Recruitment/Screening |
| 2 | 1/20 | 1/26 | PRE-TESTING |
| 3 | 1/27 | 2/2 | |
| 4 | 2/3 | 2/9 | TRAINING PHASE |
| 5 | 2/10 | 2/16 | |
| 6 | 2/17 | 2/23 | |
| 7 | 2/24 | 3/2 | |
| 8 | 3/3 | 3/9 | |
| 9 | 3/10 | 3/16 | |
| 10 | 3/17 | 3/23 | POST-TESTING |
| 11 | 3/24 | 3/30 | |

Dependent measures for this study were categorized into demographic, anthropometric, physiological, and climbing performance variables (Table 3-1). Armspan, body height, ape-index (defined as armspan minus body height), and limb circumferences were measured using standard procedures discussed below. The Incremental Overhang Test (IOT) and a climbing-specific peak oxygen uptake test ($\dot{V}O_{2peak}$ Climbing Test) comprised the climbing performance protocols on the climbing treadmill. These test protocols are described below.

Table 3-1. Variables used as dependent measures.

| Demographic | Anthropometric | Muscular Strength | Muscular Endurance | Cardiorespiratory | Climbing Performance |
|---|---|---|---|---|---|
| Age | Height | 1-Rep maximum in the Lat-Pulldown | Bent-arm Hang Time | Absolute $\dot{V}O_{2peak}$ | IOT Time |
| Climbing Experience | Weight | Grip Strength | | Relative $\dot{V}O_{2peak}$ | $VO_2$ Time |
| Gender | Armspan | | | | |
| | Ape-index | | | | |
| | (R&L) Forearm and Calf Circumferences | | | | |

## Procedures

Each subject first completed a Health History Questionnaire (Appendix A) to assess their health status and physical condition. Next, they read and signed an Informed Consent Document (Appendix A), in which the purpose and procedures of the study were explained. Instructions for the testing procedures were given to subjects, including the testing schedule and appropriate preparation for each session.

Three visits to the Movement Science Lab were required for the completion of the pre-test series. To control for biorhythmic influences of time of day on test results, subjects were asked to schedule all test sessions within plus or minus two hours of the same time of day for each visit. As suggested by the American College of Sports Medicine (2000), the required testing of each session was conducted in the following order, as applicable: body composition/anthropometric data first, followed by resting physiological measures, cardiorespiratory endurance tests, muscular strength tests, and lastly muscular endurance tests.

### First Testing Session:

During the first visit, all demographic and anthropometric variables were assessed. Two tests of upper-body muscular strength and one test of upper-body muscular endurance were conducted.

Age and gender were recorded. Climbing experience was assessed by asking subjects to choose which of the keywords “none (coded as “1”), little (“2”), moderate (“3”), or extensive (“4”) best described the amount of climbing experience each possessed. Body height and body weight were measured on a physician’s beam scale. Armspan was measured with the subject standing with his or her back against a wall, arms and fingers fully extended at shoulder height; the subject’s left middle finger was placed flush with a wooden block, to which was attached one end of a measuring tape. Armspan was read at the opposite end of the tape, at the distal end of the subject’s right middle finger. Ape-index was calculated as armspan divided by body height. Calf circumferences were measured with a tension-regulated tape at the point of greatest girth on each lower leg, with the subject sitting on the edge of a table. Forearm circumferences were measured in a similar manner bilaterally, with the subject standing upright, arms relaxed at the sides.

Maximal handgrip strength was assessed using the GRIP-A dynamometer (Takei Scientific Instruments Company, Ltd., Tokyo, Japan), which was sized according to the manufacturer's instructions for each subject. The subject was instructed to stand upright and relaxed, holding the upper arm and elbow against the side of the body. The hand being tested held the dynamometer out from the body with a 90° bend in the elbow, with the palm facing the midline. Grip strength was determined as the best trial of three for each hand. The dynamometer was reset between each trial.

Muscular strength of the latissimus dorsi was assessed in the Lat Pull-down 1-Repeition Maximum (1-RM) Test. Subjects first performed a series of three warm-up sets on a lat pull-down machine using 45-65% of body weight (self-selected) and 8, 6 and 4 repetitions, respectively. One minute of rest was allowed between sets. Then, using a front overhand grip on the pull-down bar, subjects performed a single repetition per set against increasing resistance, and rested one minute between attempts. Failure to complete the exercise through the full range of motion, or failure to maintain proper form, precluded a successful lift. Maximum strength was determined as the highest weight lifted successfully.

Upper-body isometric muscular endurance was assessed in the Bent-arm Hang Test, conducted on a Metolius Simulator hang-board (Metolius, Inc., Bend, OR). The subject was assisted through the full range of an overhand-grip pull-up until a maximally-flexed arm position (at the elbow joint) was achieved. The subject then lowered his or her body position by increasing the angle at the elbow joint until a right angle was achieved, at which point the test began. The subject attempted to remain in this position for as long as possible. The test score time was defined as the point at which the subject failed to maintain or return to an elbow-joint angle of $90^{o}$. Verbal encouragement was provided, and the best time of up to three trials was recorded.

Second Testing Session:

Two climbing performance tests on a motorized climbing treadmill (see Instrumentation) were administered in this session, separated by fifteen minutes of rest. The first test was a practice attempt on the $\dot{V}O_{2peak}$ Climbing Test and the second test was the Incremental Overhang Test, both described below.

Experimentation prior to this study indicated that a learning effect on performance exists for maximal exercise on the motorized climbing treadmill; this learning effect is minimized by allowing a practice attempt. Subjects were thus asked to practice the $\dot{V}O_{2peak}$ Climbing Test to failure during the second testing session. This test was a graded exercise test to volitional exhaustion on a motorized climbing treadmill. The protocol consisted of a maximum of eight 2-minute stages, beginning at a speed of 6.06 $m \cdot min^{-1}$ and a grade of 80° (20 $ft \cdot min^{-1}$ and 10° from vertical). Both speed and grade increased for each successive stage, by 1.82 $m \cdot min^{-1}$ and 2° (6 $ft \cdot min^{-1}$ and -2° from vertical), respectively, until exhaustion or sixteen minutes, whichever occurred first. During the practice attempt, HR was measured and recorded at 5-second intervals by telemetry (see Instrumentation). Elapsed time, distance climbed and treadmill settings at the point of exhaustion were recorded.

The Incremental Overhang Test began with the treadmill speed and grade fixed at 7.93 $m \cdot min^{-1}$ and 90° (26 $ft \cdot min^{-1}$ and 0° from vertical) for three minutes. At 3:00 minutes into the test, treadmill grade steepened by three degrees and speed increased to 9.15 $m \cdot min^{-1}$ (30 $ft \cdot min^{-1}$). Every 20 seconds thereafter, the grade steepened by three more degrees at constant speed, reaching maximum steepness of 132º (-42º from vertical) at 7:40 minutes. Subjects were encouraged to climb for as long as possible, with exhaustion defined as falling off the treadmill without the ability to continue climbing despite encouragement, or three falls from or safety-stops of the treadmill within a single stage. Heart rate was measured and recorded at five-second intervals, and elapsed time, distance climbed and treadmill settings at the point of exhaustion were recorded.

### Third Testing Session:

Climbing-specific cardiorespiratory fitness was determined using the $\dot{V}O_{2peak}$ Climbing Test protocol during this testing session. Time to exhaustion for this protocol was used as a measure of climbing performance.

Expired gases were analyzed using a portable metabolic system, and heart rate was measured by telemetry. Heart rate and expired gas data collection continued for one minute following termination of the test. Exhaustion was defined as described for the practice attempt at this protocol.

## Post-Testing Procedures

Post-training test procedures replicated the pre-training procedures described above. Subjects were instructed to schedule test sessions within plus or minus two hours of the time of day that pre-training test sessions were attended. No fewer than 24 hours nor no more than 72 hours elapsed between test sessions for all subjects during post-training testing.

## Exercise Prescription for Training Phase

For both training groups, exercise prescription was based upon measured pre-test values of absolute $\dot{V}O_{2peak}$ ($L \cdot min^{-1}$) measured on the $\dot{V}O_{2peak}$ Climbing Protocol. Once climbing-specific $\dot{V}O_{2peak}$ was determined, the appropriate percentages were chosen as the target training intensity for each experimental group (explained below). The target oxygen consumption ($L \cdot min^{-1}$) was then used to determine the appropriate treadmill speed for training purposes, given the mass of the climber and the appropriate grade ($GRD < 96°$) for each training group, according to Equation 1 (Heil, Mundinger, Stadtlander & Tesoro, in review):

$$(1) \qquad \text{SPD } (m \cdot min^{-1}) = \frac{\dot{V}O2 - (0.03221 x MASS + 0.02311 x GRD - 3.5301)}{0.1453}$$

Based on this intensity, a corresponding percentage of measured maximal heart rate was determined according to Equation 2, developed during pilot testing for this study:

$$\%HR_{max} = 0.643(\%\dot{V}O_{2peak}) + 36.8 \tag{2}$$

Equation 2 was used in conjunction with the maximal heart rate ($HR_{max}$) measured during the $\dot{V}O_{2peak}$ Climbing Test to determine the appropriate target heart rate for training. Thus, heart rate was used to monitor exercise intensity during training. Prior to each workout, subjects were instructed to warm up for five minutes at low-intensity self-selected speeds and grades.

High-intensity Interval Training Group

Training for subjects assigned to the HIT group consisted of three 6-minute bouts of climbing, separated by three-minute intervals of standing rest. Exercise intensity was prescribed as a percentage of subjects' measured pre-test climbing $\dot{V}O_{2peak}$, according to the target intensities for this type of training as explained below.

Training sessions were conducted at 80-95% of subjects' $\dot{V}O_{2peak}$. During the first week, treadmill speed at a grade (or climbing angle) of 88° was matched to training intensity to elicit approximately 80% of measured pre-test $\dot{V}O_{2peak}$. The following weeks were spent training at the lower end of the desired intensity range (approximately 80-85% $\dot{V}O_{2peak}$), increasing to 95% $\dot{V}O_{2peak}$ by week 6 of the training phase. Treadmill grade increased every two weeks after the first by 2º, up to a maximum of 94º. Table 3-2 shows the exercise prescription for the High-intensity Interval Training program by week. Three climbing repetitions per training session were prescribed as the target number, separated by three minutes of rest; in the event that a subject could not complete three full repetitions, they were instructed to attempt as many full six-minute bouts as possible. Treadmill grade remained constant for each climbing repetition as well as for each workout session.

### Endurance Training Group

Training for subjects consisted of a single bout of climbing for 20 minutes, conducted at 65-80% $\dot{V}O_{2peak}$. During the first week of training, treadmill speed at a grade (or climbing angle) of 88° was matched to proper training intensities to elicit approximately 65% of measured pre-test $\dot{V}O_{2peak}$. The following weeks were spent training at the lower end of the desired intensity range (approximately 65-70% $\dot{V}O_{2peak}$), increasing to 80% $\dot{V}O_{2peak}$ by week six of the training phase. Treadmill grade increased every two weeks after the first by 2º, up to a maximum of 94º. Table 3-2 shows the exercise prescription for the Endurance Training program by week. Training duration was held constant throughout the training phase at twenty minutes per workout; in the event that a subject could not climb continuously for that duration, they were instructed to climb for as long as possible at the prescribed intensity.

Table 3-2. Climbing treadmill exercise prescription during the training phase for the High-intensity Interval Training (HIT) program and the Endurance Training (ET) program by week.

| | **Week 1** | **Week 2** | **Week 3** | **Week 4** | **Week 5** | **Week 6** |
|---|---|---|---|---|---|---|
| **%** $\dot{V}O_{2peak}$ | | | | | | |
| HIT | 80% | 80% | 85% | 90% | 90% | 95% |
| ET | 65% | 65% | 70% | 75% | 80% | 80% |
| Grade | | | | | | |
| HIT | 88º | 90º | 90º | 92º | 92º | 94º |
| ET | 88º | 90º | 90º | 92º | 92º | 94º |
| Duration (minutes) | | | | | | |
| HIT | 6 | 6 | 6 | 6 | 6 | 6 |
| ET | 20 | 20 | 20 | 20 | 20 | 20 |
| Repetitions | | | | | | |
| HIT | 3 | 3 | 3 | 3 | 3 | 3 |
| ET | 1 | 1 | 1 | 1 | 1 | 1 |

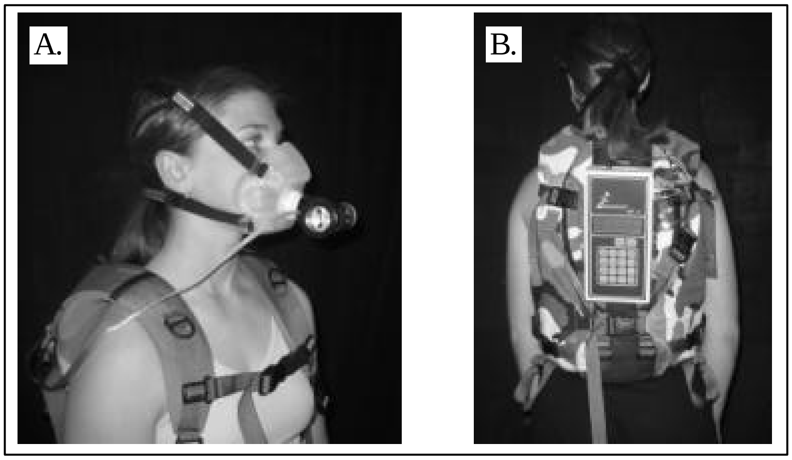
Participants in each group performed three training sessions per week on the treadmill. Heart rate was monitored during each training session. Training logs of each session were kept by each subject; information recorded included time spent climbing, route(s) and protocol(s) completed, total vertical feet climbed, and overall RPE for the session.

## Instrumentation

### Expired Gas Analysis:

Oxygen consumption and carbon dioxide production were measured during submaximal and maximal climbing treadmill tests using the KB1-C portable metabolic analyzer (Aerosport, Ann Arbor, MI). This open-circuit system was connected to the subject via a non-rebreathing mask covering the mouth and nose (Figure 3-2A), which allowed inspiration of room air. Expired air was sampled continuously and averaged over 20-second intervals by the KB1-C; samples were analyzed for $F_ECO_2$, $F_EO_2$, and $\dot{V}_E$, the fractional concentrations of carbon dioxide and oxygen in expired air, respectively, as well as the volume of air expired per minute. Calibration of the system was performed prior to each test via a gas mixture of 16.0% oxygen and 4.0% carbon dioxide. The KB-1C was mounted to the back of a 0.92-kilogram Wookey™ Shovelpack (Wookey, Inc., Bozeman, Montana), which was worn by the subject during metabolic testing (Figure 3-2B). It featured ergonomically molded plastic and foam shoulder and abdominal straps that served to stabilize the pack during upper-body motion. Range of upper-extremity motion was not restricted by the pack.

Figure 3-2. Aerosport KB1-C portable metabolic measurement system: (A.) Face mask covering mouth and nose; (B.) Analysis unit mounted on backpack worn while climbing.



## Heart Rate Monitoring:

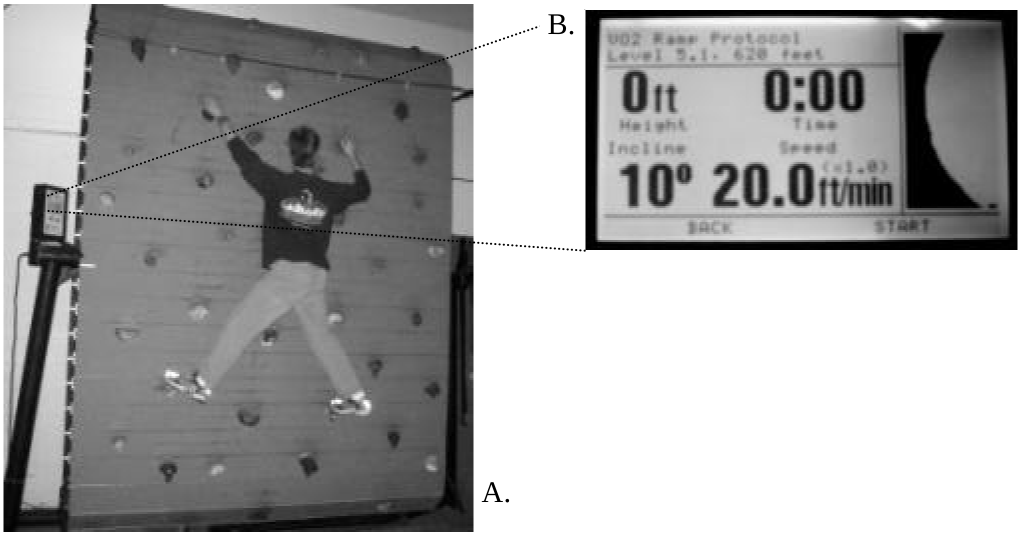
Heart rate was monitored via telemetry from an electrode strap worn around the subject's chest, and recorded as a data file on a wrist receiver (Polar Accurex, Polar USA

Enterprises). In all tests requiring heart rate to be monitored, the receiver was set to record the subject's heart rate at five-second intervals. The data file was downloaded for printing and storage to a computer file by means of the Polar SonicLink™ computer interface unit and software.

Climbing Treadmill:

All climbing-specific tests, as well as the training sessions, were conducted on a commercially available motorized climbing treadmill (The Rock™, Ascent Products, Inc., Bozeman, MT; Figure 3-3A), located in the Movement Science/Human Performance Lab at Montana State University (Bozeman, MT). The treadmill was 3.6 meters tall and 2.4 meters wide (12 x 8 feet), with a usable climbing surface area of 8.64 meters$^2$. Treadmill settings were controlled by an on-board microprocessor console (Figure 3-3B), which was capable of manual operation or storage of user-designed programs. The 110V internal motor ranged in speed from 0-15.15 m$\cdot$min$^{-1}$ (0-50 ft$\cdot$min$^{-1}$); inclination, or climbing angle, ranged from 80-180 degrees from the horizontal, and was controlled by an internal inclinometer. The treadmill has a specified weight limit of 136 kg with a two-person maximum. Treadmill speed and grade were verified using a Biddle hand tachometer (AVO International, Blue Bell, PA) and magnetic-base inclinometer (Macklanburg-Duncan, Oklahoma City, OK). The microprocessor console displayed speed in units of feet per minute, and determined incline using the vertical plane of reference; consistency with the literature necessitated that these values were converted to SI units for this report. A thick foam crash pad and a trained spotter were positioned under the treadmill to ensure safety from falls.

Figure 3-3. The Rock™ motorized climbing treadmill: (A.) In use by a single climber; (B.) The Rock™ control panel, shown as an inset.



## Pilot Study

Prior to the use of the procedures identified herein for the purposes of exercise prescription and evaluation of training effects, it was necessary to conduct two separate pilot studies on The Rock™ climbing treadmill. Data was collected for both studies simultaneously during the $\dot{V}O_{2peak}$ Climbing Test as described above, with n=12 subjects.

### $\dot{V}O_{2peak}$ Climbing Test Reliability:

The first pilot study was conducted for the purpose of evaluating the reliability of the $\dot{V}O_{2peak}$ Climbing Test. This protocol was created for the purpose of measuring climbing-specific peak oxygen uptake, and was a novel protocol for an exercise modality that has previously only been evaluated for steady-state conditions (Heil, Mundinger, Stadtlander & Tesoro, in review). It was therefore necessary to determine the validity and reliability of this test before applying it to exercise testing and prescription procedures for training.

Six male and six female (n=12) subjects volunteered to perform three graded exercise tests to volitional exhaustion on The Rock™ climbing treadmill, once without and twice wearing the KB-1C portable metabolic analyzer. Data collected included oxygen consumption, carbon dioxide production and minute ventilation, sampled at twenty-second intervals. Respiratory exchange ratio was calculated from these data. In addition, heart rate was recorded at 15-second intervals throughout each test.

Statistical analysis consisted of a combination of reliability measures of a paired t-test and correlation analysis. Each subject's $\dot{V}O_{2peak}$ from the second trial was averaged, as were those of the third trial. Using a paired t-test, the mean $\dot{V}O_{2peak}$ from trials 2 and 3 were then compared. Paired t-tests revealed no significant differences between the mean $\dot{V}O_{2peak}$ values between trial 2 (T2) and trial 3 (T3) at the $\alpha = 0.05$ level: T2=3.26±0.18 $l{\cdot}min^{-1}$, T3=3.37±0.24 $l{\cdot}min^{-1}$; P=0.443.

## Relationship of %HRmax to %$\dot{V}O_{2peak}$ in Motorized Treadmill Climbing:

Many studies have measured or compiled the results of maximal exercise tests for the purpose of determining a relationship between the percent of maximal heart rate and the intensity of exercise expressed as a percentage of maximal $\dot{V}O_{2peak}$ (Swain, Abernathy, Smith, Lee & Brown, 1994; Miller, Wallace & Eggert, 1993). However, none of these attempts could be unquestionably relied upon to predict this relationship for simulated climbing on a motorized treadmill, due to the increased role of upper-body musculature in this activity compared to walking, running or cycling. Therefore, a separate analysis of the data collected for the previous pilot study was undertaken to determine the relationship between %$HR_{max}$ and %$\dot{V}O_{2peak}$ for motorized treadmill climbing.

From the results of each maximal test on the climbing treadmill, the final three values of heart rate (the final 30 seconds) of each stage were averaged to determine a "steady state" heart rate for that intensity of exercise. These were paired with the oxygen consumption values over the final twenty seconds of each stage. It is acknowledged that two-minute stages may not have been long enough to elicit a true physiological steady state, especially at the higher intensities of exercise; however, a good approximation to steady-state conditions are provided by this method (Swain, Abernathy, Smith, Lee & Brown, 1994 ).

For each subject's test results, the paired heart rate and $\dot{V}O_2$ values for each stage were first converted into respective percents of maximum, using the highest heart rate and $\dot{V}O_2$ attained in any test by that subject as maximum. These percents were then analyzed by simple linear regression with %$\dot{V}O_{2peak}$ as the independent variable.

## Statistical Analysis

Two-way repeated measures ANOVA were used in the present study to identify significant differences between groups by time. Tukey's post-hoc analyses revealed mean and variance of dependent measures between groups by time. Two-sample t-tests were used to compare changes in dependent measures from pre- to post-testing.

Pearson’s correlation was used to examine the degree of association between selected variables.

# CHAPTER FOUR

# RESULTS

## Subject Characteristics

Thirty adults (n = 15 males and 15 females) from the Montana State University campus and surrounding community volunteered to participate in this study. Time constraints or unrelated injury prevented three subjects (two males, one female) from completing either the training phase or the post-testing series. Therefore, the results are based upon 27 subjects (n = 13 males and 14 females). These subjects were all compliant with the inclusion and exclusion criteria of the study.

Subject age ranged from 18 to 37 years, with mean and standard deviation of 22.2 ± 3.6 years. Fifteen subjects were randomly assigned to the High-intensity Interval Group (HIT) and the other 15 were assigned to the Endurance Training Group (ET); after removal of the three subjects as described above, the HIT group contained 14 subjects (seven male and seven female) and the ET group 13 subjects (six male and seven female). After assignment into groups, mean age was not significantly different between groups.

## Anthropometric Data

Mean body mass was 68.17 ± 11.70 kg (mean ± standard deviation) and mean height was 170.44 ± 9.38 cm over all subjects. Table 4-1 lists anthropometric data by group. Mean pre-test armspan was 172.93 ± 10.28 cm for the HIT group and

169.73 ± 11.61 cm for the ET group. Mean post-test armspan was significantly greater for the HIT group at 173.88 ± 10.25 cm, however mean post-test armspan for the ET group was not significantly different from its' pre-test value at 170.42 ± 11.11 cm. Accordingly, mean ape-index (defined as armspan divided by height, unitless) increased from pre-testing to post-testing for both groups; this measure increased significantly in the HIT group from 1.009 ± 0.021 to 1.014 ± 0.022, however the increase from 1.006 ± 0.028 to 1.007 ± 0.026 in mean ape-index for the ET group was not significant. Mean forearm circumferences for each arm increased from pre- to post-testing in both groups; this measure increased significantly in HIT group from 25.81 ± 2.63 cm to 26.11 ± 2.58 cm for the right forearm, and 25.44 ± 2.78 cm to 25.84 ± 2.65 cm for the left. The increases in the mean were not significant in the ET group at the $\alpha = 0.05$ level; mean right forearm circumference increased from 25.22 ± 2.78 cm to 25.37 ± 2.72 cm, while the left increased from 24.75 ± 2.90 cm to 25.02 ± 2.87 cm. Mean calf circumference decreased from pre- to post-testing in both groups; the decrease in right calf circumference was significant for both groups (37.58 ± 2.69 cm to 37.13 ± 2.82 cm for the HIT group, and 36.39 ± 2.48 cm to 35.91 ± 2.32 cm for the ET group). The decrease in mean left calf circumference was not significant at the $\alpha = 0.05$ level for either group (37.41 ± 2.55 cm to 37.26 ± 2.72 cm for the HIT group, and 36.10 ± 2.40 cm to 35.82 ± 2.28 cm for the ET group).

Table 4-1. Anthropometric data for the High-intensity Interval Training group (HIT; n = 14) and Endurance Training group (ET; n = 13).

| Variable | Pre-training | Post-training |
|---|---|---|
| **Age** | **(yrs)** | |
| HIT | 22.4 ± 2.3 | ----- |
| ET | 22.0 ± 4.7 | |
| **Height** | **(cm)** | |
| HIT | 171.41 ± 8.32 | ----- |
| ET | 169.39 ± 10.64 | |
| **Body Mass** | **(kg)** | **(kg)** |
| HIT | 69.99 ± 12.28 | 70.33 ± 12.20 |
| ET | 66.20 ± 11.19 | 65.71 ± 11.14 |
| **Armspan** | **(cm)** | **(cm)** |
| HIT | 172.93 ± 10.28 | 173.88 ± 10.25* |
| ET | 169.73 ± 11.61 | 170.42 ± 11.11 |
| **Ape-index** | | |
| HIT | 1.009 ± 0.021 | 1.014 ± 0.022* |
| ET | 1.006 ± 0.028 | 1.007 ± 0.026 |
| **Right Forearm Circumference** | **(cm)** | **(cm)** |
| HIT | 25.81 ± 2.63 | 26.11 ± 2.58* |
| ET | 25.22 ± 2.78 | 25.37 ± 2.72 |
| **Left Forearm Circumference** | **(cm)** | **(cm)** |
| HIT | 25.44 ± 2.78 | 25.84 ± 2.65* |
| ET | 24.75 ± 2.90 | 25.02 ± 2.87* |
| **Right Calf Circumference** | **(cm)** | **(cm)** |
| HIT | 37.58 ± 2.69 | 37.13 ± 2.82* |
| ET | 36.39 ± 2.48 | 35.91 ± 2.32* |
| **Left Calf Circumference** | **(cm)** | **(cm)** |
| HIT | 37.41 ± 2.55 | 37.26 ± 2.72 |
| ET | 36.10 ± 2.40 | 35.82 ± 2.28 |

Values=mean ± standard deviation.
* $p<0.05$ compared to pre-training.

## Climbing Experience Level

Subjects were each verbally asked to rate their climbing experience level given the following choices: none (coded as "1"), little (2), moderate (3), or extensive (4) (see Appendix B). Climbing experience levels for subjects in the HIT group were none = 6 subjects, little = 4 subjects, moderate = 3 subjects, and extensive = 1 subject; climbing experience levels for subjects in the ET group were none = 7, little = 5, moderate = 1, and extensive = 0. Figures 4-1 and 4-2 show histograms of climbing experience for each group.

Figure 4-1. Histogram of experience level for subjects in the High-intensity Interval Training group.

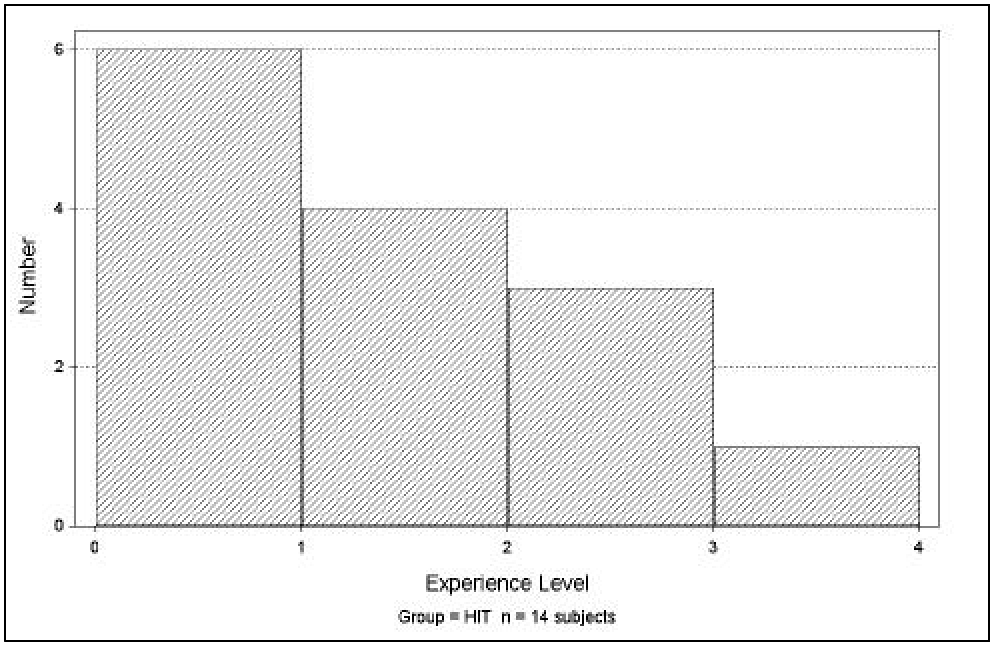
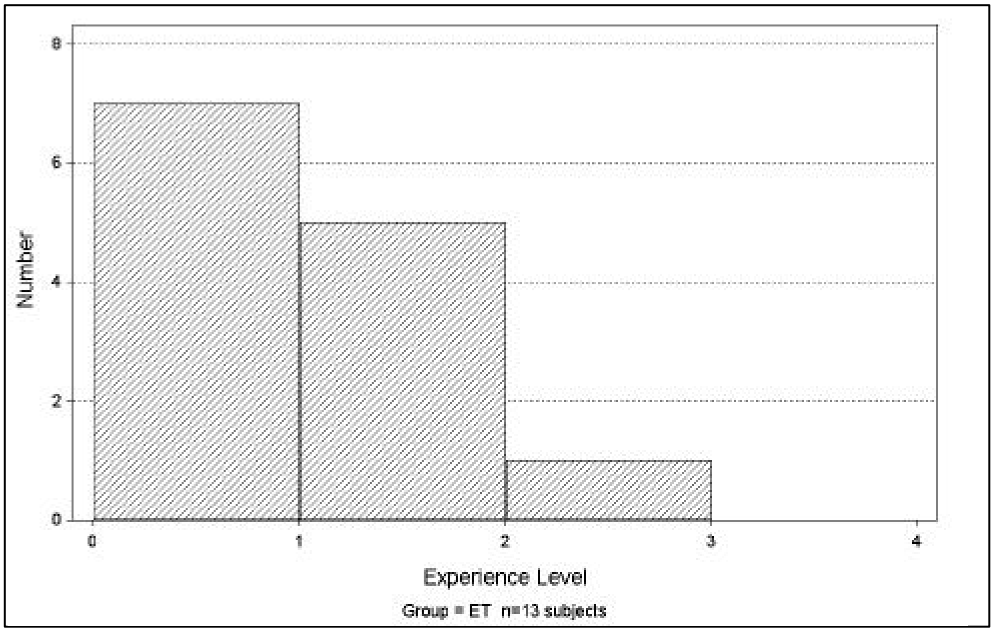


Figure 4-2. Histogram of experience level for subjects in the Endurance Training group.



## Muscular Strength Data

Data collected during the pre-testing and post-testing sessions were used to analyze the effect of training on climbing-related muscular strength. Two measures of muscular strength were chosen based on prior climbing-specific research: bilateral hand-grip strength and one-repetition maximum weight lifted in the latissimus pull-down.

### Hand-grip Strength

Results of the ANOVA for mean hand-grip strength indicate that no significant effects or interactions were present (Tables 4-2 and 4-3, for right and left hand-grip strength, respectively). Table 4-4 shows the mean and standard error for right and left hand-grip strength by group. Both groups showed a slight (non-significant) decrease in hand-grip strength, bilaterally. In the HIT group, mean right hand-grip strength values were 48.89 ± 3.34 kg in the pre-test to 48.68 ± 3.19 kg in the post-test, and mean left hand-grip strength values were 45.64 ± 3.10 kg in the pre-test to 44.93 ± 2.75 kg in the post-test. In the ET group, mean right hand-grip strength values were 44.65 ± 3.89 kg in the pre-test to 44.31 ± 3.84 kg in the post-test, and mean left hand-grip strength values were 42.46 ± 3.63 kg in the pre-test to 42.39 ± 3.89 kg in the post-test. These minor decreases amount to no more than 0.5 percent difference between pre- and post-testing.

Table 4-2. 2 x 2 repeated measures ANOVA for right hand-grip strength (n=27).

| **Source** | **Degrees of Freedom** | **Sum of Squares** | **Mean Square** | **F-ratio** | **p-value** |
|---|---|---|---|---|---|
| **Group** | 1 | 259.290 | 259.290 | 0.80 | 0.3785 |
| **Subject** | | | | | |
| **Group x Subject (e)** | 26 | 8400.08 | 323.080 | | |
| **Time** | 1 | 1.11446 | 1.11446 | 0.21 | 0.6497 |
| **Group x Time** | 1 | 0.06446 | 0.06446 | 0.21 | 0.9129 |
| **Group x Subject x Time (e)** | 26 | 137.276 | 5.27985 | | |
| **Total** | 55 | 8797.83 | | | |

Table 4-3. 2 x 2 repeated measures ANOVA for left hand-grip strength (n=27).

| Source | Degrees of Freedom | Sum of Squares | Mean Square | F-ratio | p-value |
|---|---|---|---|---|---|
| **Group** | 1 | 114.743 | 114.743 | 0.41 | 0.5297 |
| **Subject** | | | | | |
| **Group x Subject (e)** | 26 | 7352.06 | 282.772 | | |
| **Time** | 1 | 2.19226 | 2.19226 | 0.30 | 0.5875 |
| **Group x Time** | 1 | 1.42083 | 1.42083 | 0.20 | 0.6620 |
| **Group x Subject x Time (e)** | 26 | 188.890 | 7.26500 | | |
| **Total** | 55 | 7659.31 | | | |

Table 4-4. Hand grip-strength (mean ± SE) reported for the High-intensity Interval Training and Endurance Training groups (n=27).

| Variable | Pre-Test Value (kg) | Post-Test Value (kg) | Pre-Post Difference (kg) |
|---|---|---|---|
| **Left Hand-grip Strength** | | | |
| HIT | 45.64 ± 3.10 | 44.93 ± 2.75 | -0.71 ± 1.18 |
| ET | 42.46 ± 3.63 | 42.39 ± 3.89 | -0.08 ± 0.89 |
| **Right Hand-grip Strength** | | | |
| HIT | 48.89 ± 3.34 | 48.68 ± 3.19 | -0.21 ± 0.96 |
| ET | 44.65 ± 3.89 | 44.31 ± 3.84 | -0.35 ± 0.83 |

### Latissimus Pull-Down One-Repetition Maximum

Results of the ANOVA for Latissimus Pull-down One-repetition Maximum (Lat-pull 1RM, Table 4-5) indicate that the Group x Time interaction was not significant (p=0.961). Time was a significant main effect (p=0.0043), however, group was not (p=0.484). For the HIT group, the Lat-pull 1RM increased significantly (p=0.0286) from 76.05 ± 5.15 kg to 78.0 ± 5.29 kg; for the ET group, the same measure increased significantly (p=0.0247) from 70.28 ± 6.48 kg to 72.29 ± 6.93 kg (Table 4-6). Lat-pull 1RM values were not significantly different between groups.

Table 4-5. 2 x 2 repeated measures ANOVA for 1-RM in the Latissimus pull-down (n=27).

| Source | Degrees of Freedom | Sum of Squares | Mean Square | F-ratio | p-value |
|---|---|---|---|---|---|
| **Group** | 1 | 2235.76 | 2235.76 | 0.50 | 0.4840 |
| **Subject** | | | | | |
| **Group x Subject (e)** | 26 | 115315 | 4435.18 | | |
| **Time** | 1 | 265.437 | 265.437 | 9.81 | 0.0043 |
| **Group x Time** | 1 | 0.06583 | 0.06583 | 0.00 | 0.9610 |
| **Group x Subject x Time (e)** | 26 | 703.640 | 27.0631 | | |
| **Total** | 55 | 118519 | | | |

Table 4-6. One repetition maximum in the latissimus pull-down means (± SE) reported for the High-intensity Interval Training (HIT) Group and the Endurance Training (ET) Group (n=27).

| Group | Pre-Test Value (kg) | Post-Test Value (kg) | Pre-Post Difference (kg) |
|---|---|---|---|
| HIT | 76.05 ± 5.15 | 78.00 ± 5.29* | 1.95 ± 0.93 |
| ET | 70.28 ± 6.48 | 72.29 ± 6.93* | 2.01 ± 0.92 |

* $p < 0.05$ compared to pre-test value.

## Muscular Endurance Data

Climbing-specific muscular endurance was assessed via time-to-exhaustion in the Bent-arm Hang Test. Results of the ANOVA for this measure (Table 4-7) indicated that the Group x Time interaction was not significant (p=0.8024), nor was the factor effect of group (p=0.6001). However, time was a significant factor (p=0.0066). Mean time to exhaustion in the Bent-arm Hang Test (Table 4-8) for the HIT group increased from 38.19 ± 4.80 s to 41.23 ± 5.01 s, though this increase was not significant (p=0.0636). The range of the increase was –7.7 s to 13.9 s for this group. The ET group experienced a significant increase (p=0.0105) in mean time to exhaustion in this test, however, from 33.85 ± 6.44 s to 37.46 ± 6.45 s, with a range of –3.9 s to 11.0 s improvement. One subject was unable to perform this test during the pre-test series due to lack of upper-body strength, but successfully performed it in the post-test series.

Table 4-7. 2 x 2 repeated measures ANOVA for time-to-exhaustion in the Bent-arm Hang Test (n=27).

| Source | Degrees of Freedom | Sum of Squares | Mean Square | F-ratio | p-value |
|---|---|---|---|---|---|
| **Group** | 1 | 230.283 | 230.283 | 0.28 | 0.6001 |
| **Subject** | | | | | |
| **Group x Subject (e)** | 26 | 21256.5 | 817.558 | | |
| **Time** | 1 | 154.646 | 154.646 | 8.73 | 0.0066 |
| **Group x Time** | 1 | 1.13146 | 1.13146 | 0.06 | 0.8024 |
| **Group x Subject x Time (e)** | 26 | 460.443 | 17.7093 | | |
| **Total** | 55 | 22103.0 | | | |

Table 4-8. Time-to-exhaustion in the Bent-arm Hang Test (mean ± SE) reported for the High-intensity Interval Training (HIT) group and the Endurance Training (ET) group (n=27).

| **Group** | **Pre-Test Value (s)** | **Post-Test Value (s)** | **Pre-Post Difference (s)** |
|---|---|---|---|
| HIT | 38.19 ± 4.80 | 41.23 ± 5.01 | 3.04 ± 1.86 |
| ET | 33.85 ± 6.44 | 37.46 ± 6.45* | 3.61 ± 1.36 |

* $p < 0.05$ compared to pre-test value.

## Cardiorespiratory Data

Two methods of expressing peak cardiorespiratory function, or peak oxygen uptake ($\dot{V}O_{2peak}$), during exhaustive climbing were utilized in this study: absolute $\dot{V}O_{2peak}$ and relative $\dot{V}O_{2peak}$. Absolute $\dot{V}O_{2peak}$ was expressed in $L\cdot min^{-1}$, while relative $\dot{V}O_{2peak}$ was expressed in $ml\cdot kg^{-1}\cdot min^{-1}$. Relative $\dot{V}O_{2peak}$ included the total mass of the climber plus all measurement equipment, clothing and footwear worn during climbing.

Results of the ANOVA for both Absolute and Relative $\dot{V}O_{2peak}$ (Tables 4-9 and 4-10) indicated no factor effects of either Group or Time, nor significant interactions. Mean absolute $\dot{V}O_{2peak}$ (Table 4-11) for both groups remained similar from pre- to post-testing, due to extreme decreases in a few subjects' individual values, from 2.64 ± 0.147 $L\cdot min^{-1}$ to 2.63 ± 0.150 $L\cdot min^{-1}$ in the HIT group and from 2.45 ± 0.189 $L\cdot min^{-1}$ to 2.38 ± 0.155 $L\cdot min^{-1}$ in the ET group. Accordingly, mean relative $\dot{V}O_{2peak}$ (Table 22) remained similar from pre- to post-testing in both groups, from 36.53 ± 2.13 $ml\cdot kg^{-1}\cdot min^{-1}$ to 35.85 ± 1.54 $ml\cdot kg^{-1}\cdot min^{-1}$ in the HIT group and from 35.23 ± 2.06 $ml\cdot kg^{-1}\cdot min^{-1}$ to 34.45 ± 1.50 $ml\cdot kg^{-1}\cdot min^{-1}$ in the ET group, representing a percent change of –1.9% and

–2.2% for the HIT and ET groups, respectively. None of the decreases from pre- to post-testing were significant at the $\alpha = 0.05$ level.

Table 4-9. 2 x 2 repeated measures ANOVA for absolute $\dot{V}O_{2peak}$ (n=27).

| **Source** | **Degrees of Freedom** | **Sum of Squares** | **Mean Square** | **F-ratio** | **p-value** |
|---|---|---|---|---|---|
| **Group** | 1 | 25.5825 | 25.5825 | 0.37 | 0.5461 |
| **Subject** | | | | | |
| **Group x Subject (e)** | 26 | 1778.22 | 68.3932 | | |
| **Time** | 1 | 7.38052 | 7.38052 | 0.39 | 0.5375 |
| **Group x Time** | 1 | 0.03064 | 0.03064 | 0.00 | 0.9682 |
| **Group x Subject x Time (e)** | 26 | 491.496 | 18.9037 | | |
| **Total** | 55 | 2302.71 | | | |

Table 4-10. 2 x 2 repeated measures ANOVA for relative $\dot{V}O_{2peak}$ (n=27).

| **Source** | **Degrees of Freedom** | **Sum of Squares** | **Mean Square** | **F-ratio** | **p-value** |
|---|---|---|---|---|---|
| **Group** | 1 | 25.5825 | 25.5825 | 0.37 | 0.5461 |
| **Subject** | | | | | |
| **Group x Subject (e)** | 26 | 1778.22 | 68.3932 | | |
| **Time** | 1 | 7.38052 | 7.38052 | 0.39 | 0.5375 |
| **Group x Time** | 1 | 0.03064 | 0.03064 | 0.00 | 0.9682 |
| **Group x Subject x Time (e)** | 26 | 491.496 | 18.9037 | | |
| **Total** | 55 | 2302.71 | | | |

Table 4-11. Absolute and relative $\dot{V}O_{2peak}$ mean ± SE reported for the High-Intensity Interval Training (HIT) group and the Endurance Training (ET) group (n=27).

| **Variable** | **Pre-Test Value** | **Post-Test Value** | **Pre-Post Difference** |
|---|---|---|---|
| **Absolute Peak $O_2$ Uptake** | **($L·min^{-1}$)** | **($L·min^{-1}$)** | **($L·min^{-1}$)** |
| HIT | 2.64 ± 0.147 | 2.63 ± 0.150 | -0.005 ± 0.109 |
| ET | 2.45 ± 0.189 | 2.38 ± 0.155 | -0.064 ± 0.101 |
| **Relative Peak $O_2$ Uptake** | **($ml·kg^{-1}·min^{-1}$)** | **($ml·kg^{-1}·min^{-1}$)** | **($ml·kg^{-1}·min^{-1}$)** |
| HIT | 36.53 ± 2.13 | 35.85 ± 1.54 | -0.679 ± 1.81 |
| ET | 35.23 ± 2.06 | 34.45 ± 1.50 | -0.772 ± 1.57 |

Exclusion from analysis of all subjects whose peak oxygen uptake decreased by more than ten percent, a physiologically unreasonable decline over a six-week period given the frequency, intensity and duration of either training group, produced dramatically different results. Two-way repeated measures ANOVA for absolute $\dot{V}O_{2peak}$ (Table 4-12) and relative $\dot{V}O_{2peak}$ (Table 4-13) indicated that Time was a significant main effect ($p < 0.00$ for each) for both measures. The Time x Group interaction remained non-significant in both measures. Table 4-14 shows means and standard errors for absolute and relative $\dot{V}O_{2peak}$ following exclusion of the subjects described above. Mean absolute $\dot{V}O_{2peak}$ increased significantly ($p = 0.0047$) from 2.49 ± 0.174 $L·min^{-1}$ to 2.70 ± 0.186 $L·min^{-1}$ for the HIT group, and from 2.23 ± 0.180 $L·min^{-1}$ to 2.34 ± 0.175 $L·min^{-1}$ in the Endurance Training group (also significant, $p = 0.0205$). Relative peak oxygen uptake increased for both groups as well, from 33.21 ± 1.61 $ml·kg^{-1}·min^{-1}$ to 36.11 ± 1.77 $ml·kg^{-1}·min^{-1}$ for the HIT group ($p = 0.0042$), and from 32.36 ± 1.43 $ml·kg^{-1}·min^{-1}$ to 34.15 ± 1.64 $ml·kg^{-1}·min^{-1}$ for the ET group ($p = 0.0157$). These increases represent a change in relative $\dot{V}O_{2peak}$ from pre- to post-testing of 8.7% for the HIT group and 5.6% for the ET group (Table 4-15); the values of percent change were not significantly different between groups.

Table 4-12. 2 x 2 repeated measures ANOVA for absolute $\dot{V}O_{2peak}$ following exclusion of negatively-responding subjects (n=20).

| Source | Degrees of Freedom | Sum of Squares | Mean Square | F-ratio | p-value |
|---|---|---|---|---|---|
| **Group** | 1 | 0.94864 | 0.94864 | 1.52 | 0.2335 |
| **Subject** | | | | | |
| **Group x Subject (e)** | 18 | 11.2374 | 0.62430 | | |
| **Time** | 1 | 0.26244 | 0.26244 | 16.48 | 0.0007 |
| **Group x Time** | 1 | 0.02704 | 0.02704 | 1.70 | 0.2090 |
| **Group x Subject x Time (e)** | 18 | 0.28672 | 0.01593 | | |
| **Total** | 39 | 12.7622 | | | |

Table 4-13. 2 x 2 repeated measures ANOVA for relative $\dot{V}O_{2peak}$ following exclusion of negatively-responding subjects (n=20).

| Source | Degrees of Freedom | Sum of Squares | Mean Square | F-ratio | p-value |
|---|---|---|---|---|---|
| **Group** | 1 | 19.8106 | 19.8106 | 0.40 | 0.5335 |
| **Subject** | | | | | |
| **Group x Subject (e)** | 18 | 884.503 | 49.1391 | | |
| **Time** | 1 | 55.0137 | 55.0137 | 17.74 | 0.0005 |
| **Group x Time** | 1 | 3.08580 | 3.08580 | 1.00 | 0.3317 |
| **Group x Subject x Time (e)** | 18 | 55.8125 | 3.10070 | | |
| **Total** | 39 | 1018.23 | | | |

Table 4-14. Mean absolute and relative $\dot{V}O_{2peak}$ ( ± SE) reported for the High-intensity Interval Training (HIT) group and the Endurance Training (ET) group, following exclusion of negatively-responding subjects (n=20).

| **Variable** | **Pre-Test Value** | **Post-Test Value** | **Pre-Post Difference** |
|---|---|---|---|
| **Absolute Peak $O_2$ Uptake** | **$(L\cdot min^{-1})$** | **$(L\cdot min^{-1})$** | **$(L\cdot min^{-1})$** |
| HIT | 2.49 ± 0.174 | 2.70 ± 0.186* | 0.21 ± 0.065 |
| ET | 2.23 ± 0.180 | 2.34 ± 0.175* | 0.11 ± 0.046 |
| **Relative Peak $O_2$ Uptake** | **$(ml\cdot kg^{-1}\cdot min^{-1})$** | **$(ml\cdot kg^{-1}\cdot min^{-1})$** | **$(ml\cdot kg^{-1}\cdot min^{-1})$** |
| HIT | 33.21 ± 1.61 | 36.11 ± 1.77* | 2.90 ± 0.864 |
| ET | 32.36 ± 1.43 | 34.15 ± 1.64* | 1.79 ± 0.703 |

* $p < 0.05$ compared to pre-test value.

Table 4-15. Mean ± Standard Error and percent change for pre- and post-test values of relative $\dot{V}O_{2peak}$ for the High-intensity Interval Training (HIT) group and the Endurance Training (ET) group, before & after exclusion of negatively-responding subjects (n=20).

| **Relative Peak $O_2$ Uptake** | **Pre-Test Value $(ml\cdot kg^{-1}\cdot min^{-1})$** | **Post-Test Value $(ml\cdot kg^{-1}\cdot min^{-1})$** | **Percent Change** |
|---|---|---|---|
| **All Subjects** | | | |
| HIT | 36.53 ± 2.13 | 35.85 ± 1.54 | -1.9 % |
| ET | 35.23 ± 2.06 | 34.45 ± 1.50 | -2.2 % |
| **Following Exclusion** | | | |
| HIT | 33.21 ± 1.61 | 36.11 ± 1.77 | +8.7 % |
| ET | 32.36 ± 1.43 | 34.15 ± 1.64 | +5.6 % |

## Climbing Performance Data

### Analysis of Variance Results

Two measures were used to evaluate any effects of training on climbing performance in this study. Time to exhaustion in the $\dot{V}O_{2peak}$ Climbing Test evaluated climbing performance at grades less than 94°, and the same parameter in the Incremental Overhang Test evaluated climbing performance at grades greater than 94°. Results of the

ANOVA for time to exhaustion in the $\dot{V}O_{2peak}$ Climbing Test (Table 4-16) indicated that the Group x Time interaction approached significance at the $\alpha = 0.05$ level ($p = 0.0693$). For the HIT group, mean values increased significantly ($p = 0.0002$) from $11.08 \pm 0.569$ min in the pre-test to $12.51 \pm 0.710$ min in the post-test; for the ET group, mean values increased from $11.08 \pm 0.776$ min to $11.87 \pm 0.813$ min (Table 4-17). The difference between mean post-test and mean pre-test scores (the amount of increase in the mean from pre- to post-testing) was significantly greater ($p = 0.0386$) for the HIT group compared to the ET group.

Results of the ANOVA for time to exhaustion in the Incremental Overhang Test (Table 4-18) indicated that the Group x Time interaction was not significant ($p = 0.8003$); significant main effects were present for time ($p < 0.001$), but not for group ($p = 0.5775$). For the HIT group, mean time to exhaustion in the Incremental Overhang Test (Table 4-19) increased significantly ($p < 0.001$) from a pre-test value of $5.12 \pm 0.203$ min to a post-test value of $5.93 \pm 0.201$ min. For the ET group, mean time to exhaustion in this test also increased significantly ($p < 0.001$) from $4.99 \pm 0.226$ min to $5.75 \pm 0.234$ min. The amount of increase in mean time to exhaustion from pre- to post-testing was not significantly different between groups ($p = 0.8085$).

Table 4-16. 2 x 2 repeated measures ANOVA for time-to-exhaustion in the $\dot{V}O_{2peak}$ Climbing Test (n=27).

| Source | Degrees of Freedom | Sum of Squares | Mean Square | F-ratio | p-value |
|---|---|---|---|---|---|
| **Group** | 1 | 1.46578 | 1.46578 | 0.11 | 0.7395 |
| **Subject** | | | | | |
| **Group x Subject (e)** | 26 | 337.285 | 12.9725 | | |
| **Time** | 1 | 17.4052 | 17.4052 | 44.39 | 0.0000 |
| **Group x Time** | 1 | 1.40811 | 1.40811 | 3.59 | 0.0693 |
| **Group x Subject x Time (e)** | 26 | 10.1950 | 0.39212 | | |
| **Total** | 55 | 367.759 | | | |

Table 4-17. Time-to-exhaustion in the $\dot{V}O_{2peak}$ Climbing Test means (± Standard Error) reported for the High-Intensity Interval Training (HIT) group and the Endurance Training (ET) group (n=27).

| Group | Pre-Test Value (min) | Post-Test Value (min) | Pre-Post Difference (min) |
|---|---|---|---|
| HIT | 11.08 ± 0.569 | 12.51 ± 0.710* | 1.43 ± 0.301** |
| ET | 11.08 ± 0.776 | 11.87 ± 0.813* | 0.80 ± 0.158 |

* $p < 0.05$ compared to pre-testing. ** $p < 0.05$ compared to the Endurance Training group.

Table 4-18. 2 x 2 repeated measures ANOVA for time-to-exhaustion in the Incremental Overhang Test (n=27).

| Source | Degrees of Freedom | Sum of Squares | Mean Square | F-ratio | p-value |
|---|---|---|---|---|---|
| **Group** | 1 | 0.31201 | 0.31201 | 0.28 | 0.5995 |
| **Subject** | | | | | |
| **Group x Subject (e)** | 26 | 28.7013 | 1.10390 | | |
| **Time** | 1 | 8.61146 | 8.61146 | 81.90 | 0.0000 |
| **Group x Time** | 1 | 0.00686 | 0.00686 | 0.07 | 0.8003 |
| **Group x Subject x Time (e)** | 26 | 2.73388 | 0.10515 | | |
| **Total** | 55 | 40.3655 | | | |

Table 4-19. Mean time-to-exhaustion in the Incremental Overhang Test (± SE) reported for the High-intensity Interval Training (HIT) group and the Endurance Training (ET) group (n=27).

| Group | Pre-Test Value (min) | Post-Test Value (min) | Pre-Post Difference (min) |
|---|---|---|---|
| HIT | 5.12 ± 0.203 | 5.93 ± 0.201* | 0.81 ± 0.144 |
| ET | 4.99 ± 0.226 | 5.75 ± 0.234* | 0.76 ± 0.104 |

* $p < 0.05$ compared to pre-testing.

Correlation Results

Climbing performance data were correlated with selected physiological variables in order to determine significant relationships between performance and physiological data. Table 4-20 shows the Pearson’s r-value for these variables. All r-values above 0.37 were significant at the $\alpha = 0.05$ level.

Considering the demographic data, climbing experience correlated more strongly with time to exhaustion in the Incremental Overhang Test than it did with the same measure in the $\dot{V}O_{2peak}$ Climbing Test. The correlation r-value decreased from pre-testing (r=0.7199) to post-testing (r=0.5408) in the IOT, while remaining essentially unchanged in the $\dot{V}O_{2peak}$ Climbing Test (r=0.5611 to r=0.5881).

Pre-test performance measures correlated very highly with post-test performance measures from the same test, though this correlation was lower for the results of the Incremental Overhang Test. Pearson's R for pre- to post-test time-to-exhaustion was r=0.9417 in the $\dot{V}O_{2peak}$ Climbing Test and r=0.8274 for the IOT. Regression analysis of post-test time-to-exhaustion on pre-test values in the $\dot{V}O_{2peak}$ Climbing Test revealed a slope of 1.07 and a y-intercept of 0.34 min. Regression of post-test time-to-exhaustion in the Incremental Overhang Test on pre-test values revealed a slope of 0.84 and a y-intercept of 1.59 min.

Considering the strength and endurance variables measured in this study, correlations with climbing performance were moderately high. Pre-test time-to-exhaustion in the $\dot{V}O_{2peak}$ Climbing Test correlated strongly with time-to-exhaustion in the bent-arm hang test (r=0.7695), mean grip strength (r=0.6720) and 1-RM in the latissimus pull-down (r=0.5818). The same correlations for post-test time-to-exhaustion in the $\dot{V}O_{2peak}$ Climbing Test increased marginally or remained unchanged (r=0.8228, 0.6402 and 0.5936, respectively). Time-to-exhaustion in the IOT correlated similarly with the same physiological variables (pre-test vs. post-test r-value: 0.8193 vs. 0.8100 with time-to-exhaustion in the bent-arm hang test; 0.7468 vs. 0.6967 for grip strength; and 0.6365 vs. 0.6343 for 1RM in the latissumus pull-down).

Using the cardiorespiratory data modified to exclude non-responding subjects, strong correlations were found between relative peak oxygen uptake and performance in both climbing tests. Pre-test time-to-exhaustion in the $\dot{V}O_{2peak}$ Climbing Test correlated more strongly with relative $\dot{V}O_{2peak}$ (VO2REL, r=0.9192) than did the same post-test measure (r=0.8464). Pre-test and post-test values of time-to-exhaustion in the IOT had similar correlations with relative $\dot{V}O_{2peak}$ (r=0.8041 and 0.7664, respectively).

Table 4-20. Pearson's correlation of climbing performance data with selected physiological variables.

| | VO2TIME1 | VO2TIME2 | IOTTIME1 | IOTTIME2 |
|---|---|---|---|---|
| EXPERIENCE | 0.5611 | 0.5881 | 0.7199 | 0.5408 |
| VO2TIME2 | 0.9417 | - | x | 0.9285 |
| IOTTIME1 | 0.8796 | x | - | 0.8274 |
| IOTTIME2 | x | 0.9285 | 0.8274 | - |
| GRIP1 | 0.6720 | x | 0.7468 | x |
| GRIP2 | x | 0.6402 | x | 0.6967 |
| HANG1 | 0.7695 | x | 0.8193 | x |
| HANG2 | x | 0.8228 | x | 0.8100 |
| LAT1 | 0.5818 | x | 0.6365 | x |
| LAT2 | x | 0.5936 | x | 0.6343 |
| VO2ABS1 | 0.7698 | x | 0.7066 | x |
| VO2ABS2 | x | 0.7920 | x | 0.6922 |
| VO2REL1 | 0.9192 | x | 0.8041 | x |
| VO2REL2 | x | 0.8464 | x | 0.7664 |

* As defined in Table 1-1, with 1 = pre-test measurement and 2 = post-test measurement.

## Training Session Parameters

### Workout Duration

Workout duration for each group during the training phase of the study was prescribed in advance, based upon suggestions in the literature, expected time constraints of the subjects and equivalent training volume between groups. Subjects in the HIT group were encouraged to attain a target training time of three 6-minute bouts of climbing, separated by three minutes of rest; subjects in the Endurance Training group were encouraged to attain a duration of 20 minutes in a single bout of climbing. Target training times did not include the duration of warm-up activity prior to climbing, which was prescribed as five minutes of self-selected low-intensity climbing for both groups. Following the first week of training, in which target intensities were adjusted for training heart rate, subjects generally attained target training times. It was more common, though rare, that subjects in the HIT group failed to attain target training times during a workout session due to exhaustion or lack of motivation compared to subjects in the ET group. It should be noted that on occasion, a subject exceeded his or her target training time, though this was discouraged. Despite these observations, all subjects generally trained according to their individual workout prescriptions.

Mean workout durations by week (Table 4-21) for both groups were similar to the time prescribed for each. Training durations for week 1 were not recorded (see below). For the HIT group, mean workout duration (± SD) for the remainder of the training phase was 17.93 ± 1.21 min during week 2, 18.10 ± 0.25 min during week 3, 17.07 ± 1.82 min during week 4, 17.38 ± 1.52 min during week 5, and 16.77 ± 2.28 min during week 6.

Mean workout duration (± SD) for the Endurance Training group was 18.18 ± 4.64 min during week 2, 20.21 ± 1.25 min during week 3, 19.48 ± 2.49 min during week 4, 20.13 ± 2.41 min during week 5, and 19.15 ± 3.87 min during week 6. The range of workout durations for each group by week are given in Table 4-21. For weeks 3 to 6, mean workout duration was significantly lower in the HIT group compared to the ET group ($p = 0.3728$ for week 2; $p < 0.001$ for weeks 3, 4 and 5; $p = 0.0013$ for week 6). Mean workout duration over the entire training phase for the HIT group was 17.47 ± 1.62 min, significantly lower ($p < 0.001$) than mean workout duration over the entire training phase for the ET group, 19.43 ± 3.23 min.

Table 4-21. Training duration per workout by week: Mean, standard deviation, minimum and maximum for the High-intensity Interval Training group (HIT; n = 14) and the Endurance Training group (ET; n = 13).

| | **Week 2 (min)** | **Week 3 (min)** | **Week 4 (min)** | **Week 5 (min)** | **Week 6 (min)** |
|---|---|---|---|---|---|
| **HIT Group** | | | | | |
| Mean ± SD | 17.93 ± 1.21 | 18.10 ± 0.25* | 17.07 ± 1.82* | 17.38 ± 1.52* | 16.77 ± 2.28* |
| Minimum | 12.0 | 17.7 | 11.9 | 13.1 | 9.3 |
| Maximum | 20.0 | 19.3 | 18.4 | 18.4 | 18.4 |
| **ET Group** | | | | | |
| Mean ± SD | 18.18 ± 4.64 | 20.205 ± 1.25 | 19.481 ± 2.49 | 20.13 ± 2.41 | 19.15 ± 3.87 |
| Minimum | 10.0 | 15.0 | 10.0 | 12.0 | 14.8 |
| Maximum | 27.3 | 22.7 | 23.1 | 30.3 | 28.1 |

* $p < 0.05$ compared to ET group.

Treadmill Climbing Speed

The primary determinant of workout intensity was treadmill speed. During the first week of training, treadmill speed was determined based upon predicted values; this parameter was then adjusted for observed heart rate values in order to provide the appropriate training intensity. Table 28 shows mean treadmill speed for each group by week. For the HIT group, mean treadmill speed was 9.23 ± 2.48 $m{\cdot}min^{-1}$ for week 2, 10.67 ± 2.12 $m{\cdot}min^{-1}$ for week 3, 11.55 ± 2.49 $m{\cdot}min^{-1}$ for week 4, 11.67 ± 2.67 $m{\cdot}min^{-1}$ for week 5, and 12.02 ± 2.64 $m{\cdot}min^{-1}$ for week 6. For each week, mean treadmill speed was significantly higher ($p < 0.001$) for the HIT group compared to the ET group, whose mean treadmill speed was 7.25 ± 2.01 $m{\cdot}min^{-1}$ for week 2, 8.05 ± 1.88 $m{\cdot}min^{-1}$ for week 3, 8.20 ± 2.06 $m{\cdot}min^{-1}$ for week 4, 8.94 ± 2.09 $m{\cdot}min^{-1}$ for week 5, and 9.2691 ± 2.25 $m{\cdot}min^{-1}$ for week 6. The range of speeds for each group by week are given in table 4-22.

Table 4-22. Treadmill speed per workout by week: Mean ± SD, minimum and maximum for the High-intensity Interval Training (HIT) group (n = 14) and the Endurance Training (ET) group (n = 13).

| | **Week 2 (m·min-1)** | **Week 3 (m·min-1)** | **Week 4 (m·min-1)** | **Week 5 (m·min-1)** | **Week 6 (m·min-1)** |
|---|---|---|---|---|---|
| **HIT Group** | | | | | |
| Mean ± SD | 9.23 ± 2.48* | 10.67 ± 2.12* | 11.55 ± 2.49* | 11.67 ± 2.67* | 12.02 ± 2.64* |
| Minimum | 5.49 | 6.10 | 6.10 | 6.40 | 5.49 |
| Maximum | 15.24 | 14.02 | 15.24 | 16.46 | 16.46 |
| **ET Group** | | | | | |
| Mean ± SD | 7.25 ± 2.01 | 8.05 ± 1.88 | 8.20 ± 2.06 | 8.94 ± 2.09 | 9.2691 ± 2.25 |
| Minimum | 4.88 | 5.49 | 4.88 | 5.49 | 5.49 |
| Maximum | 14.63 | 11.89 | 10.98 | 12.20 | 12.80 |

* $p < 0.05$ compared to ET group.

### Distance Climbed per Workout

Distance climbed per workout was a function of training intensity (treadmill speed, above) and training duration. It is included here to illustrate the difference between training programs for each week of the training phase. Mean distance climbed (± SD) per workout by week (Table 4-23) for the HIT group was 164.48 ± 42.13 m for week 2, 193.26 ± 39.42 m for week 3, 196.68 ± 45.75 m for week 4, 202.51 ± 48.63 m for week 5, and 201.54 ± 52.59 m for week 6. For the Endurance Training group, mean distance climbed per workout was 133.98 ± 55.76 m for week 2, 163.31 ± 42.12 m for week 3, 162.45 ± 49.78 m for week 4, 181.75 ± 53.47 m for week 5, and 180.28 ± 61.99 m for week 6. With the exception of week 6, all values of mean distance climbed per workout for each week were significantly greater ($p = 0.0040$, 0.0008, 0.0023, and 0.0384 for weeks 2, 3, 4 and 5, respectively) for the HIT group compared to the ET group; for week 6, the distance climbed by the HIT group was almost ($p = 0.0588$) significantly higher than the ET group. The range of values for mean distance climbed per workout are given by week in Table 4-23 for each group.

Table 4-23. Distance climbed per workout by week: Mean ± SD, minimum and maximum for the High-intensity Interval Training (HIT) group (n = 14) and the Endurance Training (ET) group (n = 13).

| | **Week 2 (m)** | **Week 3 (m)** | **Week 4 (m)** | **Week 5 (m)** | **Week 6 (m)** |
|---|---|---|---|---|---|
| **HIT Group** | | | | | |
| Mean ± SD | 164.48 ± 42.13* | 193.26 ± 39.42* | 196.68 ± 45.75* | 202.51 ± 48.63* | 201.54 ± 52.59[1] |
| Minimum | 99.39 | 109.76 | 99.09 | 94.51 | 92.99 |
| Maximum | 241.46 | 254.27 | 265.24 | 294.82 | 297.56 |
| **ET Group** | | | | | |
| Mean ± SD | 133.98 ± 55.76 | 163.31 ± 42.12 | 162.45 ± 49.78 | 181.75 ± 53.47 | 180.28 ± 61.99 |
| Minimum | 54.88 | 96.04 | 48.78 | 65.85 | 36.28 |
| Maximum | 274.70 | 247.26 | 225.00 | 332.32 | 307.93 |

* $p < 0.05$ compared to ET group during the same week. [1] $p = 0.0588$ compared to ET group during the same week.

Climbing Grade by Week

The secondary determinant of training intensity was the treadmill setting of grade. Both groups climbed at the same prescribed grade for all weeks in the training phase (Table 4-24). During week 1, the treadmill was set to 88° from the horizontal; this increased to 90° for weeks 2 and 3, 92° for weeks 4 and 5, and 94° for week 6. This parameter was strictly controlled.

Table 4-24. Treadmill climbing grade settings by week for the High-intensity Interval Training (HIT) group and the Endurance Training (ET) group.

| **Group** | **Week 1 (degrees)** | **Week 2 (degrees)** | **Week 3 (degrees)** | **Week 4 (degrees)** | **Week 5 (degrees)** | **Week 6 (degrees)** |
|---|---|---|---|---|---|---|
| **HIT** | 88 | 90 | 90 | 92 | 92 | 94 |
| **ET** | 88 | 90 | 90 | 92 | 92 | 94 |

## Heart Rate Training Zone Comparison

Workout intensity was prescribed based upon a percentage of pre-test values of $\dot{V}O_{2peak}$ for each subject according to the group he or she was assigned to, and by week. For the HIT group, workout intensities (Table 4-25) were prescribed to be 80-95% of measured $\dot{V}O_{2peak}$; for the ET group, the intensities were prescribed to be 65-80% of pre-test $\dot{V}O_{2peak}$. Using a pre-established relationship for $\%HR_{max}$-$\%\dot{V}O_{2peak}$, workout intensities were monitored using heart rate, recorded via telemetry.

Table 4-25. Prescribed workout intensity by week for the High-intensity Interval Training (HIT) group and the Endurance Training (ET) group, as a percentage of measured pre-test $\dot{V}O_{2peak}$.

| **Group** | **Week 1 (%** $\dot{V}O_{2peak}$**)** | **Week 2 (%** $\dot{V}O_{2peak}$**)** | **Week 3 (%** $\dot{V}O_{2peak}$**)** | **Week 4 (%** $\dot{V}O_{2peak}$**)** | **Week 5 (%** $\dot{V}O_{2peak}$**)** | **Week 6 (%** $\dot{V}O_{2peak}$**)** |
|---|---|---|---|---|---|---|
| **HIT** | 80% | 80% | 85% | 90% | 90% | 95% |
| **ET** | 65% | 65% | 70% | 75% | 80% | 80% |

Treadmill speed settings were adjusted individually to allow subjects to train within a 10 bpm heart rate training zone. Table 4-26 shows the mean (± SD) time spent climbing in the prescribed training zone for week 5 of the training phase for both groups, in absolute values and as a percentage of the total time spent climbing. Subjects in the HIT group spent a mean of 35.14% of training time within their prescribed heart rate zone, with a minimum value of 11.3% and a maximum value of 64.9%. Subjects in the ET group spent a mean of 62.3% of training time within their prescribed training zone, with a minimum value of 33.1% and a maximum value of 86.5%.

Table 4-26. Mean ± SD, minimum and maximum workout duration, time within heart rate training zone, and percentage of time within training zone during Week 5 for the High-intensity Interval Training (HIT) group (n = 14) and the Endurance Training (ET) group (n = 13).

| | **Workout Duration (min)** | **Time Within Training Zone (min)** | **Time Within Training Zone (%)** |
|---|---|---|---|
| **HIT Group** | | | |
| Mean ± SD | 18.73 ± 2.04 | 6.68 ± 2.86 | 35.14 ± 12.81 |
| Minimum | 14.92 | 1.92 | 11.30 |
| Maximum | 23.17 | 14.25 | 64.90 |
| **ET Group** | | | |
| Mean ± SD | 20.42 ± 3.22 | 12.75 ± 3.60 | 62.34 ± 14.57 |
| Minimum | 11.17 | 5.83 | 33.10 |
| Maximum | 30.83 | 18.17 | 86.50 |

# CHAPTER FIVE

# DISCUSSION

## Introduction

The primary goal of this study was to determine the effectiveness of six weeks of systematic physical training utilizing a motorized climbing treadmill on the enhancement of climbing performance and related physiological variables. The secondary goal was to compare the effectiveness of two training programs in improving these same parameters. The two training programs compared were High-intensity Interval Training (HIT), consisting of three 6-minute bouts of climbing at 80-95% of measured pre-test $\dot{V}O_{2peak}$, separated by three minutes of rest; and Endurance Training (ET), consisting of a single twenty-minute climbing session at 60-85% of measured pre-test $\dot{V}O_{2peak}$. Cardiorespiratory fitness, or peak oxygen uptake ($\dot{V}O_{2peak}$), was assessed in the $\dot{V}O_{2peak}$ Climbing Test, an incrementally-graded climbing test to exhaustion at treadmill grades less than 94º on the motorized climbing treadmill. This test also provided a measure of climbing performance in the time to exhaustion. A second measure of climbing performance was time to exhaustion in the Incremental Overhang Test, another graded climbing test to exhaustion, at treadmill grades greater than 94º. Climbing-specific muscular strength was assessed by Latissimus Pull-down 1RM and by hand-grip strength; climbing-specific muscular endurance was assessed by time to exhaustion in the Bent-arm Hang Test. All variables were measured prior to and following six weeks of training.

With respect to the primary goal of the study, climbing performance, cardiorespiratory fitness, upper-body muscular strength and muscular endurance all increased as a result of systematic training on a motorized climbing treadmill. With respect to the secondary goal, the HIT program improved climbing performance by a greater amount than did ET training. In terms of the amount of time spent climbing during the training phase, subjects in the HIT group climbed significantly greater distances per workout and spent significantly less time climbing.

## Subject Characteristics

Thirty subjects (15 male, 15 female) of varying climbing experience from the Montana State University (MSU) – Bozeman campus and surrounding community were recruited for this study. Three subjects (two male, one female) were dropped from the study prior to the post-testing series due to time constraints which prevented the required number of training sessions to be attended, or due to injuries unrelated to the study. Thus all data included in the analysis came from a total sample size of 27 subjects (13 male, 14 female).

Following random assignment of subjects to either High-intensity or Endurance Training, groups were similar for gender (HIT group: seven males, seven females; ET group: six males, seven females) and previous climbing experience, evaluated by guided self-assessment as per the questionnaire in Appendix B. The heterogeneity of subjects in experience level permits a greater generalizability of the results than if all subjects had been homogenous in this characteristic. Ironically, the subject with the greatest amount of climbing experience was dropped from the study due to a climbing over-use injury from extracurricular activity. Only one subject had prior familiarity with a motorized climbing treadmill.

## Anthropometric Data

Subjects in this study tended to be classified as "average" in terms of mean body mass, height and BMI (170.4 ± 9.4 cm, 68.2 ± 11.7 kg, BMI = 23.4 ± 2.9, mean ± standard deviation over all subjects) (ACSM, 2000). Table 5-1 shows how subjects in this study compared to climbers in published research. In this study, subjects were younger than in the studies cited below (23.2 years for males and 21.3 years for females). The subjects herein had greater body mass compared to that of elite climbers recorded by Watts, Martin & Durtschi (1993) (76.7 vs 66.6 kg for men; 60.2 vs 51.5 kg for women) and of climbers of varying experience level recorded by Mermier, Janot, Parker & Swan (2000) (72.8 kg for men, 60.1 kg for women). However, subjects in this study were shorter on average than the subjects in either of those studies (176.7 cm for men, 164.7 cm for women in this study vs. 178.6 cm and 163.9 (Watts et al.) or 177.4 cm and 166.4 cm (Mermier et al.). Therefore, on average, subjects in this study had a higher BMI value than either elite or recreational climbers studied elsewhere. The difference in these values can be accounted for by the fact that the two studies cited here described accomplished elite climbers (Watts et al.) or those of many years experience (7.1 ± 8.4 years, Mermier et al.), while the subjects in the present study were of low experience level on average, and were not active at a competitive level.

Table 5-1. Anthropometric data for males and females from selected studies.

| | Present study | | Watts et al. | | Mermier et al. | |
|---|---|---|---|---|---|---|
| | males | females | males | females | males | females |
| n | 14 | 15 | 28 | 24 | 24 | 20 |
| age | 23.2 ± 4.7 | 21.3 ± 1.9 | 25.9 | 27.7 | 30.4 ± 6.0 | 32.2 ± 9.2 |
| Height (cm) | 176.7 ± 8.0 | 164.7 ± 6.5 | 178.6 ± 5.8 | 163.9 ± 4.5 | 177.4 ± 8.8 | 166.4 ± 5.7 |
| Weight (kg) | 76.7 ± 11.0 | 60.2 ± 4.6 | 66.6 ± 5.3 | 51.5 ± 4.7 | 72.8 ± 11.6 | 60.1 ± 5.9 |
| BMI | 24.6 ± 3.5 | 22.2 ± 1.7 | n/a | n/a | n/a | n/a |
| Ape-index | 1.02 ± 0.02 | 1.0 ± 0.02 | n/a | n/a | 1.0 ± 0.02 | 1.0 ± 0.03 |

It was expected that certain anthropometric variables would change as a result of six weeks of training on a motorized climbing treadmill; these include forearm and calf circumferences, and the climbing-specific measure of ape-index. Results of this study support this to a limited degree. No change in mean body mass was noted, though the training programs represented an increase in physical activity for many subjects. Mean armspan, and thus ape-index (ratio of armspan to height), increased significantly for the HIT group, though not for the ET group, possibly due to increased range of motion at the shoulder joint as a result of the higher climbing speeds and distance climbed for that group. Recent climbing research (Watts, Joubert, Lish, Mast & Wilkins, 2003; Mermier, Janot, Parker & Swan, 2000) describes competitive young sport climbers as having, among other anthropometric characteristics, significantly greater ape-index than non-climbing controls; though this is not attributed to the activity of climbing, it remains possible that repetitive motion at the shoulder joint over time increases the armspan. Girourd and Hurley (1995) provide evidence that flexibility training only increases shoulder range of motion over strength-and-flexibility training. In this study, the repetitive overhead reaching motions may be considered a form of flexibility training in that no resistance was applied to the extremity; as such, it is conceivable that increased range of shoulder motion may have resulted from training for climbing.

Mean forearm circumferences increased in both groups, with the increase in the mean significant bilaterally in the HIT group and in the left forearm only for the ET group. Muscular hypertrophy of the forearm was anticipated due to a progressive overload stimulus applied during the training phase in the form of increasing climbing grade each week. As illustrated by Quaine, Martin and Blanchi (1997), as climbing angle increases, the contact forces at the hand increase; muscular adaptation to the progressive stress may reasonably have included hypertrophy. The greater volume of climbing experienced by the HIT group may account for the discrepancy between groups in right forearm mean circumference; the significant increase in left forearm circumference seen in the ET group may be related to hand-dominance factors in that novice climbers (the majority in both groups) experienced a dramatic increase in left-hand use compared to pre-study activity patterns. This suggestion is based on the observation that most subjects were right-hand dominant, though no data to support this suggestion were gathered. Alternatively, measurement error arising from inaccurate anatomical landmark location may also have been a contributing factor.

Mean calf circumferences decreased in both HIT and ET groups as a result of training, with the decrease significant for the right leg in both groups. Though measurement error resulting from inconsistent circumference site choice between pre-and post-testing seems the most likely factor in explaining these results, a physiological explanation is worthy of exploration. Strojnik, Apih & Dempsar (1995) observed that active runners and climbers had greater whole-muscle cross-sectional area in calf-region musculature than non-sport-active controls; however, the more relevant finding was that the sport-active subjects in their study had significantly lower subcutaneous fat over the calf muscle than controls. It is plausible that six weeks of training for climbing decreased the circumference of the calf by reducing the amount of subcutaneous fat over the calf muscle in this study; this idea implies a spot-reduction effect, however, which has been invalidated (Jensen, 1997). Since body composition was not a dependent variable in this study, it cannot be ruled out that whole-body subcutaneous or regional intramuscular fat played a role in the observed results. It seems unlikely that gastrocnemius or smaller calf-region musculature atrophy would have played a role in the observed decrease in circumference. A longer training phase may have resulted in muscular hypertrophy of the calf region, though establishing this definitively would necessitate costly and involved methods including magnetic resonance imaging.

## Muscular Strength Data

### Hand-Grip Strength

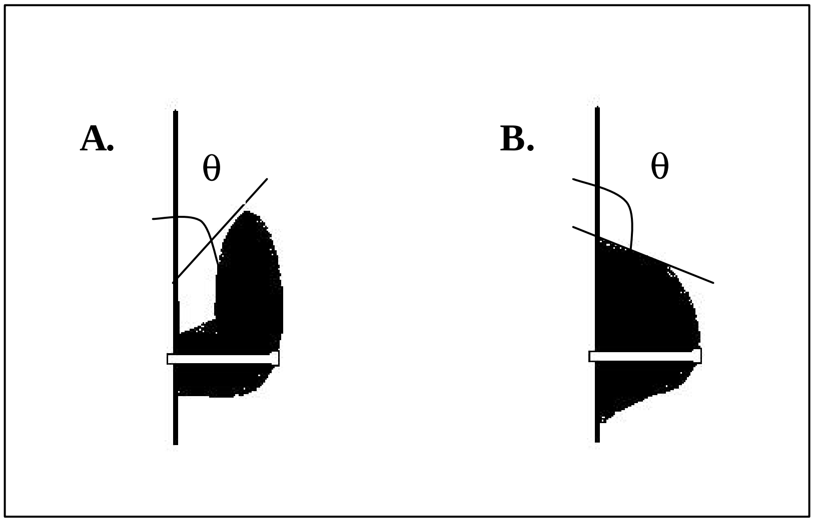
It was expected that six weeks of training for climbing, in either a high-intensity program or an endurance program, would result in increased hand-grip strength. Results of this study indicated otherwise. No significant changes were observed for hand-grip strength, despite an increase in mean forearm circumference as discussed above. No prior research has been done on hand-grip strength utilizing a motorized climbing treadmill and thus no comparisons can be made with respect to the findings for this measure of climbing fitness. The possibility exists that subjects did not perform the test protocol correctly in either the pre- or post-test series, as this measure was supervised by research assistants and not directly overseen by the primary investigator. Alternatively, the lack of a proper muscular warm-up prior to performing this test may have dramatically affected the results. It seems illogical that mean hand-grip strength would decrease, for reasons similar to the above discussion regarding contact forces necessary to maintain climbing position on the treadmill, and the increase in training load over the course of the training phase of the study. However, it has been suggested that elite climbers may not need to develop extremely high levels of grip strength (Watts, Martin & Durtschi, 1993), though this stands in contrast to the observed difference in grip strength between elite and recreational or non-climbers (Grant, Hynes, Whittaker & Aitchison, 1996).

In comparison to other forms of training, it is interesting that climbing-specific training utilizing the forearm musculature for repeated hand-gripping did not have the hypothesized result of increasing hand-grip strength. For example, 4 weeks of hatha yoga practice in healthy adults increased hand-grip strength significantly (Dash & Telles, 2001), though this form of physical activity requires no hand-specific movement patterns. In comparison to hand-movement patterns, one possibility worthy of exploration is that conventional hand-grip strength quantification techniques via dynamometer are not sensitive to changes in climbing-specific grip-strength. The complex musculature of the forearm is capable of a large number of hand configurations from a hook grip, a scissors grip, a five-jaw chuck, a disc grip, or a spherical grip, to name a few, each of which requires a precise combination of muscle tensions (Pinker, 1997). Climbers often utilize pincer-like movements (Grant, Hynes, Whittaker & Aitchison, 1996), or "crimping" movements (see Figure 5-1), in which tendon strength is more important than grip strength. It therefore seems reasonable that the conventional hand-grip dynamometer is not the most appropriate measurement device for climbing-specific muscular strength. Tan, Aziz, Teh & Lee (2001) found that a bowling-grip specific hand-strength test was more valid than a conventional dynamometer in competitive bowlers. Thus a climbing-specific pincer-grip or tendon strength test, such as those developed by Grant et al., may be more sensitive to changes resulting from climbing-specific training; these should be considered for use in future studies of adaptations to climbing-specific training programs.

A factor of potential importance to the development of grip strength concerns the particular holds used on the climbing treadmill. The majority of artificial climbing hold manufacturers utilize molds to form a variety of shapes, which are bolted to the climbing surface. Holds are available in sizes ranging from less than 1 cm in diameter to upwards of 10 cm, in shapes ranging from simple geometric forms to complex, irregular forms with many features. Two relevant characteristics of hold design are the degree of "positivity" of the hold (the degree to which the upper edge of the hold slopes downwards *toward* the climbing surface, Figure 5-2) and the radius of curvature of the upper edge of the hold. Climbing holds designed for novices or for severely overhanging routes are highly positive, allowing the fingers to curl over the edge in a very secure fashion; in addition, these holds tend to have large radii of curvature, allowing more segments of the fingers and some of the palm of the hand to be in contact with the hold. In contrast, holds designed for difficult routes for climbers of greater tendon strength and climbing experience may be exceedingly small in size, with small radii of curvature, and possibly have a very low degree of positivity (termed a “sloper”, or a hold which slopes downwards *away from* the climbing surface). The holds used on the climbing treadmill in this study were primarily small-to-medium in overall size, though large holds occurred roughly every body length on the treadmill surface. All holds were positive to highly-positive. Thus, treadmill climbing in this study required hand- and finger-tendon strength, but did not necessarily require pincer-gripping or hand-squeezing hand movements. It is therefore suggested that climbing-specific training adaptations may have occurred despite the results that hand-grip strength as tested via conventional dynamometer showed no significant changes.

Figure 5-1. Examples of crimping movements with the hand in climbing.

Figure 5-2. Examples of positive (A) and negative (B) climbing hand-holds.



Upper-body Strength

As an indicator of climbing-specific upper-body strength, the single-repetition maximum weight lifted (1RM) in the latissimus pull-down exercise was expected to increase as a result of training for climbing. In both the HIT and the ET groups, 1RM increased significantly compared to pre-test values as a result of the training programs prescribed in this study. The magnitude of strength gains was similar between genders. Though traditional resistance training was not a component of either program in this study, the observed increase may possibly be attributed to a few key factors of adaptation to exercise, including neuromuscular factors, cardiovascular factors and metabolic factors.

Neuromuscular adaptations to resistance training include increased neural activation of motor units of muscle fibers. During the initial period of a resistance-training program, the majority of strength increase is due to heightened motor unit activation, as movement patterns are learned and neuromuscular control becomes more efficient. Subsequent to this phase, muscle fiber architecture begins adaptation through fiber type conversion from type IIb to type IIa fibers (Staron, Karapondo, Kraemer, Fry, Gordon, Falkel, Hagerman & Hikida, 1994), changes in mitochondrial density and metabolic enzyme activity (Tanaka & Swensen, 1998). When trained properly, these physiological adaptations are similar between gender (Deschenes & Kraemer, 2002; Staron et al.), though the absolute magnitude of adaptation is greater among males. However, the training programs compared in this study were not considered to be a form of resistance exercise, thus it is questionable as to whether these adaptations are responsible for the gains observed in upper-body strength.

Motorized treadmill climbing is considered to be continuous dynamic exercise, and therefore may be classified as a form of endurance activity because it is performed for durations of up to twenty minutes or more. A cross-training effect from muscular endurance training to greater muscular strength may be possible; many studies have explored the inverse relationship. Bishop, Jenkins, Mackinnon, McEniery & Cary (1999) examined the effect of strength training on female endurance-trained cyclists and observed no significant changes in average power output in a one-hour cycling test nor lactate threshold, peak oxygen consumption, muscle fiber size or muscle enzyme activity. The possibility that subjects in their study performed too little resistance training (2x per week for 12 weeks), or too little endurance training (none during the training phase of the study) exists; contradictory results were found by Tanaka & Swensen (1998) upon review of published performance data following coupled resistance and endurance training.

They suggest that performance improvements may be linked to the capacity of resistance training to alter muscle fiber size and contractile properties in runners and cyclists. An important exception to their suggestion was data on competitive swimmers, who require more specific forms of training to realize performance improvement. Given the idea that for some competitive activities, a "cross-training" effect exists between resistance training and endurance performance, it may be reasonable to suspect that the inverse relationship holds as well, that endurance training is capable of enhancing muscular strength. This hypothesis should be tested rigorously in multiple activities. In summary of this topic, the observed increase in muscular strength as a result of six weeks of training on a motorized climbing treadmill may be attributed to muscular adaptation to endurance exercise in factors related to neuromuscular recruitment, muscle architecture, or metabolic enzyme activity; further investigation is needed to conclude which of these, if any, are responsible for the gains observed. Greater importance should be placed on the notion that upper-body strength is a predictor of climbing performance (Mermier, Janot, Parker & Swan, 2000), and that six weeks of training on a climbing treadmill is capable of increasing this measure.

## Muscular Endurance

Shoulder girdle and arm endurance have been suggested to be essential characteristics of a high standard of climbing performance (Grant, Hynes, Whittaker & Aitchison, 1996) and have been considered to be one of the significant factors in predicting climbing ability (Watts, Martin & Durtschi, 1993). Among other tests, the Bent-arm Hang Test clearly distinguished elite climbers from recreational or non-climbers (Watts et al.). In this study, time to exhaustion in the Bent-arm Hang Test was therefore hypothesized to increase as a result of six weeks of training on a motorized climbing treadmill, and this in fact was observed for subjects in the Endurance Training group. This measure tended to be higher for subjects in the HIT group, with the p-value approaching significance ($p = 0.0636$).

Mean pre-test hang time values were much lower than those published by Grant, Hynes, Whittaker & Aitchison (1996) for elite male climbers (36.1 ± 20.4 vs. 53.1 ± 13.2 s), though they were higher than the time reported for recreational climbers (31.4 ± 9.0 s) or non-climbers (32.6 ± 15.0 s) in the same study. Gender appears to play a major role in the difference between observed and published data, as the mean pre-test value of hang time for males only in this study was 50.0 ± 17.5 s. Bent-arm hang time to exhaustion found by Grant et al. is comparable to that observed for the male climbers of varying experience level by Mermier, Janot, Parker & Swan (2000) of 51.8 ± 14.6 s, which are greater than the values found for the males in this study. Only Mermier et al. report data for women in this measure, which are higher than the mean pre-test value observed in this study for female subjects (25.1 ± 14.4 s vs. 23.2 ± 13.1 s). The fact that subjects in this study had a lower mean pre-test value than the elite male climbers (in Grant et al.) is easily understood when experience is considered. However, the higher mean pre-test value found for the male subjects in this study compared to male recreational and non-climbers tested by Mermier et al. is not explained by experience. The possibility for a difference in methodology does not explain the difference either; both this study and that of Mermier et al. used the criterion measure of 90º at the elbow joint, estimated visually, as the determinant of failure. Grant et al. determined failure in a more absolute method, in which the position of the subjects' eyes relative to the hang-board was the determinant. The data of those studies compare favorably with each other, suggesting that this difference in methodology was not responsible for the higher values noted herein for males compared to the recreational and non-climbers studied by Grant et al. The explanation is proposed that the subjects in this study simply had a higher level of fitness in this measure than the recreational and non-climbers studied elsewhere.

Following training, mean values increased significantly for subjects in the Endurance Training group, from 54.4 ± 14.9 s to 58.8 ± 10.8 s for males and 16.2 ± 10.4 to 19.1 ± 11.7 s for females. Mean values for subjects in the HIT group increased without significance ($p = 0.0636$) from 46.3 ± 19.9 s to 50.3 ± 20.6 s for males and from 30.1 ± 12.3 s to 32.2 ± 12.1 s for females. The highest values for males in the ET group rank above the elite climbers studied elsewhere, suggesting that either these individuals were of greater climbing fitness, or call into question the test administrator's skill in determining the point of failure. If the latter is true, no conclusion should be drawn regarding the importance of the difference between the two groups; if the former is true, these individuals may not have responded to the training stimulus by increasing their hang time significantly. Over all subjects, the increase in time to exhaustion in the bent-arm hang test was significant, allowing the conclusion that six weeks of training on a motorized climbing treadmill is capable of producing an increase in the bent-arm hang test time to exhaustion, a significant predictor of climbing ability.

## Climbing-specific Cardiorespiratory Fitness

Motorized treadmill climbing is physiologically different from "wall" climbing primarily due to the absence of the static component found in the latter activity in the form of rests. The primary physiological basis for this claim is the linear relationship of heart rate and oxygen uptake at submaximal intensities of treadmill climbing (Davis, unpublished). This physiological response to treadmill climbing and the continuous movement patterns necessary to maintain position on the treadmill categorize motorized treadmill climbing as a dynamic activity. When performed at submaximal intensities, this activity may be considered to be similar to other well-researched continuous, dynamic endurance activities such as walking and running (Heil, Mundinger, Stadtlander & Tesoro, in review). Therefore, motorized treadmill climbing may be seen as fitting the endurance performance model of Pate & Branch (1992) which describes endurance activities as being limited by three factors related to oxygen consumption: maximal oxygen consumption ($\dot{V}O_{2max}$), lactate threshold (as a percentage of $\dot{V}O_{2max}$), and economy ($\dot{V}O_2$ at a given submaximal intensity). In a heterogeneous population, $\dot{V}O_{2max}$ has been shown to be a significant predictor of athletic performance (Cavanaugh & Kram, 1985). As the upper limit for oxygen uptake in an individual (Basset & Howley, 2000), $\dot{V}O_{2max}$ is fundamental in defining the lactate threshold as a percentage of maximum oxygen uptake. Thus the peak oxygen consumption elicited by motorized treadmill climbing, $\dot{V}O_{2peak}$, was considered to be a primary determinant of climbing performance; as such, it was hypothesized that it would be improved by six weeks of climbing-specific training on a motorized climbing treadmill.

Results of this study may be interpreted in two ways. Considering mean pre- and post-test values for absolute $\dot{V}O_{2peak}$ and $\dot{V}O_{2peak}$ relative to total climbing mass of the subject plus all equipment worn while climbing over all subjects, mean $\dot{V}O_{2peak}$ decreased during the training phase of the study. However, due to factors discussed below, removal of data considered to be outside the range of legitimate physiological response to the training programs (termed "negative responders") resulted in a significant increase in the mean $\dot{V}O_{2peak}$ over all remaining subjects. Results of the 2-factor repeated measures ANOVA, following exclusion of negative responders, indicate that the interaction term group x time was not significant, suggesting that the HIT group did not experience a significantly greater physiological adaptation stimulus compared to the Endurance Training group, despite a significantly greater training intensity. However, the main factor time did have a significant effect. This indicates that six weeks of climbing-specific training was capable of increasing both absolute and relative $\dot{V}O_{2peak}$.

Subjects considered to have been "negative responders" were those whose post-test $\dot{V}O_{2peak}$ were more than 10 percent lower than their pre-test value. The primary basis for this cut-off was physiological. Mujika and Padilla (2001; 2000) studied the effects of detraining on $\dot{V}O_{2max}$, finding that in well-trained athletes, maximal values decline markedly in as little as four weeks of insufficient training stimulus. However, $\dot{V}O_{2max}$ still remains above control values (subjects who were not recently trained). Given that the subjects in this study were not highly trained athletes, declines of over ten percent in $\dot{V}O_{2max}$ are therefore considered too dramatic to be accounted for by a detraining effect. A secondary reason for a cut-off of greater than ten percent decrease between pre- and post-test values concerns test-retest reliability of the equipment used to measure climbing-specific $\dot{V}O_{2peak}$. Though no statistical analyses of reliability were performed in this study, pilot research conducted prior to data collection indicate strong repeatability with the equipment used. However, experience with occasional 'bad' tests suggests that a number of technical errors may be responsible for the remarkably lower post-test measurements. These include poorly-sized, poorly positioned or poorly stabilized face masks, which covered the mouth and nose of the subject in order to collect expired gases; any of these possibilities would result in abnormal measurements by the portable metabolic unit used in this study. The unit was confirmed to be calibrated correctly immediately prior to the study, eliminating this possibility as a reason for measurement error. Some decrease in $\dot{V}O_{2peak}$ is theoretically possible, thus a decline was not automatically ruled out as an erroneous measurement; however, more than ten percent was considered physiologically unreasonable. Conclusions drawn regarding changes in climbing-specific $\dot{V}O_{2peak}$ are therefore based upon the reduced data set following exclusion of the negatively responding subjects.

No studies published to date have quantified maximal or peak oxygen consumption of motorized treadmill climbing, and thus no direct comparisons are possible. The data herein are put forth as the first attempt to quantify norms of climbing-specific $\dot{V}O_{2peak}$ for motorized treadmill climbing. The values compare favorably to norms published by the ACSM (2000) for the age and fitness levels of the subjects included in this study.

Significant differences were not found between the HIT and Endurance Training groups as a result of six weeks of climbing-specific training. This is best accounted for by the suggestion that six weeks of training was not a sufficient duration to result in a differentiation of adaptation between groups; it has been clearly demonstrated that the HIT group performed higher-intensity exercise during the training phase based upon significantly greater distances climbed per workout in significantly less time, at significantly greater speeds and higher heart rate training zones. It is should be noted that the mean time spent in the training zone during week 5 of the training phase was less for the HIT group than for the ET group. However, a valid reason for this can be found in the fact that more time was needed to reach the training zone in the HIT group, due to higher training thresholds and multiple rest bouts between climbing intervals. When workout intensity was gauged by climbing speed as a treadmill setting, and by total distance climbed per unit time, workout intensity was clearly higher for the HIT group. Thus it is suggested that a longer training phase may have allowed greater differentiation between the two training programs.

In summary of this topic, mean climbing-specific cardiorespiratory fitness was observed to decrease in both groups due to a small number subjects who exhibited remarkable decreases in $\dot{V}O_{2peak}$. Exclusion of these subjects' data resulted in significant increases from pre- to post-testing in both absolute and relative $\dot{V}O_{2peak}$. The increase in mean values of $\dot{V}O_{2peak}$ from pre- to post-test was not significantly different between groups. It is therefore concluded that six weeks of training on a motorized climbing treadmill is capable of producing an increase in climbing-specific $\dot{V}O_{2peak}$, as measured by an incrementally-graded climbing test to exhaustion at climbing grades less than $92^o$.

## Climbing Performance

Many sport climbing competitions use a scoring system in which each successive handhold increases by one in point value (Mermier, Janot, Parker & Swan, 2000). An analogous, though simpler, scoring system simply assigns a point value of one to each handhold successfully attained. If the rate of a climber's progress is held constant between climbers on a given route, for which the handholds are the same, then the elapsed time until the climber is unable to continue becomes equivalent to the number of holds successfully attained. In the two measures of climbing performance in this study, time to exhaustion was deemed equivalent to the simpler scoring method. The first protocol on the climbing treadmill used to obtain a measure of climbing performance was the $\dot{V}O_{2peak}$ Climbing Test; the second was the Incremental Overhang Test (IOT). The distinguishing characteristics between these protocols were the speed (increments of 1.8 $m \cdot min^{-1}$ up to a maximum of 15 $m \cdot min^{-1}$ for the $\dot{V}O_{2peak}$ Climbing Test; constant speed of 7.9 $m \cdot min^{-1}$ for the IOT) and the grade (less than 94° for the $\dot{V}O_{2peak}$ Climbing Test, greater than 94° for the IOT) at which the protocols were performed. Thus climbing performance was assessed at a variety of speed and grade combinations. It was hypothesized that six weeks of climbing-specific training on a motorized climbing treadmill would improve climbing performance. Furthermore, it was hypothesized that

HIT would improve performance to a greater degree than Endurance Training. Results of this study indicate that these were valid hypotheses.

The results of the 2-factor repeated measures ANOVA indicate that mean time to exhaustion in both climbing performance tests was improved following the six-week training phase. The interaction term Group x Time for the Incremental Overhang Test was not significant; the same interaction term for the $\dot{V}O_{2peak}$ Climbing Test was not significant at the $\alpha = 0.05$ level, but indicated a trend towards differentiation ($p = 0.0693$) in mean time to exhaustion between groups. Mean improvement in time to exhaustion in the $\dot{V}O_{2peak}$ Climbing Test was 12.9% for the HIT group, compared to 7.2% for the ET group. In the Incremental Overhang Test, mean improvement in time to exhaustion was 15.8% for the HIT group and 15.2% for the ET group.

Workout prescription for both the HIT and Endurance Training programs constrained treadmill grades to less than 95º; furthermore, treadmill grades were the same for both programs during the training phase. It is therefore reasonable that both training programs resulted in greater climbing performance in the $\dot{V}O_{2peak}$ Climbing Test, as the treadmill grades in this test were less than 94º. The principle of training specificity suggests that training at particular grades would result in improvements in climbing performance at those grades. However, the results of the Incremental Overhang Test, which indicate that both training programs resulted in climbing performance at grades steeper than 94º, suggest that improved performance at steep grades may result from moderate-angle training.

Therefore, a general training effect on climbing performance existed for motorized treadmill climbing, which was not limited to the treadmill grades used during training. However, superior improvements in climbing performance resulting from high-intensity training, compared to endurance training, were seen when the climbing angle of the performance test was similar to the angle at which training was performed.

The variables used to gauge climbing performance in this study, the time-to-exhaustion in the $\dot{V}O_{2peak}$ Climbing Test and the Incremental Overhang Test, correlated rather strongly with each other and with some of the physiological variables assessed during the pre- and post-testing phases. The high correlation between pre-test and post-test time to exhaustion in the $\dot{V}O_{2peak}$ Climbing Test ($\dot{V}O_2$ Time; r=0.94) is interpreted to suggest that subjects with initially high values in the pre-test also had high values following training. Linear regression analysis of post-test $\dot{V}O_2$ Time on pre-test values revealed a slope of 1.07 and a y-intercept of 0.34 min (Figure 5-3); the slope of the regression line suggests that improvements were similar over all initial fitness levels. The y-intercept of the regression line shows a positive change from pre- to post-testing. The pre-test time-to-exhaustion in the Incremental Overhang Test (IOT Time) also correlated rather strongly with the post-test value, though less so than in the $\dot{V}O_{2peak}$ Climbing Test, with r=0.83. This suggests that initial climbing performance level was less important to post-training performance level on very steep terrain than it was for moderate-to-vertical terrain; as such, some of the improvement in performance may be attributed to training-induced changes in physiological variables. Regression of post-test IOT Time on pre-test values revealed a slope of 0.84 and a y-intercept of 1.59 min

(Figure 5-4). The slope-value less than 1.0 indicates that greater improvements in steep-terrain climbing performance tended to be made by subjects of initially lower performance level, which supports the suggestion that improvements in performance may be attributed to training-induced changes in physiological variables.

Figure 5-3. Linear regression plot of time-to-exhaustion in the $\dot{V}O_{2peak}$ Climbing Test post-test vs. pre-test: VO2Time (post) = 0.344 + 1.07 VO2Time (pre); n = 27, $R^2$ = 0.89, SEE = 0.953, P < 0.001.

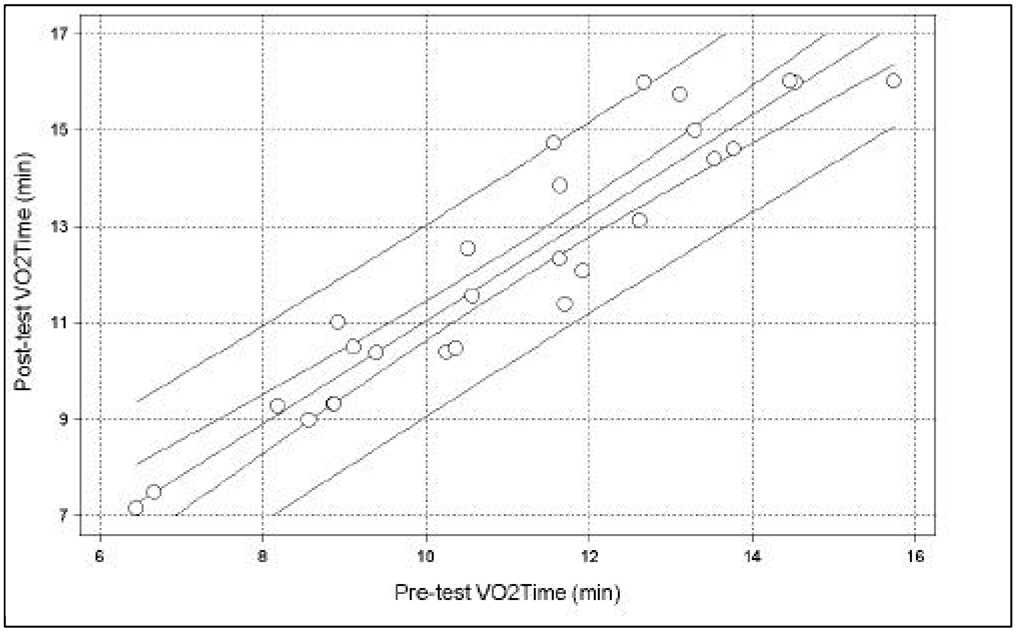
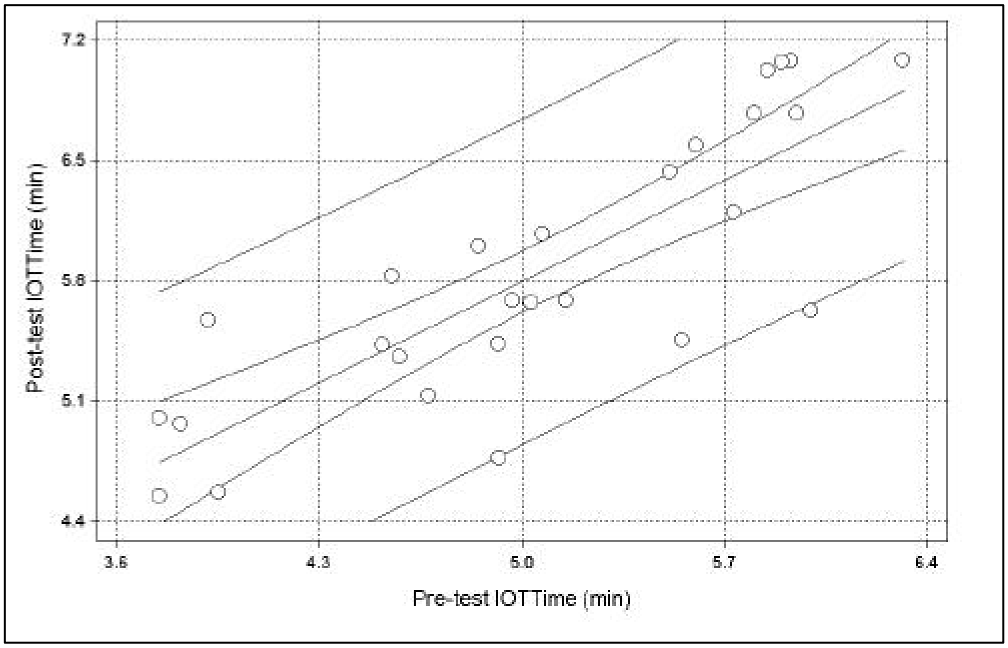


Figure 5-4. Linear regression plot of time-to-exhaustion in the Incremental Overhang Test post-test vs. pre-test: IOT Time (post) = 1.59 + 0.84 IOT Time (pre); n = 27, $R^2$ = 0.68, SEE = 0.698, $P < 0.001$.



Time-to-exhaustion in the Bent-arm Hang Test, a measure of upper-body muscular endurance, correlated highly with pre- and post-test $\dot{V}O_2$ Time, with r=0.77 and r=0.82, respectively. The slight increase in r-value suggests that increased muscular endurance following training played a role in the greater performance observed in the post-test. The same measure, time-to-exhaustion in the Bent-arm Hang Test, correlated more strongly with pre- and post-test IOT Time, with r=0.82 and r=0.81, respectively. Muscular endurance was more closely associated with low-angle climbing performance than were grip strength or latissimus strength, with r=0.67 and r=0.58, respectively, in the pre-test and r=0.64 and r=0.59 in the post-test. At steeper climbing angles, the correlation coefficients remained similar for grip and back strength (grip strength, pre- to post-test: r=0.75 and r=0.70; 1-RM lat pull-down: r=0.64 and r=0.63). As expected, grip strength and back strength were slightly more correlated with steep climbing performance than moderate-angle climbing performance, due to the increased reliance on upper-body musculature for maintaining position on the climbing wall as climbing angle steepened. The slight decrease in the correlation coefficient from pre- to post-testing in all of these physiological measures, however, suggests that skill played a role in the observed increase in climbing performance as well.

# CHAPTER SIX

# CONCLUSION

The primary purpose of this study was to test the effectiveness of six weeks of climbing-specific training using a motorized climbing treadmill in improving climbing performance and related physiological variables. The secondary purpose was to compare two training programs on the treadmill using these same variables. The Rock ™ (Ascent Products, Inc., Bozeman, MT) was developed to provide continuous climbing at a wide range of speeds and climbing angles. The two training programs were analogous to training programs used in other dynamic endurance activities, Endurance Training of lower intensity and longer duration, and High-intensity Interval Training, of higher intensity and multiple shorter-duration work bouts, separated by passive rest.

Pre-testing and post-testing procedures were similar. Anthropometric, muscular strength and muscular endurance measurements were taken during the first testing session. A practice trial of the $\dot{V}O_{2peak}$ Climbing Test was then performed, followed by the Incremental Overhang Test, in the second testing session. The third testing session consisted of one trial in the $\dot{V}O_{2peak}$ Climbing Test, in which metabolic data were gathered via indirect calorimetry using a portable expired gas analyzer.

A six-week training program was implemented following the pre-testing procedures in one group of 14 subjects and one group of 13 subjects. The subjects were mostly college-aged (22.2 ± 3.6 years) with similar numbers of male and female subjects in each group. The first group performed High-intensity Interval Training at 80-95% of measured pre-test climbing-specific $\dot{V}O_{2peak}$ for 3 bouts of up to six minutes in duration, separated by three minutes of rest. The second group performed Endurance Training at 60-85% of measured pre-test climbing-specific $\dot{V}O_{2peak}$ for up to 20 minutes in a single climbing session. Both groups trained three days per week, and missed no more than two workouts during the training phase. The HIT group climbed greater distances per workout in less time, at higher speeds and heart rates than the ET group, at the same climbing angle.

The results of this study indicate that six weeks of climbing-specific training on a motorized climbing treadmill improve climbing performance, climbing-specific cardiorespiratory fitness, and muscular strength and endurance variables associated with climbing performance. No differences in physiological variables were found between the two training programs, although a longer training phase may have resulted in greater performance following High-intensity Interval Training. Improvements in climbing performance at steep climbing angles (> 94º) were seen despite the fact that climbing angles during the training phase were constrained to less than 95º. These results suggest that climbing-specific training on a motorized climbing treadmill of six weeks duration is capable of improving climbing performance and related muscular strength and endurance variables, as well as climbing-specific cardiorespiratory fitness.

It should be noted that one important measure of climbing-specific fitness did not improve following the training phase. Hand grip strength, as measured by conventional hand-grip dynamometer, did not improve following training in either group. Though the sensitivity of this device to changes in climbing-specific hand-grip strength is questionable, and other tools have been developed to target the strength of the hand and forearm specific to climbing, it remains that conventional hand-grip strength was not improved following training on a climbing treadmill.

Further research, perhaps using a longer training phase or a greater difference between training programs, may provide support for the suggestion that high-intensity training results in greater improvements in climbing performance than lower-intensity endurance training. Other research suggested includes investigating the lactate response to motorized treadmill climbing at different angles, which may enhance the potential for exercise prescription at higher intensities.

These results lead to the conclusion that climbing-specific training using a motorized climbing treadmill is an appropriate tool for improving climbing performance and associated physiological, muscular strength and endurance variables. However, muscular strength development of the forearms and hands is limited when the hand-holds are large and positive. It is suggested that an additional training component of forearm- and hand-strength training using a climbing-specific "hangboard" be incorporated into a training program as a complement to motorized treadmill climbing, in order to maximize the sport-specific benefit of training for climbing.

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# APPENDICES

# APPENDIX A:  SUBJECT INFORMATION FORMS

## SUBJECT CONSENT FORM
## FOR PARTICIPATION IN HUMAN RESEARCH - MONTANA STATE UNIVERSITY

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| | |
|---|---|
| **PROJECT TITLE:** | *A Comparison of Training Methods for Enhancing Climbing Performance.* |
| **PROJECT DIRECTOR:** | Colin Davis, Graduate Student, Exercise Physiology<br>Dept. of Health and Human Development, Movement Science Laboratory<br>Lab Phone: (406) 994-6325; Email: cmdavis@montana.edu |
| **PROJECT SUPERVISOR:** | Daniel P. Heil, PhD., Assistant Professor, Exercise Physiology<br>Dept. of Health and Human Development, Movement Science Laboratory<br>Montana State University, Bozeman, MT 59717-3540<br>Phone: (406) 994-6324; FAX: (406) 994-6314; E-mail: dheil@montana.edu |
| **FUNDING:** | This project is NOT funded. |

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Each participant is presented with this *Informed Consent Document* to explain the purpose of the research, as well as the expected risks and benefits associated with participation. Each participant will be screened by the project director using responses provided by participants in a Physical Activity Readiness Questionnaire.

> **<u>Health Screening Prior to Testing</u>:** Prior to any testing each participant is required to read and sign a Subject Consent Form. In addition, medical clearance will be obtained using a ***Medical Health History Questionnaire***. Factors that will exclude you from participating as a subject in this study include all known contraindications to participating in maximal and submaximal exercise activities. Some examples include:
>
> - ✓ Preexisting musculoskeletal/joint injury or disorder (for example, severe arthritis) that limits your ability to walk normally.
> - ✓ You have been diagnosed with cardiovascular or pulmonary disease.
> - ✓ You are recovering from recent surgery.
> - ✓ You have a metabolic disorder, such as diabetes.
> - ✓ You are currently sick or recovering from a cold or flu.
> - ✓ You have a history of reoccurring and/or untreated low-back pain.

All testing and screening procedures are in accordance with those outlined for testing “Low Risk” adults by the American College of Sports Medicine[1]. Please talk with the Project Director, Colin Davis, about any pre-existing health conditions that may limit your participation in this project *BEFORE* testing.

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[1] American College of Sports Medicine (2000). *ACSM’s Guidelines for Exercise Testing and Prescription* (6th edition). Lea & Fibiger; Philedelphia, PA.

**PURPOSE OF THE STUDY:**

This study is designed to measure the effects of two eight-week training programs conducted on a motorized climbing treadmill. Participation in this study requires enrollment in a semester-long course (HDPE 489 or 270, Undergraduate Research), meeting three days per week in the Movement Science / Human Performance Lab (Romney Building, MSU Campus), at regular individualized times. Each meeting will consist of exercise testing or physical training, as well as instruction in data collection techniques. Our lab is primarily interested in the degree of any training effects (e.g. increased climbing-specific aerobic fitness, increased upper-body and handgrip strength, increased climbing endurance) due to the structured use of the climbing treadmill. Your participation will also serve as a means to learn more about research methodology by serving as both a subject *and* research assistant.

**PROCEDURES:**

**In General:**

You are being asked to visit the Movement Science Lab three separate days per week for the first half of the Spring 2003 semester, to perform climbing-specific training on a climbing treadmill (located within the lab). The first week of the course (January 20-24) consists of baseline testing. The following six weeks (the remainder of the semester prior to Spring Break) are designated as the training phase, during which three visits will occur within each week, with all visits occurring at a similar time of day (within 2-3 hrs). The week following spring break (March 17-21) is designated as the post-testing phase. **You will need to provide your own climbing shoes** and you should be physically rested for each session.

The climbing treadmill has a climbing surface approximately 12 ft by 8 ft with various sized hand holds (similar to an indoor climbing wall). The surface of the treadmill can be set at grades from 80° (like walking up an inclined ramp), to 90° (vertical), and even 180° (like climbing on a ceiling), whereas the speed of the treadmill surface can be set between 2 ft/min and 50 ft/min. Regardless of speed and grade, when the treadmill surface is moving the job of the climber is to maintain a position somewhere in the middle of the treadmill surface by moving from hand hold to hand hold. If the climber either goes too high or too low on the treadmill surface during the test, infrared sensors mounted at the top and bottom of the treadmill, respectively, will trigger the treadmill surface to stop moving. If the climber happens to fall (*vertical distance of fall is NEVER more than 2-3 ft*), there is a thick foam pad covering the floor underneath the treadmill to cushion the fall. A fall usually occurs as a result of missing a hand hold or slipping from a hand hold, both of which will tend to occur with fatigue. During any maximal testing on the climbing treadmill, a trained spotter will be positioned to ensure a safe a landing in the event of a fall from the treadmill.

**Testing:**

As a participant in this study, your climbing fitness level before and after training will be assessed via multiple exercise tests and fitness measurements. These tests measure parameters that have been identified with climbing performance by previous research:

(1.) Your upper-body muscular strength will be tested by the Latissimus Pull-down 1-Repetition Maximum Test, into which a warm-up has been built.
(2.) Your handgrip strength of each hand will be measured with a hand dynamometer (which shows how hard you can squeeze).
(3.) Your upper-body isometric endurance will be measured in the Bent-arm Hang Test, which is a test of how long you can hang from your arms, with your elbow joint held at a 90° angle.

(4.) Your upper-body dynamic endurance will be measured in the Incremental Overhang Test, a climbing performance test on the treadmill. The protocol for this test begins with three minutes of warm-up climbing at a speed of 26 feet per minute and an incline of 90° (vertical), after which the speed increases to 30 feet per minute and the grade becomes steeper by three degrees every 30 seconds.

(5.) The final test in the series is the $\dot{V}O_{2peak}$ Climbing Test, designed to measure your climbing-specific cardiorespiratory fitness. This protocol begins after a 5-10 minute warm-up on the climbing treadmill at a self-selected speed and grade. You will be fitted with a portable metabolic measurement system for measuring oxygen consumption ($VO_2$) while you climb. The system calculates $VO_2$ by measuring how much air you breath and then determining the concentrations of oxygen and carbon dioxide in your exhaled breath. In order to measure these variables, you will breath through a mask (covering your mouth and nose) that allows you to breath room air normally but funnels your exhaled air toward sample tubes. Except for the novelty of breathing through a mask of this type, there are absolutely no risks or problems associated with breathing through this mask at rest, during submaximal exercise, or even during maximal exercise. The metabolic system itself is battery powered and will be carried on a backpack worn while climbing. The total weight of the backpack and metabolic system is about 5 lbs. In addition, you will also wear a telemetry heart rate monitor strap around your chest for the recording of heart rate. Once you have been properly hooked up to this equipment, your treadmill test is ready to begin.

The climbing protocol is designed to start out very easy (slow speed, grade < 90°) and then progress in difficulty every 2 minutes by increasing the speed, the grade, or both. As the 2 minute stages progress it will become more and more difficult to climb without tripping the infrared sensors or dropping to the foam pads covering the floor. As a climber, it is your goal to last as long as possible into the climbing protocol (shown below) without tripping the infrared sensors or dropping off the treadmill. During the last 2-4 minutes of each test, the perceived intensity of the effort will be similar to that of running 800 m for time. Any situation that causes the treadmill surface to stop repeatedly (like tripping the infrared sensors) or that causes the climber to lose contact with the treadmill surface (dropping or falling to the foam pad) will signal the end of the test. The exact progression of 2 minute stages for the $VO_{2peak}$ climbing protocol is given below:

**Training:**

As mentioned above, the purpose of this study is to evaluate the effects (if any) of six weeks of training on the climbing treadmill. Once pre-testing has been completed, you will be randomly assigned to one of two training groups, each of which will train three days per week for comparable amounts of time (between 30-60 minutes per session). One group will perform endurance training, at moderate intensities; the other group will perform interval training at higher intensities, with short rest periods between intervals. Once you have been placed in a group, you may then find a training partner(s), and schedule your training at times that fit your schedule. The Project Director will assist you with this process.

During training, you will wear a telemetry-based heart rate monitor for all sessions. One of your duties as a researcher will be to record your training time and intensity, based on heart rate. You will also be asked to record any additional activities that you perform outside of training.

## $\dot{V}O_{2peak}$ Climbing Protocol

| Stage | Time | Treadmill Speed | Treadmill Grade |
|---|---|---|---|
| **1** | *0:00 - 1:59* | 20 ft/min | 80° |
| **2** | *2:00 - 3:59* | 26 ft/min | 82° |
| **3** | *4:00 - 5:59* | 32 ft/min | 84° |
| **4** | *6:00 - 7:59* | 38 ft/min | 86° |
| **5** | *8:00 - 9:59* | 44 ft min | 88° |
| **6** | *10:00 - 11:59* | 50 ft/min | 90° |
| **7** | *12:00 - 13:59* | 50 ft/min | 92° |
| **8** | *14:00 - 15:59* | 50 ft/min | 94° |

**Research Duties:**
In order to gain understanding of the intricacies of data collection in controlled research, you will be asked to record your training program activities, intensity, and duration in a log and on a chart. In your log, you will also be asked to record additional activities as mentioned above. The information in your log will be given to the Project Director on a weekly basis. Following the training and post-testing phases, you will participate in data analysis and interpretation exercises. If you start out as a researcher/subject in the class and are unable to continue participation as a subject, for any reason
(due to sickness, injury, etc.), you may continue to participate by reverting to the researcher-only responsibilities of data collection and data processing. In this case, your time demands will remain the same.

**POTENTIAL RISKS:**
There are several possible risks associated with participating in this study. First, as mentioned above, it is possible that you will fall or drop off the treadmill at the end of testing. However, all possible precautions will be taken to ensure your safety and make you feel comfortable before any testing takes place. Second, you should be aware that a $\underline{V}O_{2peak}$ test will cause extreme fatigue immediately after the test and possibly the next day, especially for those people less accustomed to high intensity aerobic exercise. Due to the intensity of the effort required at the end of each test, it is possible (though unlikely) for $VO_{2peak}$ testing to precipitate a cardiac event (such as abnormal heart rhythms) or even death. However, the possibility of such an occurrence is slight (*less than 1 in 10,000*), since you are in good physical condition with no known symptoms of heart disease, and since the test will be directed by trained personnel. Lastly, the measuring devices (heart rate monitor and face mask) may feel restrictive and/or uncomfortable during testing, but all possible adjustments will be used to achieve the greatest comfort for you. All possible precautions will be taken to ensure your safety and make you feel comfortable before any testing takes place.

**BENEFITS:**

After completing all pre-training tests, participants will receive a copy of their own test results. In addition, participants may request a summary of the entire study findings by contacting the Project Director, Colin Davis, by phone (406-994-6325) or E-mail (cmdavis@montana.edu). Participants will obtain supervised training for climbing, and may acquire increased climbing-specific fitness. As participants in the research methods course, students will be exposed to data collection and analysis techniques in the field of exercise physiology. 2 MSU course credits will be awarded upon successful completion of the course; if you find it necessary to withdraw your participation as a subject, you may still qualify for course credit by continuing to assist with research duties for the duration of the study. You may also drop the course if you choose to do so, within the specified university timeline for dropping a course.

**CONFIDENTIALITY:**

The data and personal information obtained from this project will be regarded as privileged and confidential. They will not be released except upon your written request. Your right to privacy will be maintained in any ensuing analysis and/or presentation of the data by using coded identifications of each person's data.

**FREEDOM OF CONSENT:**

You may withdraw consent for participation in writing, by telephone, or in person without prejudice or loss of benefits (as described above). Please contact the Project Director, Colin Davis, by phone (406-994-6325) or E-mail (cmdavis@montana.edu) to discontinue participation. *Participation in this project is completely voluntary*.

In the UNLIKELY event that your participation in this project results in physical injury to you, the Project Director will advise and assist the participant in receiving medical treatment. Montana State University cannot be held responsible for injury, accidents, or expenses that may occur as a result of your participation in this project. In addition, Montana State University cannot be held responsible for injury, accidents, or expenses that may occur as a result of traveling to and from your appointments at the Movement Science / Human Performance Lab. *Further information regarding medical treatment may be obtained by calling the Project Supervisor, Dan Heil, at 406-994-6324.* You are encouraged to express any questions, doubts or concerns regarding this project. The Project Director will attempt to answer all questions to the best of his ability prior to any testing. The Project Director fully intends to conduct the study with your best interest, safety and comfort in mind. *Additional questions about the rights of human subjects can be answered by the Chairman of the Human Subjects Committee, Mark Quinn, at 406-994-5721.*

| | |
|---|---|
| **PROJECT TITLE:** | *A Comparison of Training Methods for Enhancing Climbing Performance* |

## STATEMENT OF AUTHORIZATION

I, *the participant*, have read the Informed Consent Document and understand the discomforts, inconvenience, risks, and benefits of this project. I, ______________________________________ *(print your name)*, agree to participate in the project described in the preceding pages. I understand that I may later refuse to participate, and that I may withdraw from the study at any time. I have received a copy of this consent form for my own records.

**Signed:**____________________________ **Age** _______ **Date**_______________

***Subject's Signature***

---

If you, the participant, are **less than 18 years of age** at the time of signing this consent form, you MUST have the consent of a parent or legal guardian as indicated by their signature below.

I, *the parent or legal guardian*, have read the Informed Consent Document and understand the discomforts, inconvenience and risk of this study. I, __________________________________ *(printed name of parent or guardian)*, related to the legal minor signed above as ____________________ *(state relationship to the minor)*, agree to the participation of _________________________________ *(print the name of the minor)* in the project described in the preceding pages. I understand that I may later refuse participation in this project and that the legal minor, through his/her own action or mine, may withdraw from the study at any time.

**Signed:**_______________________________________ **Date**_______________

***Parent or legal Guardian***

## PAR-Q: PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

The PAR-Q is designed to help you help yourself. Many health benefits are associated with regular exercise and completion of a PAR-Q is a sensible first step to take if you are planning to increase the amount of physical activity in your life. For most people, physical activity should not pose any problem or hazard. PAR-Q has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the type of activity most suitable for them.

Common sense is your best guide in answering these few questions. Please read the following questions carefully and check the ***YES*** or ***NO*** opposite the question if it applies to you.

| ***YES*** | ***NO*** | |
|---|---|---|
| ☐ | ☐ | **1.** Has your doctor ever said you have heart trouble? |
| ☐ | ☐ | **2.** Do you ever have pains in your heart or chest? |
| ☐ | ☐ | **3.** Do you ever feel faint or have spells of severe dizziness? |
| ☐ | ☐ | **4.** Has a doctor ever said your blood pressure was too high? |
| ☐ | ☐ | **5.** Has a doctor ever said your blood cholesterol was too high? |
| ☐ | ☐ | **6.** Have you ever been diagnosed with diabetes mellitus? |
| ☐ | ☐ | **7.** Has your doctor ever told you that you have a bone or joint problem such as arthritis that has been aggravated by exercise, or might be made worse with exercise? |
| ☐ | ☐ | **8.** Is there a good physical reason not mentioned here why you should not follow an activity program even if you wanted to? |
| ☐ | ☐ | **9.** Are you over the age of 65 or NOT accustomed to vigorous exercise? |
| ☐ | ☐ | **10.** Are you a habitual cigarette or cigar smoker?<br>If *"Yes"*, how many years? __________<br>If *“No”* AND you have recently quit smoking, how long ago did you quit?<br>__________ (give answer in months or years) |
| ☐ | ☐ | **11.** Is there any other physical ailment not mentioned above that could be considered a health risk if you were to participate in the testing described by the Informed Consent Document? If “***Yes”***, please describe below... |

*If you answered "**YES"** to one or more questions...*

If you have not recently done so, consult with your personal physician by telephone or in person before increasing your physical activity, taking a fitness test, or participating in the present research study. Tell the physician what questions you answered *"YES"* on PAR-Q or show a copy of this form. Be certain to talk with the principal investigator before preceding further with your involvement in this study.

*If you answered **"NO"** to <u>all</u> questions...*

You have reasonable assurance that your participation in the present study will not put you at higher risk for injury for illness.

*NOTE: Postpone exercise testing if you suffer from minor illness such as a common cold or flu!*

Your signature below indicates that you have filled out the preceding PAR-Q form to the best of your knowledge.

Signed:____________________________________Date____________
Subject's Signature

Signed:____________________________________Date____________
Project Director

# Health Status Questionnaire - Montana State University
# Movement Science/Human Performance Laboratory

## INSTRUCTIONS

Complete each of the following questions as accurately as possible by filling in the blanks or checking the most appropriate box. All information provided is confidential and no information will be released without your written consent.

*Today's Date _______________*

## GENERAL INFORMATION

*Mr.* ○ *Ms.* ○ *Miss* ○ *Mrs.* ○ *Dr.* ○

*Last Name* _____________________________ *First Name* _____________________

*Mailing Address* ___________________________________________________

___________________________________________________

_

*Home Phone* _________________________ *Office Phone* ______________________

*Occupation* ________________________________________________________

*Employer* ________________________________________________________

*Person to Contact in Emergency:* *Name* ___________________________________

*Relationship* ______________________________

*Phone* _____________________________

- *Descriptive information:*

*Gender:* *Male* ○ *Female* ○

*Age* ________________ *Date of Birth* _________________

· *Why are you filling out this questionnaire?*

○ *Your have volunteered for a research study or project.*

○ *You are being screened for fitness testing in the Movement Science Lab.*

○ *Other reason...*_____________________________________________

## MEDICAL HISTORY

*Name of your physician* ______________________________

*(Address/phone?)* ______________________________

- *Family History:*

  *Did your father, or other first degree male relative (like a brother) die before the age of 55?*

  *No* ○ *Yes* ○ *If Yes, cause?* ____________

  *Age at death?* ____________

  *Which relative?* ____________

  *Did your mother, or other first degree female relative (like a sister) die before the age of 65?*

  *No* ○ *Yes* ○ *If Yes, cause?* ____________

  *Age at death?* ____________

  *Which relative?* ____________

- *List any food or drug allergies:* ______________________________

  ______________________________

  ______________________________

  ______________________________

- *List any medication you are currently taking (non-prescription and prescription, including oral contraceptives). Please comment on the reason for each medication.*

______________________________

______________________________

______________________________

______________________________

______________________________

- *Please describe any recent illnesses, hospitalizations, or surgical procedures:*

______________________________

______________________________

______________________________

______________________________

______________________________

· *Any of these health symptoms that occurs frequently, either at rest or during physical exertion, is the basis for a prompt medical evaluation. Circle the number indicating how often you have each of the following:*

***0*** *= Never* ***1*** *= Practically never* ***2*** *= Infrequently*

***3*** *= Sometimes* ***4*** *= Fairly often* ***5*** *= Very often*

| | | | | | | |
|---|---|---|---|---|---|---|
| *a. Coughing up blood.* | *0* | *1* | *2* | *3* | *4* | *5* |
| *b. Abdominal pain.* | *0* | *1* | *2* | *3* | *4* | *5* |
| *c. Low-back pain.* | *0* | *1* | *2* | *3* | *4* | *5* |
| *d. Chest pain.* | *0* | *1* | *2* | *3* | *4* | *5* |
| *e. Neck, jaw, arm, or shoulder pain.* | *0* | *1* | *2* | *3* | *4* | *5* |
| *f. Leg pain.* | *0* | *1* | *2* | *3* | *4* | *5* |
| *g. Swollen joints, especially the ankles.* | *0* | *1* | *2* | *3* | *4* | *5* |
| *h. Feel faint.* | *0* | *1* | *2* | *3* | *4* | *5* |
| *i. Feeling of dizziness.* | *0* | *1* | *2* | *3* | *4* | *5* |
| *j. Breathless with slight exertion.* | *0* | *1* | *2* | *3* | *4* | *5* |
| *k. Palpitation or fast heart rate.* | *0* | *1* | *2* | *3* | *4* | *5* |
| *l. Unusual fatigue with normal activity.* | *0* | *1* | *2* | *3* | *4* | *5* |
| *m. Abnormal/labored breathing at night.* | *0* | *1* | *2* | *3* | *4* | *5* |

*For any score of “4" or higher, use the space below to explain the frequency and the conditions under which you experience that particular symptom:*

· *Please indicate which of the following for which* ***you have been diagnosed or treated*** *by a physician or health professional. Please be as complete as possible.*

| *Check if "Yes"* | *If "Yes", please comment further...* |
|---|---|
| ○ *Alcoholism* | |
| ○ *Anemia, sickle cell* | |
| ○ *Anemia, other* | |
| ○ *Asthma* | |
| ○ *Back strain* | |
| ○ *Blood pressure - High?* | |
| *Low?* | |
| ○ *Bronchitis* | |
| ○ *Cancer* | |
| ○ *Cirrhosis, liver* | |
| ○ *Cholesterol - High?* | |
| ○ *Concussion* | |
| ○ *Congenital defect* | |
| ○ *Diabetes Type?* | |
| ○ *Emphysema* | |
| ○ *Epilepsy* | |
| ○ *Eye problems* | |
| ○ *Gout* | |
| ○ *Hearing loss* | |
| ○ *Heart problems* | |
| ○ *Hypoglycemia* | |
| ○ *Hyperlipidemia* | |
| ○ *Infectious mononucleosis* | |
| ○ *Kidney problems* | |
| ○ *Menstrual irregularities* | |
| ○ *Mental illness* | |
| ○ *Obesity* | |
| ○ *Phlebitis* | |
| ○ *Rheumatoid arthritis* | |
| ○ *Stroke* | |
| ○ *Thyroid problems* | |
| ○ *Ulcer* | |
| ○ *Other* | |

## BLOOD CHEMISTRY PROFILE

· *Have you ever had a fasting blood sample analyzed for cholesterol?* ○ *Yes* ○ *No*

*If "Yes", when was last time your blood was analyzed?*

___________________________

*If "Yes", please provide as much detail as possible with regard to the specific blood components requested below. Ideally, we would like both the numerical value of the test result AND the units of the measurement (the units are typically reported along with the numerical value of the test result).*

- *Total serum cholesterol* __________ *units?* ______
- *HDL (high density lipoprotein)* __________ *units?* ______
- *LDL (low density lipoprotein)* __________ *units?* ______
- *VLDL (very low density lipoprotein)* __________ *units?* ______
- *Triglycerides* __________ *units?* ______
- *Blood glucose* __________ *units?* ______
- *Hemoglobin* __________ *units?* ______
- *Hematocrit* __________ *units?* ______
- *Iron* __________ *units?* ______

## HEALTH-RELATED BEHAVIORS

· *Do you now smoke?* ○ *Yes* ○ *No*

*If "Yes", indicate the number smoked per day (on average):*

*Cigarettes:* *40 or more* *20-39* *10-19* *1-9*

*Cigars/pipes - describe:*_______________________________________

· *Have you recently quit smoking?* ○ *Yes* ○ *No*

*If "Yes", how long ago did you quit?* ________ *years* _______ *months*

· *Do you drink alcoholic beverages on a regular basis?* ○ *Yes* ○ *No*
*(i.e. at least once/week)*

*If "Yes", please answer the following:*
*1) How frequently do you drink?*

*2) What alcoholic beverages do you typically consume?*

· *Do you* ***exercise*** *regularly?* ○ *Yes* ○ *No*
*If "Yes", describe in terms of frequency, duration, intensity, and type of exercise:*

· *Do you consider yourself* **physically active** *due to work-related demands, home or farm chores, etc.?* ○ *Yes* ○ *No*
*If "Yes", describe in terms of frequency, duration, intensity, and type of exercise:*

· *Please describe anything not already described on this questionnaire that might cause you problems during exercise (use the space below).*

· *Are there any other health-related problems or concerns NOT addressed on this questionnaire that we should know about?*

○ *Yes* ○ *No*

*If "Yes", please describe:*

*****For Lab Personnel Use Only*****

- Contraindications to exercise or exercise testing?

- CAD risk factors?

- Issues that need clarification from the subject/patient?

- Initial risk stratification?  Circle one...

| | |
|---|---|
| ***Low Risk*** | Younger individuals (men < 45 yrs, women < 55 yrs) who are symptomatic and meet no more than one risk factor threshold (see Table 2-1 of ACSM text). |
| ***Moderate Risk*** | Older individuals (men ≥ 45 yrs, women ≥ 55 yrs) or those who meet the threshold for two OR more risk factors thresholds (see Table 2-1 of ACSM text). |
| ***High Risk*** | Individuals with one or more cardiopulmonary signs/symptom (see Box 2-1 of ACSM text) OR known cardiovascular, pulmonary, or metabolic disease. |

# APPENDIX B: SUBJECT EXPERIENCE QUESTIONNAIRE

## Subject Experience Questionnaire

You are being asked to rate the amount of experience you have at rock climbing in any environment, either outdoors or indoors. Consider your degree of familiarity with climbing-specific movements, your degree of mastery of these, and the skill or difficulty level at which you climb. In addition, consider the number of years spent climbing. Please choose which of the following keywords best describes your own climbing experience level:

| | |
|---|---|
| ▪ None | No prior climbing experience. |
| ▪ Little | Some climbing experience, not very proficient. |
| ▪ Moderate | A moderate amount of experience and proficiency. |
| ▪ Extensive | A great deal of experience and mastery, very skilled. |

If you are unsure of an answer, the project director will assist you in choosing the most appropriate experience level.

# APPENDIX C: TABLE OF RAW DATA

Table C-1. Variable Definition Key for Table C-2.

| Abbreviation Used in Table C-2 | Variable Name from Text | Abbreviation Used in Table C-2 | Variable Name from Text |
|---|---|---|---|
| SUBJ | Subject case number. | LCALF1 | Pre-test left-calf circumference. |
| SUBJECTID | Subject ID#. | LCALF2 | Post-test left-calf circumference. |
| GROUP | Group. | RGRIP1 | Pre-test right-hand grip strength. |
| GENDER | Gender. | RGRIP2 | Post-test right-hand grip strength. |
| AGE | Age. | LGRIP1 | Pre-test left-hand grip strength. |
| EXPERIENCE | Experience. | LGRIP2 | Post-test left-hand grip strength. |
| HEIGHT | Height. | LAT1 | Pre-test lat-pull 1RM. |
| WEIGHT1 | Pre-test body mass. | LAT2 | Post-test lat-pull 1RM. |
| WEIGHT2 | Post-test body mass. | HANG1 | Pre-test time-to-exhaustion in the Bent-arm Hang Test. |
| BMI | Body mass index. | HANG2 | Post-test time-to-exhaustion in the Bent-arm Hang Test. |
| ARMSPAN1 | Pre-test armspan. | IOTFEET1 | Pre-test feet climbed in the Incremental Overhang Test. |
| ARMSPAN2 | Post-test armspan. | IOTFEET2 | Post-test feet climbed in the Incremental Overhang Test. |
| APE1 | Pre-test ape-index. | IOTTIME1 | Pre-test time-to-exhaustion in the Incremental Overhang Test. |
| APE2 | Post-test ape-index. | IOTTIME2 | Post-test time-to-exhaustion in the Incremental Overhang Test. |
| RARM1 | Pre-test right-arm circumference. | VO2TIME1 | Pre-test time-to-exhaustion in the $\dot{V}O_{2peak}$ Ramp Test. |
| RARM2 | Post-test right-arm circumference. | VO2TIME2 | Post-test time-to-exhaustion in the $\dot{V}O_{2peak}$ Ramp Test. |
| LARM1 | Pre-test left-arm circumference. | VO2ABS1 | Pre-test $\dot{V}O_{2peak}$ expressed in $L \cdot min^{-1}$. |
| LARM2 | Post-test left-arm circumference. | VO2ABS2 | Post-test $\dot{V}O_{2peak}$ expressed in $L \cdot min^{-1}$. |
| RCALF1 | Pre-test right-calf circumference. | VO2REL1 | Pre-test $\dot{V}O_{2peak}$ expressed in $ml \cdot kg^{-1} \cdot min^{-1}$. |
| RCALF2 | Post-test right-calf circumference. | VO2REL2 | Post-test $\dot{V}O_{2peak}$ expressed in $ml \cdot kg^{-1} \cdot min^{-1}$. |

Table C-2. Table of raw data.

| SUBJ | SUBJECTID | GROUP | GENDER | AGE | EXPERIENCE | HEIGHT | WEIGHT1 | WEIGHT2 | BMI |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | 24 | 2 | 175 | 62.7 | 62 | 20.5 |
| 2 | 2 | 0 | 1 | 21 | 1 | 177.5 | 88.6 | 89 | 28.1 |
| 3 | 3 | 0 | 0 | 22 | 3 | 176.9 | 65.7 | 67.4 | 21 |
| 4 | 5 | 0 | 1 | 24 | 4 | 180.5 | 90 | 91.2 | 27.6 |
| 5 | 9 | 0 | 1 | 27 | 3 | 163.7 | 75.9 | 76.6 | 28.3 |
| 6 | 12 | 0 | 0 | 20 | 3 | 166.7 | 58.9 | 60.2 | 21.2 |
| 7 | 14 | 0 | 1 | 21 | 2 | 187.5 | 73.8 | 73 | 21 |
| 8 | 18 | 0 | 0 | 23 | 2 | 167.5 | 56.5 | 58.2 | 20.1 |
| 9 | 20 | 0 | 0 | 25 | 1 | 168 | 70.5 | 70.7 | 25 |
| 10 | 22 | 0 | 0 | 22 | 1 | 159 | 57.7 | 57.2 | 22.8 |
| 11 | 25 | 0 | 1 | 24 | 1 | 178 | 91.4 | 90.4 | 28.8 |
| 12 | 26 | 0 | 0 | 18 | 1 | 169 | 64.5 | 63 | 22.6 |
| 13 | 28 | 0 | 1 | 20 | 2 | 172 | 64.5 | 67 | 21.8 |
| 14 | 29 | 0 | 0 | 23 | 1 | 158.5 | 59.2 | 58.7 | 23.6 |
| 1 | 4 | 1 | 1 | 19 | 3 | 164.5 | 61.1 | 60.5 | 22.6 |
| 2 | 6 | 1 | 0 | 22 | 1 | 164.1 | 54.5 | 54.4 | 20.2 |
| 3 | 7 | 1 | 1 | 24 | 2 | 173 | 68.2 | 68 | 22.8 |
| 4 | 10 | 1 | 0 | 21 | 1 | 158.5 | 61.8 | 60 | 24.6 |
| 5 | 11 | 1 | 0 | 19 | 1 | 151 | 53.6 | 52.4 | 23.5 |
| 6 | 13 | 1 | 0 | 20 | 2 | 168 | 57.7 | 59.7 | 20.4 |
| 7 | 15 | 1 | 1 | 21 | 2 | 187.5 | 69.6 | 69.3 | 19.8 |
| 8 | 16 | 1 | 1 | 20 | 2 | 188.5 | 80.1 | 81.14 | 22.5 |
| 9 | 17 | 1 | 1 | 20 | 1 | 171.5 | 81.8 | 80.5 | 27.8 |
| 10 | 19 | 1 | 0 | 20 | 1 | 169 | 58.6 | 57.5 | 20.5 |
| 11 | 23 | 1 | 0 | 23 | 2 | 161 | 61.4 | 61.5 | 23.7 |
| 12 | 24 | 1 | 0 | 20 | 1 | 168 | 62.7 | 61.1 | 22.2 |
| 13 | 27 | 1 | 1 | 37 | 1 | 177.5 | 89.5 | 88.2 | 28.4 |

Table C-2.  Table of raw data (continued).

| SUBJ | SUBJECTID | ARMSPAN1 | ARMSPAN2 | APE1 | APE2 | RARM1 | RARM2 | LARM1 | LARM2 | RCALF1 | RCALF2 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 178.5 | 178.5 | 1.02 | 1.02 | 24.1 | 24.5 | 23.3 | 23.8 | 34.5 | 33 |
| 2 | 2 | 176 | 175 | 0.99 | 0.99 | 29.9 | 30.3 | 29 | 29 | 39.7 | 39.7 |
| 3 | 3 | 177 | 178.5 | 1 | 1.01 | 25 | 25.5 | 25.6 | 25.8 | 36 | 35.9 |
| 4 | 5 | 185 | 185.5 | 1.02 | 1.03 | 29.5 | 30.1 | 29.4 | 29.8 | 43.3 | 43.3 |
| 5 | 9 | 165.5 | 168.5 | 1.01 | 1.03 | 28.5 | 28.2 | 27.2 | 27.9 | 38 | 37.5 |
| 6 | 12 | 164.5 | 165.5 | 0.99 | 0.99 | 24.4 | 25 | 23.8 | 24.3 | 37.4 | 37.1 |
| 7 | 14 | 190 | 192 | 1.01 | 1.02 | 25.8 | 25.4 | 25.3 | 25 | 34.2 | 33.9 |
| 8 | 18 | 174 | 174 | 1.04 | 1.04 | 22 | 22.3 | 20.9 | 22.3 | 33.6 | 33.2 |
| 9 | 20 | 168 | 169.3 | 1 | 1.01 | 25 | 25.5 | 24.9 | 25.3 | 36.2 | 36.2 |
| 10 | 22 | 158.5 | 158.5 | 1 | 1 | 23.6 | 23.7 | 23.1 | 22.7 | 38.4 | 38.4 |
| 11 | 25 | 181 | 183 | 1.02 | 1.03 | 30.2 | 30.1 | 30.9 | 31 | 40.2 | 40 |
| 12 | 26 | 170 | 171.5 | 1.01 | 1.01 | 23.3 | 23.6 | 23.3 | 23.7 | 38.3 | 36.6 |
| 13 | 28 | 180 | 180 | 1.05 | 1.05 | 25.4 | 26.1 | 24.8 | 25.7 | 36.3 | 36.3 |
| 14 | 29 | 153 | 154.5 | 0.97 | 0.97 | 24.7 | 25.2 | 24.6 | 25.4 | 40 | 38.7 |
| 1 | 4 | 175 | 175.5 | 1.06 | 1.07 | 26.5 | 26.6 | 25.7 | 25.6 | 33.2 | 33 |
| 2 | 6 | 160.5 | 160.5 | 0.98 | 0.98 | 22.7 | 22.6 | 22 | 22.8 | 33.5 | 34.3 |
| 3 | 7 | 175 | 175.5 | 1.01 | 1.01 | 27 | 26.8 | 26.6 | 26.5 | 36.4 | 34.4 |
| 4 | 10 | 157 | 156.5 | 0.99 | 0.99 | 23.5 | 24.5 | 23.4 | 23.9 | 37 | 36.1 |
| 5 | 11 | 153.5 | 156 | 1.02 | 1.03 | 23.5 | 23.6 | 23 | 23 | 37.5 | 37.2 |
| 6 | 13 | 170 | 170 | 1.01 | 1.01 | 23.3 | 24.6 | 23.1 | 23.2 | 35 | 35.7 |
| 7 | 15 | 190.5 | 188 | 1.02 | 1 | 25.5 | 24.9 | 25.2 | 25 | 33.2 | 33 |
| 8 | 16 | 188 | 188.5 | 1 | 1 | 27.6 | 27.8 | 28.2 | 28.7 | 37.9 | 36 |
| 9 | 17 | 178.5 | 178 | 1.04 | 1.04 | 29.8 | 30.8 | 29.4 | 30 | 41.5 | 41.4 |
| 10 | 19 | 163 | 163 | 0.96 | 0.96 | 22.5 | 22.4 | 21.7 | 21.7 | 34.7 | 34.3 |
| 11 | 23 | 159 | 159 | 0.99 | 0.99 | 22.5 | 22.6 | 21.5 | 22.6 | 36.4 | 36.6 |
| 12 | 24 | 169.5 | 168 | 1.01 | 1 | 23.1 | 23.2 | 22.5 | 22.6 | 37.2 | 36.1 |
| 13 | 27 | 177 | 177 | 1 | 1 | 30.3 | 29.4 | 29.5 | 29.7 | 39.5 | 38.7 |

Table C-2. Table of raw data (continued).

| SUBJ | SUBJECTID | LCALF1 | LCALF2 | RGRIP1 | RGRIP2 | LGRIP1 | LGRIP2 | LAT1 | LAT2 | HANG1 | HANG2 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 34.3 | 34 | 53 | 55 | 46 | 45 | 150 | 165 | 43.4 | 55.75 |
| 2 | 2 | 39.9 | 39.6 | 52 | 56 | 48 | 54 | 195 | 205 | 18 | 29.8 |
| 3 | 3 | 36.5 | 35.4 | 56.5 | 51 | 56 | 49 | 170 | 185 | 43.25 | 45.7 |
| 4 | 5 | 43.2 | 43.6 | 73 | 76 | 65 | 68 | 245 | 252.5 | 54.3 | 68.2 |
| 5 | 9 | 37.5 | 37 | 55 | 48 | 50 | 44 | 200 | 195 | 45.7 | 39.84 |
| 6 | 12 | 37.5 | 37.1 | 39 | 38.5 | 36 | 32.5 | 145 | 140 | 41.4 | 34.3 |
| 7 | 14 | 34.5 | 34.2 | 61 | 56 | 53.5 | 51 | 215 | 215 | 80.2 | 84.42 |
| 8 | 18 | 34 | 33.8 | 39 | 39.5 | 36 | 37.5 | 115 | 120 | 33.7 | 34.4 |
| 9 | 20 | 36.7 | 36.8 | 38 | 37.5 | 35 | 36 | 150 | 157.5 | 26 | 30.75 |
| 10 | 22 | 37.6 | 37.8 | 31.5 | 37 | 29 | 35 | 95 | 105 | 10 | 12.2 |
| 11 | 25 | 40.9 | 40.7 | 60 | 60 | 62 | 57 | 200 | 205 | 29 | 28.2 |
| 12 | 26 | 36.8 | 36.8 | 32.5 | 34 | 32.5 | 36 | 130 | 120 | 19.2 | 22.3 |
| 13 | 28 | 36.4 | 36.3 | 56 | 55 | 54 | 48 | 195 | 202.5 | 53.35 | 45.7 |
| 14 | 29 | 38 | 38.6 | 38 | 38 | 36 | 36 | 137.5 | 135 | 37.21 | 45.7 |
| 1 | 4 | 33 | 32.6 | 60 | 60 | 52 | 50 | 195 | 205 | 56.9 | 53.04 |
| 2 | 6 | 34.5 | 34.4 | 31 | 29 | 31 | 32 | 100 | 110 | 22.2 | 22.3 |
| 3 | 7 | 35.2 | 34.4 | 59 | 52 | 54 | 49.5 | 200 | 205 | 62.1 | 66.03 |
| 4 | 10 | 37.7 | 36.8 | 29.5 | 30.5 | 29.5 | 29.5 | 105 | 110 | 14.1 | 20.24 |
| 5 | 11 | 37.3 | 37.2 | 34 | 33 | 31 | 26 | 120 | 117.5 | 10.1 | 7.8 |
| 6 | 13 | 35.1 | 36.4 | 39 | 41 | 41 | 40 | 130 | 140 | 32 | 36.87 |
| 7 | 15 | 32.5 | 33 | 58 | 56 | 55 | 53 | 187.5 | 180 | 75.2 | 73.2 |
| 8 | 16 | 38 | 36.5 | 62.5 | 61 | 63.5 | 66 | 200 | 210 | 58 | 65.23 |
| 9 | 17 | 40.7 | 40.5 | 56 | 62 | 52.5 | 60 | 205 | 220 | 37.3 | 48.3 |
| 10 | 19 | 33.7 | 33.3 | 31.5 | 31.5 | 31.5 | 31 | 110 | 105 | 12 | 20.6 |
| 11 | 23 | 35.8 | 35.8 | 33 | 31 | 29 | 29 | 117.5 | 120 | 23.1 | 25.1 |
| 12 | 24 | 37.2 | 36.1 | 29 | 31 | 27 | 28 | 95 | 90 | 0.1 | 1.1 |
| 13 | 27 | 38.6 | 38.7 | 58 | 58 | 55 | 57 | 245 | 255 | 37 | 47.19 |

Table C-2. Table of raw data (continued).

| SUBJ | SUBJECTID | IOTFEET1 | IOTFEET2 | IOTTIME1 | IOTTIME2 | VO2TIME1 | VO2TIME2 | VO2ABS1 | VO2ABS2 | VO2REL1 | VO2REL2 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 155 | 181 | 5.51 | 6.43 | 13.3 | 15 | 3.44 | 2.94 | 53.58 | 45.6 |
| 2 | 2 | 129 | 142 | 4.68 | 5.13 | 10.25 | 10.37 | 2.77 | 3.15 | 29.95 | 34 |
| 3 | 3 | 169 | 157 | 6 | 5.62 | 11.7 | 11.38 | 2.24 | 2.15 | 32.7 | 30.43 |
| 4 | 5 | 178 | 200 | 6.32 | 7.08 | 13.12 | 15.75 | 3.27 | 3.6 | 35.3 | 38.22 |
| 5 | 9 | 137 | 159 | 4.97 | 5.68 | 10.53 | 12.55 | 2.97 | 3.09 | 37 | 38.67 |
| 6 | 12 | 155 | 152 | 5.55 | 5.45 | 11.92 | 12.08 | 2.17 | 2.64 | 34.16 | 41.5 |
| 7 | 14 | 166 | 201 | 5.93 | 7.08 | 12.68 | 16 | 2.86 | 2.79 | 36.9 | 37.5 |
| 8 | 18 | 140 | 170 | 5.07 | 6.07 | 11.58 | 14.72 | 2.73 | 1.99 | 48.3 | 32.5 |
| 9 | 20 | 105 | 155 | 3.92 | 5.57 | 9.4 | 10.37 | 2.25 | 2.65 | 30.35 | 35.4 |
| 10 | 22 | 125 | 163 | 4.55 | 5.83 | 8.92 | 11.02 | 1.68 | 2.02 | 27.9 | 33 |
| 11 | 25 | 124 | 151 | 4.52 | 5.43 | 9.12 | 10.47 | 3.18 | 2.88 | 34 | 30.54 |
| 12 | 26 | 116 | 125 | 3.95 | 4.57 | 6.45 | 7.15 | 1.72 | 1.73 | 25.2 | 26.4 |
| 13 | 28 | 164 | 199 | 5.85 | 7.02 | 14.53 | 16 | 2.94 | 3.19 | 42.65 | 46 |
| 14 | 29 | 134 | 168 | 4.85 | 6 | 11.63 | 12.32 | 2.7 | 2.03 | 43.45 | 32.17 |
| 1 | 4 | 165 | 200 | 5.9 | 7.07 | 13.55 | 14.4 | 2.5 | 2.69 | 38.03 | 42.03 |
| 2 | 6 | 136 | 131 | 4.92 | 4.77 | 8.88 | 9.32 | 2.63 | 1.77 | 45.6 | 30.5 |
| 3 | 7 | 160 | 174 | 5.73 | 6.2 | 14.47 | 16 | 3.75 | 3.12 | 52.08 | 43.87 |
| 4 | 10 | 101 | 138 | 3.75 | 5 | 8.88 | 9.33 | 1.96 | 1.98 | 30 | 31.6 |
| 5 | 11 | 126 | 149 | 4.58 | 5.35 | 8.58 | 8.97 | 1.61 | 1.7 | 28.6 | 30.6 |
| 6 | 13 | 139 | 158 | 5.03 | 5.67 | 10.58 | 11.55 | 2.04 | 2.26 | 33.1 | 35.67 |
| 7 | 15 | 156 | 186 | 5.6 | 6.58 | 11.65 | 13.83 | 2.6 | 2.58 | 35.4 | 35.83 |
| 8 | 16 | 167 | 191 | 5.95 | 6.77 | 15.75 | 16 | 3.35 | 3.46 | 40.66 | 41.15 |
| 9 | 17 | 162 | 191 | 5.8 | 6.77 | 13.77 | 14.62 | 3.12 | 2.68 | 36.67 | 32.04 |
| 10 | 19 | 103 | 137 | 3.82 | 4.97 | 8.18 | 9.27 | 1.62 | 1.72 | 28.83 | 27.75 |
| 11 | 23 | 143 | 159 | 5.15 | 5.68 | 12.63 | 13.12 | 2.08 | 2.49 | 32.23 | 38.31 |
| 12 | 24 | 101 | 125 | 3.75 | 4.55 | 6.68 | 7.48 | 1.74 | 1.85 | 26.2 | 29 |
| 13 | 27 | 136 | 151 | 4.92 | 5.43 | 10.37 | 10.45 | 2.81 | 2.68 | 30.54 | 29.55 |