Determination of a training zone by heart rate curves for three activities in cross-country skiers

Katherine A. Faryniarz
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DETERMINATION OF A TRAINING ZONE BY HEART RATE CURVES
FOR THREE ACTIVITIES IN CROSS-COUNTRY SKIERS

By
Katherine A. Faryniarz
B.S., University of Vermont, 1984

Presented in partial fulfillment of the requirements
for the degree of
Master of Science
University of Montana
1987

Approved by

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Chairman, Board of Examiners

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Dean, Graduate School

[Signature]
Date
May 28, 1987
The determination of heart rate deflection point signifying the anaerobic threshold (as described by Conconi et al. 1982, *J. Appl. Physiol.* 52:864-873) in the heart rate workload curve, and the effects of exercises with varying amounts of muscle mass on the deflection point were investigated in 14 national-level Nordic ski racers.

Heart rate deflection points were determined for 11 of 14 subjects in rollerskiing and for all subjects in running and cycling. Significant differences were found between deflection points in rollerskiing versus cycling (p = 0.007) and for running versus cycling (p = 0.03), but not for rollerskiing versus running (p = 0.74).

Although not statistically significant, several individual trends with rollerskiing producing higher heart rates than running were present.

The diversity among the subjects related to age, fitness level, training modes, time of year, as well as technique factors and the nature of arm activities may explain the variability among the heart rate data. It appears that the heart rate deflection point differences may be related to amount of muscle mass employed which results in varying levels of muscle afferent stimulation of the cardiovascular control center: the more muscle mass involved in the exercise the higher the heart rates.
ACKNOWLEDGMENTS

The author wishes to thank Dr. Brian Sharkey, Dr. James Stray-Gundersen, Dr. Donald Hardin and Professor Patterson for their time, teaching and interest given to me.

A special thanks is extended to Robert H. Sleamaker whose shining example started me on this road. Lastly, I dedicate this work to Bruce for his patience and support given generously throughout this pursuit.

Afoot and light-hearted I take to the open road,
Healthy, free, the world before me,
The long brown path before me leading wherever I choose.

Henceforth I ask not good-fortune, I myself am good-fortune,
Henceforth I whimper no more, postpone no more, need nothing,
Done with indoor complaints, libraries, querulous criticisms,
Strong and content I travel the open road.

Walt Whitman,
"Song of the Open Road"
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CHAPTER ONE

THE PROBLEM

Introduction

Cross-country ski racing is a unique sport. It is one of the most demanding in terms of oxygen consumption because it engages most of the major muscle groups. Whether using the traditional diagonal stride or skating techniques, both the upper and lower body as well as the trunk muscles are utilized. Much of the volume of pre-competition training occurs in the late summer and fall months when snow is unavailable for skiing. This "dryland" training predominately involves rollerskiing/skating (mimicking skiing motions on pavement using short two-wheeled metal skis or skates), cycling and running.

Cross-country ski training prescriptions have evolved over the years to include three basic levels of intensity:

1. long-slow distance
2. pace work
3. intervals.

The United States Nordic Ski Team currently uses five levels of intensity for training, based on heart rate. These have been adapted from the Norwegian Coaching System (Karlsen 1986).
Level 3 is thought to be equated with the anaerobic threshold (AT), which indicates the transition from predominantly aerobic to anaerobic metabolism. AT is commonly defined as that work load intensity where the rate of lactate production exceeds the rate of removal resulting in an increase in blood lactate level (Macdougall 1977), and a deviation from linearity in the relationship between oxygen consumption and ventilation due to a strong ventilatory stimulus provided by both an increased acidity and the release of CO₂ (McArdle and Magel 1970). Brooks and Fahey (1984) attempt to clarify the term by stating that the blood lactate increases because pyruvate production from glycolysis exceeds the capacity of the mitochondria for its use. Up to a critical intensity the lactic acid can be reoxidized or buffered, beyond that point excess accumulation occurs and performance is
limited.

Training at or near the AT develops the aerobic abilities of fast-oxidative glycolytic fibers, raising the intensity of effort which can be sustained aerobically (Sharkey 1984). This ability to maintain a high intensity of effort is crucial to skiers who want to ski at a fast rate for long distances.

Level-3 type training is used predominantly in the late-fall and early-winter training sessions. These training sessions can be on or off snow. A preferred session on snow would be doing a relaxed time trial, trying to ski at a fast tempo, challenging the body under hard aerobic work and training neuromuscular pathways (Kass 1981, Karlsen 1986).

Previous attempts to assign heart rate (HR) parameters for different intensities of exercise have been based on either predicted or measured maximal heart rates. Training prescriptions based on predicted maximal heart rates ignore the individual differences in maximal heart rates, for the same age, especially in well-trained athletes. Measured maximal heart rate prescriptions assume that the exercise intensities are a certain percentage of maximal heart rates in everyone, and do not vary with level of fitness. For example, one athlete could have a higher percent of maximal HR at AT than another and training at a pre-prescribed HR
may not elicit the same desired training effect. Also, one maximal HR obtained through a maximal O\textsubscript{2} consumption test (usually running on a treadmill) has generally been used to base training intensities for all types of activities for the same person, although varying amounts of muscle mass may be used in different activities, which could influence the heart rate. Informal investigations with the U.S. Ski Team (Stray-Gundersen 1987) looked at differences in the body's response (HR, VO\textsubscript{2}, lactate) between various techniques in cross-country skiing. Higher heart rates were found with skating technique compared to traditional diagonal techniques. It has been postulated that the skating involves more muscle groups. There appears some support for this concept in the literature. Stenberg et al. (1967) and Vokac et al. (1975) reported that the HR at a given O\textsubscript{2} uptake is higher when exercise is performed with the arms than with the legs. In addition, Mitchell et al. (1981) found the larger the muscle mass involved the more pronounced the blood pressure and HR response.

Heart rate response is not thoroughly understood but a reflex control of the cardiovascular function (HR, SV, CO) is thought to be triggered from at least two independent mechanisms; one being a central command, related to the activation of the motor units, and a peripheral control mediated by muscle afferents reporting the metabolic...
changes in the contracting muscle (Astrand and Rodahl 1986).

There has been much interest recently in observing these physiological associations with training intensities in endurance athletes. The U.S. Ski Team has been interested in exploring these training zones, especially level 3, for the aforementioned reasons. Due to the shortcomings in predictions of heart rate intensities among individuals, a specific physiological marker to identify this zone that could be used on a daily basis, after verification by laboratory methods, would prove useful.

Previous heart rate predictions are based on the concept that the $HR/VO_2$ (work load) relationship during incremental exercise tests is linear throughout (Astrand and Hyming 1954, Margaria et al. 1963).

Conconi et al. (1982) challenged the concept of linearity by describing a field test to measure the AT in runners. Such a test, if valid, would be useful in prescribing training, monitoring progress, and perhaps performance prediction. The relationship between heart rate and running speed (work load) was examined in 210 subjects who ran progressively faster 200-meter intervals continuously on a track. Blood lactate levels were subsequently measured on ten subjects simulating running on the track at various speeds as predetermined by the
HR/running speed (RS) relationship. Conconi et al. observed a deflection in the HR/RS relationship from linearity, a flattening in the ascent of the curve, in all athletes at submaximal running speeds with a test-retest correlation of 0.99 in the 26 subjects who were retested within one week. In the ten subjects who were examined for lactate levels at various speeds, Conconi et al. cite a correlation of 0.99 between HR deflection point and AT. The explanation for this high correlation and the departure from linearity in the HR curve was at least in part caused by the addition of the anaerobic mechanisms of ATP production to the aerobic mechanisms. The phenomenon probably depends on an increase in VO$_2$ higher than the augmentation in HR and cardiac output which has been shown to occur at high work loads (Saltin and Astrand 1967).

**Statement of the Problem**

The purpose of this study was to apply the Conconi concept, with a modified test for ski training, and to explore the heart rate response to three conditioning modes (rollerskiing, running and cycling) in the same athlete. Observations by Conconi et al. (1982) dealt with athletes in one sport. Observations of athletes training in multiple activities have not appeared in the literature at this time. The information gained could be of importance
to the training of cross-country skiers and perhaps other endurance athletes who use various conditioning modes in their training.

As primarily an exploratory study, the following null hypothesis was constructed:

The mean difference between HR deflection points for rollerskiing, running and cycling will be zero.

The alternative hypotheses will be:

1. The mean difference in HR deflection point will not be zero.

2. Rollerskiing will produce the highest HR deflection point, followed by running and cycling.

Limitations

Only one test for each activity (running, cycling and rollerskiing) was performed with each subject due to the length of stay of the skiers at the testing site; therefore, reliability studies were not performed.

Definitions

Heart rate deflection point (HRDP): The point at which departure from linearity of the heart rate/work load (speed) curve occurs when plotted against each other; an obvious flattening in the progression of the curve.

Linearity: When plotting the HR and work load (speed) an increase in heart rate from one point in time to the next
is proportional to the difference in time (work load).

**Training zones:** Levels of training intensity based on the percent of maximal heart rate, used by the U.S. Ski Team.

**VO₂ max:** The highest obtainable oxygen uptake by working muscles as measured by circuit spirometry.
CHAPTER TWO
REVIEW OF THE LITERATURE

Importance of Anaerobic Threshold and Endurance Training

The effects of endurance training on the anaerobic threshold are coming into the literature in recent years. Astrand and Rodahl (1977) noted that endurance athletes could improve performance without a simultaneous increase in \( V_{O_2}^{\text{max}} \), which could be due to an increased AT. This level has been found to vary among athletes and may become a critical factor in determining an athlete's capacity for prolonged work.

LaFoutain et al. (1982), when comparing low intensity, medium intensity-high quantity, and high intensity-low quantity exercise found that the higher intensity workouts (expressed as a percentage of \( V_{O_2}^{\text{max}} \)), led to increases in AT. This was confirmed by Williams et al. (1968) and Davis et al. (1979).

Skinner and McLellan (1981) proposed three phases in the progression from low to maximal intensity exercise which take into account lactate levels and influences by muscle fiber type:

1. The transition from phase 1 to 2 (40 to 60 percent \( V_{O_2}^{\text{max}} \)) called the aerobic threshold with lactates in the 2 mmol/l range.
2. The transition from phase 2 to 3 (60 to 90 percent \( \text{VO}_2\text{max} \)) which is referred to as the AT with lactates at approximately 4 mmol/l increasing in a nonlinear fashion.

It is suggested from this study that the amount and intensity of training necessary to produce changes in the aerobic threshold and the anaerobic threshold are not fully understood at this time.

Sjodin et al. (1982) reported that steady state training at obla (onset of blood lactate accumulation, or 4 mmol of lactate) will increase time to obla and result in measurable local metabolic adaptations in the active skeletal muscle which will increase the potential to oxidize pyruvate/lactate, and slow the rate of glycogenolysis. Therefore it seems important to train at obla and slightly above. Higher intensity training (95 percent \( \text{VO}_2\text{max} \)) has resulted in no change in obla after 6 weeks when compared with training at obla.

The general sense of the literature seems to suggest that in order to elevate AT the athlete must train at the upper end of his aerobic steady state where the athlete may be recruiting oxidative and nonoxidative muscle fibers, oxidizing pyruvate and fatty acids (Skinner and Mclellan 1981).
Training Intensities Based on Percent of Heart Rate Max

Much discussion has occurred on the proper amount, type and intensity of exercise needed for a training stimulus for endurance athletes. Astrand and Rodahl (1977) stated that endurance training is needed for stimulating an increase in capillary density, myoglobin and enzyme activity involved in the metabolism of free fatty acids.

In addition, previous research has defined a number of changes taking place as a result of endurance training, including: lowered resting heart rate, increased work capacity, the development of slow twitch muscle fibers, increased size and number of mitochondria, enzyme activity and fat utilization (Sharkey 1984). Several investigators have chosen 70 percent of available heart rate range as the threshold for training (Karvonen et al. 1957, Fox and Skinner 1964, Cooper 1966). Edwards (1974), when examining 17 to 21 year-olds exercising 15 minutes a day for four weeks found that work intensities of HR 145 versus 125 were sufficient to stimulate the classic training effects (decreased submaximal heart rate, lower basal pulse rate and increased physical capacity). Sharkey and Holleman (1967) observed 16 college males divided into groups training at HR's of 120, 150 or 180 beats per minute (bpm), training for 10 minutes a day for three weeks. The data revealed that the HR 180 group had significantly better
endurance compared to the other two groups, as measured on the Balke treadmill post tests. The HR 150 group also performed significantly better on the post test than the HR 120 group. Support was cited for "intense" activity in order to bring about changes in cardiorespiratory endurance.

However, Karvonen et al. (1957) found a progressive reduction in resting heart rate when training for 30 minutes a day for four weeks at HR of 130 to 135 in young men. Astrand (1967) working with sedentary subjects observed "measurable effects" when training at HR's in the 120 bpm range. The opinion of many of the investigators was that the effects of training at the lower HR was that HR 120 was the minimal rate associated with the attainment of maximal stroke volume. Perhaps the lower intensity training, which has not been clearly and consistently used in the research, is most useful in the development at the local muscular level, increasing oxidative processes.

Most physical training studies, such as the above, are designed using the relative percent concept for HR or $O_2$ uptake intensities. Heart rate percent applied to the AT is the one most commonly used of late. Katch et al. (1978) evaluated the validity of the relative percent concept for equating training intensity. They investigated whether individuals training at the same percent of HRmax (i.e. 80
percent) obtained the same response in relation to AT and, more importantly, the same benefits of training at that level. As they found when reviewing 31 subjects training at 80 percent HRmax (62 percent VO₂max), 17 of the subjects were training at or above their measured AT, while 14 were training below the AT. Therefore the relative stress and training adaptations would be different between subjects. The study by Katch et al. also indicated that the regression of percent VO₂max on percent HRmax was a spurious one resulting in poor prediction of individual VO₂ values. Recommendations were made for considering AT as the method for equating the training stimulus between subjects.

One concept is apparent, that endurance athletes need to train at various levels in order to tax and develop the different energy systems used in their specific sport.

**Specificity in Testing and Training**

It is becoming widely accepted that specificity in testing physiological parameters, namely VO₂max and AT, is of utmost importance (Dixon and Faulkner 1971, Pechar et al. 1974, Stromme et al. 1977). Measurement of oxygen uptake, to be valid must utilize ergometry and testing methods which mimic the movements of the specific activity in which the athlete is engaged. Previous studies have
shown a wide intra-subject variability in VO₂max scores (Astrand and Holmes 1972, Bouchard 1979).

Stromme et al. (1977) showed the value of specificity in testing for maximal aerobic power in elite cross-country skiers. When testing the subjects on a standard running treadmill protocol, compared to uphill rollerskiing with poles on the treadmill, the rollerskiing resulted in significantly higher (P < 0.005) VO₂ values. The conclusion was made that in the evaluation of maximal aerobic power in athletes it is crucial to select a work situation which allows optimal use of the specifically trained muscle fibers. Such testing specificity can be extended to the testing and training of athletes who employ several activities, such as cross-country skiers who train by running, rollerskiing and cycling. In a recent study by Stray-Gundersen (1987), the differences in economy between traditional (diagonal) skiing and skating techniques were evaluated. Economy was measured as oxygen uptake, blood lactate levels, and heart rates averaged during the last 3 minutes of a 5 minute bout of rollerskiing on a treadmill at 5 mph and a 5 percent grade. Skating resulted in significantly higher (p < 0.001) oxygen uptake values, heart rates and lactate levels, leading the investigator to reject the hypothesis that skating was more economical than diagonal skiing. The results were qualified by suggesting
that the removal of kickwax (decreasing the resistance due to friction) and the ability to use arm and trunk movements to a greater extent may explain the improved performance of skating on snow. Skiers are generally highly trained but may be in better condition for one of the three methods and need a higher work load to maintain or improve their status.

In looking at the affect of training specificity on the AT, Wither et al. (1981) tested 10 endurance trained cyclists and 10 endurance trained runners, both on cycle ergometers and treadmills. When AT was expressed as a percentage of VO₂max, there were no statistical differences between the cyclists and runners; however when AT was expressed in ml/kg/min, independent t tests indicated that the cyclists had significantly greater AT's than the runners on the bicycle ergometer whereas the runners had higher AT's on the treadmill. Additionally the cyclists and runners worked at a statistically significant, lower percentage of HRmax in their specialty. The relative stress was less in the subject's specialty as each was working at a smaller percentage of VO₂max as well. Thus it was suggested that the adaptive responses to exercise are in part a function of specific movement patterns executed in training, and so measurement of VO₂max and AT must allow optimal innervation of the specifically trained
muscle fibers.

**Summary**

It appears that AT is important in endurance training and performance. Endurance athletes were shown to have higher AT's (Costill 1970), and AT can be elevated by certain kinds of training, of which the exact intensities have not been definitely proven.

Methods for equating training intensities appear to be available but further study is needed in this area. A strong concept presented is the need for specificity in testing and training, especially for multi-activity athletes. Further investigation is needed to determine reliable and valid indicators of training and intensity.
CHAPTER THREE
METHODS AND PROCEDURES

Scope

Fifteen subjects (12 males and 3 females), ages 17 to 35 years and members of the junior or senior U.S. Cross-Country Ski Teams, participated in this study. The subjects were recruited as part of a larger longitudinal study done at the University of Texas, Dallas Human Performance Laboratory, designed to observe long-term effects of continuous endurance training in young elite skiers. The effort was directed at identifying potential world class athletes and monitoring their physiological progress by the development of optimal training loads.

Methods

Informed consent was obtained from all subjects (Appendix A). Over approximately 7 to 8 days measurements were made of: body composition by underwater weighing, running VO_2max tests, height and weight measurements, and three separate incremental tests (running, cycling and rollerskiing) on the treadmill. These tests were separated by at least four hours to one day.
Specific Protocols

Cycling: On a Monarch ergometer equipped with racing handlebars, seat and toe clips each subject pedalled at a cadence of 80 rpm's (as maintained by lab personnel with a timer). Work loads started at 480 kpm and were increased by 80 kpm every minute until the subject was unable to continue the proper cadence or was too fatigued. Additional criteria concerning respiratory parameters as described at the end of this section were considered.

Running: At a grade of 0 percent and speed of 5 mph subjects ran on a motorized treadmill which was specially designed for running rollerskiing. The speed could be adjusted to increase from 1 to 15 mph and the grade from 10 to 50 percent. Measurements of the treadmill were 4-feet 3-inches wide by 8-feet long. Subjects increased the speed of running by one-half mph every minute until the respiratory parameters were satisfied or they were unable to continue.

Rollerskiing: At a grade of 5 percent and speed of 3 mph the subjects increased the speed by one-half mph every minute. With the same respiratory parameter considerations and the subject's ability to maintain a smooth tempo at the faster speeds the tests were continued. The same rollerskis were used for all subjects with the exception of
a few whose boots did not fit the particular bindings, in which case they used a similar pair of rollerskis. (See Figure 1).

**General Protocol**

Subjects warmed up prior to each test for 5 to 10 minutes at an easy load, HR 110 to 120. Heart rates were measured by the Quantum X-L Fitness monitor with memory. Each subject wore a monitor and watch receiver and a second backup receiver was held by one of the lab personnel to ensure reliability of the "on-person" monitor. Respiratory parameters, oxygen uptake, ventilation, and CO₂ production were measured by open circuit spirometry with a Rayfield Spirometer and Ametek O₂ and CO₂ analyzers which were on-line with an Apple-2 computer. Every thirty seconds plots were viewed and printed comparing ventilation/oxygen consumption to ventilation/VCO₂ production to visualize ventilatory threshold and RER (respiratory exchange ratio). Each test was continued until an RER of greater than 1 and a split in the VE/VO₂ versus VE/VCO₂ relationship was noted, with VE/VO₂ increasing while VE/VCO₂ remained constant as described by Davis et al. (1979) and Skinner and McLlelan (1981). It was not the intent to establish a maximal O₂ uptake for the subjects but to get beyond the proposed AT and obtain additional HR measurements. The
Figure 1. Diagonal technique used during a rollerskiing test.
majority of subjects felt that they could have continued the test further except when the mechanics of rollerskiing became awkward at high speeds.

At the completion of each test the heart rate monitors were connected to a Commodore computer and a heart rate/time relationship was plotted. Work loads (VO$_2$) were regressed and noted on the time axis. Two independent observers then determined the deflection point (as noted by a flattening of the curve from increasing linearity). If the two determinations were not within 2 heart-beat points a mutual decision was made. If it was obvious that the curve was without a clear deflection point it was so stated. Later the same heart rate data were examined in a Clinfo computer package and presence of linearity was determined by regression analysis. With the particular computer program available a more exact determination of a deflection point was not possible.

**Statistical Measures**

Descriptive data for the subjects were expressed as mean and standard deviation. These measurements appear in Chapter 4. Subjective determination of HR deflection points was employed with two independent observers. Means for HR deflection points and differences between deflection points for each of the three activities were calculated.
Spearman correlation coefficients were calculated between oxygen consumption and HR deflection point. Paired $t$ tests were used to test the hypothesis of zero mean difference in HR deflection point between each pair of the three activities. Ninety-five percent confidence intervals for the mean differences were computed. A non-parametric test, the Wilcoxon signed rank test, was also applied since the $t$ test is sensitive to outliers. (This test detects the distribution of differences being shifted to left or right of zero.) Significance was set at 0.05 for all tests.
CHAPTER FOUR
RESULTS AND DISCUSSION

This chapter presents results for physical characteristics, individual exercise tests, and statistical analysis of the results, and discusses their meaning and implications.

Results

Fourteen subjects completed the study. Physical characteristics (sex, age, weight and body composition) are presented in Table 1.

Heart rate (HR) deflection point was determined in 11 of 14 subjects for rollerskiing. (Two subjects did not have an identifiable deflection point, and one subject was unable to achieve high work loads due to a lack of technical skiing ability.) HR deflection points were determined for both cycling and running in all 14 subjects. See Appendix B for raw HR deflection points and differences between points for each activity, and Appendix C for a sample heart rate graph.

Means and standard deviations for HR deflection points are presented in Table 2. Box plots for HR deflection points are presented in Figure 2. Both running and rollerskiing exhibit outliers at the lower end of heart rates.
Table 1. Physical characteristics of subjects.

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<th>Body Fat (%)</th>
<th>VO₂max (Running) (ml/kg/min)</th>
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<td>F</td>
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<td>45.5</td>
<td>15.4</td>
<td>67.2</td>
</tr>
<tr>
<td>14</td>
<td>F</td>
<td>27</td>
<td>57.7</td>
<td>16.2</td>
<td>61.2</td>
</tr>
</tbody>
</table>

Table 2. Actual heart rate deflection points for each activity.

<table>
<thead>
<tr>
<th>HEART RATE DEFLECTION POINT (bpm)</th>
<th>Rollerski</th>
<th>Run</th>
<th>Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>167.63</td>
<td>166.29</td>
<td>156.64</td>
</tr>
<tr>
<td>S.D.</td>
<td>9.25</td>
<td>12.61</td>
<td>14.10</td>
</tr>
<tr>
<td>Range</td>
<td>145 - 178</td>
<td>140 - 182</td>
<td>140 - 173</td>
</tr>
</tbody>
</table>
Figure 2. Box plots for heart rate deflection points for rollerskiing, running and cycling.
HR deflection point was plotted against VO$_2$ uptake (ml/kg/min) for each activity to examine trends in the relative work load at the HR deflection points (see Figures 3, 4, 5). Spearman correlation coefficients for each activity are listed in Table 3.

Table 3. Spearman rank order correlation coefficient for oxygen consumption and heart rate deflection.

<table>
<thead>
<tr>
<th>Activity</th>
<th>$r_s$</th>
<th>$p$ (2-sided)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rollerskiing</td>
<td>0.53</td>
<td>$0.05 &lt; p &lt; 0.10$</td>
</tr>
<tr>
<td>Running</td>
<td>0.51</td>
<td>$p &gt; 0.20$</td>
</tr>
<tr>
<td>Cycling</td>
<td>0.29</td>
<td>$0.05 &lt; p &lt; 0.10$</td>
</tr>
</tbody>
</table>

Actual differences in HR deflection points between pairs of activities can be found in Appendix B. Paired t tests (with 2-tailed probability) were performed on the mean differences between each of the three activities. Results are presented in Table 4 and box plots are in Figure 6. Marked outliers are found in the running-cycling HR deflection points and a moderate outlier in the rollerskiing-running plot.
Figure 3. Relationship of oxygen consumption to cycling heart rate deflection point. (0 = female; 1 = male.)
Figure 4. Relationship of oxygen consumption to running heart rate deflection point. (0 = female; 1 = male.)
Figure 5. Relationship of oxygen consumption to rollerskiing heart rate deflection point. (0 = female; 1 = male.)
<table>
<thead>
<tr>
<th>Activity Pair</th>
<th>N</th>
<th>$\bar{X}$ (S.D.)</th>
<th>$95%$ Confidence Interval</th>
<th>d.f.</th>
<th>$t$ value</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rollerski-Run</td>
<td>11</td>
<td>0.818 (8.18)</td>
<td>(-4.677, 6.313)</td>
<td>10</td>
<td>0.3316</td>
<td>0.747&lt;sup&gt;a/&lt;/sup&gt;</td>
</tr>
<tr>
<td>Run-Cycle</td>
<td>14</td>
<td>9.64 (15.76)</td>
<td>(0.544, 18.740)</td>
<td>13</td>
<td>2.289</td>
<td>0.039&lt;sup&gt;b/&lt;/sup&gt;</td>
</tr>
<tr>
<td>Cycle-Rollerski</td>
<td>11</td>
<td>-10.45 (10.97)</td>
<td>(-17.838, -3.076)</td>
<td>10</td>
<td>-3.309</td>
<td>0.008&lt;sup&gt;c/&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a/</sup>For 2-sided $|t| \geq 2.228$; not significant at $p = 0.05$

<sup>b/</sup>For 2-sided $|t| \geq 2.160$; significant at $p = 0.05$

<sup>c/</sup>For 2-sided $|t| \geq 2.228$; significant at $p = 0.05$
Figure 6. Box plots of differences in heart rate deflection points between each pair of activities.
Regarding rollerski-run (p = 0.747) there was insufficient evidence to reject the null hypothesis that the mean differences equaled 0. With running-cycling there was a statistically significant difference (p = 0.039), with running HR higher than that of cycling. There was also a significant difference with cycling versus rollerskiing (p = 0.0078). It appears that rollerskiing elicits a significantly higher heart rate than cycling. A 95% confidence interval for each of the mean differences is presented in Table 4. The Wilcoxon signed rank test confirmed the t test results (see Table 5).

Table 5. Wilcoxon signed rank test for activity pairs.

<table>
<thead>
<tr>
<th>Activity Pair</th>
<th>Absolute T value</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rollerski-Run</td>
<td>31.5</td>
<td>p &gt; 0.10</td>
</tr>
<tr>
<td>Run-Cycle</td>
<td>18.5*</td>
<td>0.02 &lt; p &lt; 0.05</td>
</tr>
<tr>
<td>Cycle-Rollerski</td>
<td>1.0*</td>
<td>p &lt; 0.01</td>
</tr>
</tbody>
</table>

\[ \text{Absolute T value} = \text{the smaller of the absolute value sum of positive ranks or negative ranks of the differences (Ott 1984:161).} \]

*Significant at p = 0.05
Discussion

The subjects in this study were highly trained athletes with a mean VO$_2$ max (running) of 70 ml/kg/min for males and 65 ml/kg/min for females. These values correspond with levels from other studies of cross-country skiers (Astrand and Rodahl 1977, 1986; Rusko et al. 1980). There was significant variation within the groups. Age ranged from 17 to 35 years. VO$_2$ max for running ranged from 61.2 to 78.2. Body fat for men ranged 3.0 to 10.3 percent, and from 5.5 to 16.2 for women.

The diversity among the subjects may have influenced the heart rate data. The wide age span also results in varying levels of training and experience in ski racing.

Determination of Heart Rate Deflection Point

The presence of the HR deflection point in 39 of the 42 exercise tests supports the findings of Conconi et al. (1982) and Droghetti et al. (1985) and challenges the concept of linearity throughout the HR work load curve as described by several investigators (Margaria et al. 1963, Astrand and Rodahl 1977, Brooks and Fahey 1984).

Brooks and Fahey (1984) state that in dynamic exercise the HR increases with the work load and oxygen consumption, and the extent of the increase depends on the type of exercise, and the fitness level, age and sex of the
subjects. The HR then levels off at VO$_2$\textsuperscript{max}.

Subjects in this study had increasing VO$_2$ values after the deflection point and subjectively, all felt as if they could have continued with the test. This indicates that the observed leveling of the HR was not similar to the HR at VO$_2$\textsuperscript{max} that Brooks and Fahey (1984) describe.

Although criticisms of the subjectivity in determining the deflection point may be cited, the investigator feels that the agreement of the two observers and the support of the findings by Conconi et al. (1982) provide a strong indication of the nonlinearity of the curve. Additionally, many of the athletes subjectively felt most efficient when at their deflection point, indicating a possible steady state response.

**Differences in Heart Rate Deflection Point for Various Activities**

The mean HR deflection point between rollerskiing and running was not statistically significant (Tables 2 and 4) but differences between cycling and running, and between cycling and rollerskiing, were significant. Confidence intervals for differences between rollerskiing and cycling, and between running and cycling, indicate that rollerskiing and running always elicit higher heart rate deflection points when compared to cycling.

The results of significant differences in HR
deflection points between running and cycling and between rollerskiing and cycling lend evidence to the concept of amount of muscle mass producing higher heart rates and ATs. The possible cause of these interactions is not conclusive but investigations by Mitchell et al. (1983) shed light on this area.

The literature from experimental evidence suggests two theories about the initiation and maintenance of the cardiovascular (CV) response to exercise (Coote et al. 1971, Goodwin et al. 1972, Rowell et al. 1981). The first is called the central command theory and is believed to occur from neural impulses arising from the central activity that recruits motor units, exciting medullary and spinal neuronal circuits that cause the CV changes during exercise. The second theory, the peripheral command theory, states that muscular contraction stimulates afferent endings within the skeletal muscle which in turn reflexly evoke the CV changes.

Animal studies by Mitchell et al. (1983) suggest that there exists a specific subset of groups III and IV muscle afferents that may serve as ergoreceptors activated by mechanical or metabolic activity. Mitchell et al. conclude that contraction of skeletal muscle and these afferents cause changes in the efferent sympathetic and parasympathetic outputs to the CV system that are in turn
responsible for increases in arterial blood pressure, heart rate, and left ventricular contractility and changes in the distribution of blood flow. Perhaps the leveling of the HR curve at AT is influenced by metabolic changes occurring with increased anaerobiosis and that varying amounts of muscle mass utilized in the exercise involve more or less of the afferent signals back to the CV control center.

It was the opinion of the investigator that rollerskiing could result in higher heart rates than running and cycling because mechanically, rollerskiing by using arms with ski poles as well as leg muscles, would involve more muscle groups and tax the CV system more severely, resulting in higher $O_2$ consumption and heart rates. The data did not support this opinion in regards to running.

There are conflicting reports in the literature regarding oxygen costs of different activities. Astrand and Rodahl (1977) found $VO_2 \text{max}$ approximately the same whether measured running, cross-country skiing or cycling. In a later study, Astrand and Rodahl (1977) reported that the greatest individual differences in $O_2$ uptake were during running versus cycling, especially in well-trained athletes. Hermansen (1973) found slightly higher $VO_2 \text{max}$ levels obtained by ski walking (striding up a 12 degree incline with ski poles). Meen and Stromme (1972, cited in
Astrand and Rodahl 1977) found differences in $O_2$ uptake of 2 to 3 percent higher for skiing than treadmill running.

When examining the relationship of $O_2$ consumption at the deflection point in this study, a large variability among the subjects is present, especially in rollerskiing HRs.

Spearman rank order correlation coefficients were applied to measure the strength of relationship between HR deflection point and $O_2$ consumption. Running and cycling HR deflection points had the strongest association with oxygen consumption, with $r_s = 0.51$ and $r_g = 0.52$ respectively. Rollerskiing resulted in a very weak relationship ($r_s = 0.29$).

The data obtained in this study imply that there is not a very strong relationship between oxygen consumption and the HR deflection points obtained. Along similar lines Brooks and Fahey (1984) found large fluctuations in submaximal HR were possible at identical levels of $O_2$ consumption.

An assumption from the data in this study, and supported by the findings of Conconi et al. (1982), is that the HR deflection point signifies the anaerobic threshold. It would seem logical that because of the amount of muscle mass used in the exercise, as well as the high fitness levels of the subjects in a particular activity, the AT
would be higher than was measured in this study. Therefore, the subjects could work at a higher work load without getting fatigued. This affect is demonstrated in a recent study of combined arm and leg exercise with application to Nordic ski racing (Millerhagen and Kelley 1983).

Millerhagen and Kelley (1983) examined \( VO_2^{\text{max}} \), AT, length of time to AT and power output in skiers performing arm, leg, or combined ergometry. AT occurred at a higher percent of \( VO_2^{\text{max}} \) when both arms and legs were utilized. AT was also delayed about 3 minutes longer with the combined exercise. The data imply that if more muscle mass is involved in producing a given amount of power, the AT will be delayed even though \( VO_2 \) at AT may remain essentially the same.

Due to the variability in rollerskiing heart rate deflection point (and the absence of 3 out of 14 deflection points), significant evidence of rollerskiing producing higher heart rate deflection points (and ATs) compared to running was not found. In 5 of the 11 tests, higher heart rates were produced with rollerskiing versus running, indicating individual trends. There also appears a trend for older, more experienced ski racers (probably fitter in all activities) to have less variation between the three activities. The older racers probably are more highly
trained over all the activities than the younger skiers and have higher volumes of training built up over the years.

Factors Involved in Variability of Rollerskiing Heart Rate Deflection Point

Several factors may influence the results regarding nonsignificant differences in heart rate deflection points between running and rollerskiing in this study. The testing was performed in May and June, essentially the off-season or low intensity training period for this group of skiers. Little or no rollerskiing or snow skiing had been done for 1 to 2 months, as the final national competition on snow was in late March to early April. General physical status of the skiers is lower in May and June, which agrees with Bergh (1974, cited in Astrand and Rodahl 1977) who measured VO₂ max in elite Swedish skiers throughout the year and found the highest values in January and the lowest in May and June. Since the subjects were resting or doing light cycling and running, one could conclude that work intensities, ATs and HRs would be lower and this might explain why rollerskiing heart rates were not significantly higher than running HRs. The results of Bergh's study indicated that athletes in sports such as cross-country skiing are highly trained in many forms of exercise and therefore may be at a higher level of fitness in a given activity depending on the time of year. The time of year
and training season is important to acknowledge when evaluating physiological parameters.

The nature of rollerskiing motion may lend itself to variability as suggested by Washburn (1985). Heart rate reliability of arm cranking versus leg cycling at various power outputs was examined. The leg cycling resulted in a high degree of reliability while arm cranking resulted in low reliability especially at low power outputs. Lack of experience and a learning effect could have contributed to the results. Washburn suggests that variation in arm cranking HRs over testing sessions is probably not a function of variation in metabolic costs of the activity, but more likely a function of biomechanical influences due to arm/shoulder lengths, and strength. These biomechanical factors would affect joint receptors and other sensory inputs to the cardiovascular system control center, resulting in individual HR responses.

Another explanation of the nonsignificant differences in the rollerskiing-running heart rate deflection points could be technique related. The diagonal technique on rollerskis was employed because of limitations of available equipment, number of subjects and range of ski boot sizes. This technique somewhat mimics the motions of running: arm swinging while poling, and alternating forward and back leg motions with a downward kick (enabled by the ratcheted ski
wheels) are similar motions found in running. The similarities in the technique may explain lack of significant differences in HR response. With the arrival of the "ski skating" technique that has become popular on the racing circuit in the past few years, and which the subjects frequently used in the preceding season, it is possible the skiers were less efficient, less comfortable and less well-trained in the diagonal technique. This may have prevented some subjects from reaching higher heart rates, ATs, etc.

Skating involves more of a side to side, gliding motion, twisting the upper body and lifting the arms higher at the shoulders. Had this technique been tested, higher heart rates may have resulted. It is possible the skating heart rates would be higher than running HRs in this study had the skating technique been used by the subjects.
CHAPTER FIVE
CONCLUSIONS/RECOMMENDATIONS/SUMMARY

This chapter contains conclusions and recommendations based on the results and a summary of the overall study.

Conclusions

In this study it appears that deflection heart rates signifying the AT were present in the subjects in most of the tests. As in previous studies, supporting data reveals that AT is not a constant percent of VO\textsubscript{2 max} for all individuals. The influence of fuel use and lactate accumulation suggests that precise training prescriptions with respect to metabolic stress may be developed with the AT as the major consideration. The higher values for rollerskiing versus cycling and for running versus cycling are in part explained by the amount of muscle mass used in these activities. The nonsignificant differences for rollerskiing versus running may be explained somewhat by the level of variability in the subjects' physical parameters as well as the technique and time during the training year.

The results of this study have application for coaches and physiologists. The type of activity, muscle mass used, level of fitness, and time of year when testing and prescribing training levels for athletes who employ
multiple modes of exercise in their training should be considered. It appears that the HR deflection point as determined in laboratory testing may be used in the field for everyday training of athletes.

**Recommendations**

Based on the results of this study, the following recommendations are proposed:

1. Exploration and development of a more objective statistical/mathematical method to determine the point where deviation from linearity occurs in the HR curve.
2. Development of a quantitative measurement to clearly isolate various groups of muscles involved in different activities and reliability tests for arm activities.
3. Further study of the deflection point in more heterogenous samples of elite athletes.
4. Further study of the effects of training season and altitude on the deflection point.
5. Standardization of specific test protocols, especially in skiers with relation to ski technique used.

**Summary**

The determination of heart rate deflection point signifying the AT (as described by Conconi et al. 1982) in the heart rate work load curve, and the effects of
exercises with varying amounts of muscle mass on the
deflection point were investigated in 14 national-level
Nordic ski racers.

Heart rate deflection points were determined for 11 of
14 subjects in rollerskiing and for all subjects in running
and cycling. Significant differences were found between
deflection points in rollerskiing versus cycling (p =
0.007) and for running versus cycling (p = 0.03), but not
for rollerskiing versus running (p = 0.74).

Although not statistically significant, several
individual trends with rollerskiing producing higher heart
rates than running were present.

The diversity among the subjects related to age,
fitness level, training modes, time of year, as well as
technique factors and the nature of arm activities may
explain the variability among the heart rate data. It
appears that the heart rate deflection point differences
may be related to amount of muscle mass employed which
results in varying levels of muscle afferent stimulation of
the CV control center: the more muscle mass involved in
the exercise the higher the heart rates.
APPENDIX A

The University of Texas Health Science Center at Dallas
General Clinical Research Center, Parkland Memorial Hospital

SUBJECT CONSENT FOR PARTICIPATION IN RESEARCH

TITLE: A Longitudinal Study of Oxygen Utilization in Young Cross-Country Skiers

PRINCIPAL INVESTIGATORS: James Stray-Gundersen, M.D., Jere Mitchell, M.D.
ASSOCIATE INVESTIGATORS: Gunnar Blomquist, M.D., Sharon Cassidy, M.D., Andrew Gaffney, M.D., Robert Johnson, Jr., M.D., Samuel Lewis, M.D., Russell Moore, Ph.D., Dorabeth Parsons, Ph.D., James Schutte, Ph.d., Peter Snell, Ph.D.

You are invited to participate in a research study of oxygen utilization in young cross-country skiers. We hope to learn what physiological variables of oxygen transport and use change with continued heavy training. You were selected as a possible participant in this study because you are an accomplished cross-country skier between the ages of 13 and 18 inclusively at the time of entrance to the study and you intend to pursue a cross-country skiing career over the course of the study, approximately 6 to 10 years.

If you decide to participate, you will be asked to undergo the following tests and procedures. These tests will be administered on an annual basis with two exceptions. The two exceptions are the muscle biopsies and the MUGA scan, which will be performed only twice, the first and last years of your participation in the study.

**Anthropometric Measurements**

In order to determine your body's muscle, fat, and water composition we will obtain detailed measurement of height, weight, skin fold thickness, etc., using measuring tape and calipers. There is no discomfort or risk.

Plasma Volume will be measured by the Evans Blue dye technique. Five ml of a dye solution will be injected into a vein in one arm. A catheter will be inserted into a vein in the opposite arm and 7cc blood samples will be withdrawn before dye injection (for creatinine concentra-
tion analysis) and then at 10, 20, and 30 minutes after the dye has been injected. This procedure will be performed by a physician.

Lean Body Mass will be measured with deuterium oxide (D₂O: a stable isotope of water) dilution of the total body water. You will be given an oral dose of 20cc of D₂O and about 2-3 hours later, we will collect a 5ml sample of urine. Anthropometry will consist of measuring your external dimensions (height, weight, skinfolds, circumferences, etc.) Neither the D₂O procedure nor the anthropometry involve any risk or discomfort to you.

Risks: The only discernible risk is the possibility of injury to the vein that might occur during the insertion of the hypodermic needles used to inject the dye and to withdraw the blood samples. Additionally, there is a slight possibility that some of the dye might "leak" out of the vein during injection, and this would result in an unsightly blue stain under the skin. This stain would be visible for several weeks. To avoid these possibilities, all needle insertions will be performed by a physician.

Benefits: An elevated serum creatinine may be indicative of kidney disease. If your serum creatinine is abnormally high, you will be advised of this and referred to an appropriate medical specialist. You will also be advised of your body composition (i.e., the amount of fat, muscle, plasma, etc.) and will be informed of the body weight that is most appropriate for you to maintain.

**Venipunctures**

Samples of blood will be removed from a vein in your arm and will be used for various analyses. The amount that will be withdrawn may vary but will not in any case affect your health or well-being. Usually this procedure is done without difficulty, but occasionally, a bruise results.

**Venous Catheters (Peripheral)**

A venous catheter, usually a thin, soft plastic tube may be inserted into a vein to avoid repeated punctures during studies that require several blood samples. There is a very small risk of infection and a still smaller risk of a blood clot or breakage of the catheter. The likelihood of any complications is very remote when--as in your case--the procedure is carried out by trained personnel and proper equipment is used.
**Exercise Tests**

Exercise tests may be performed using a stationary bicycle or a treadmill. You will be asked to exercise at increasing levels in several tests and at a high constant level until you decide to stop in another test to measure the effects of stress on your heart and lungs. A qualified physician will directly supervise the test in a lab equipped to handle virtually any problem. Exercise rarely causes any problems in normal subjects but in patients with known or hidden heart disease, the test may cause chest pain, dizziness, or bouts of irregular heart rhythm. There is a very slight risk of a heart attack occurring during or after such exercise in patients with pre-existing heart disease but this risk is no different than if you were performing such exercise at home. In fact, it is probably safer in that you are being closely watched and exercise will be stopped immediately if there are any signs of excessive strain. Your pulse, blood pressure, and EKG will be recorded during the test.

**Lower Leg Flow**

To measure maximal blood flow to the muscles of the lower leg, we will place two blood pressure cuffs on your leg and inflate these to temporarily arrest arterial and/or venous blood flow. You will be asked to perform mild heel and toe raising exercise while the blood supply to the lower leg is occluded. This exercise is performed until fatigue or discomfort levels indicate that you discontinue. There are no known problems with this procedure in normal subjects. The purpose of the combined occlusion and exercise is to induce maximal blood flow, and this typically requires 2-3 minutes before flow and blood pressure measurements are made simultaneously in the supine position.

**Forearm Flow**

This procedure is similar to that for measurement of lower leg flow. The arterial occlusion cuff is placed above the elbow and another is located at the wrist. Hand gripping exercise is performed to the point of fatigue during arterial occlusion. As with the leg flow measurements, there is no known problem with this procedure in normal subjects.
**Cardiac Output**

We will measure the heart's pumping capacity by analyzing your expired air while you breathe through a mouthpiece connected to a bag full of air and a small concentration of harmless non-radioactive tracer gases, including helium and acetylene. There is no known risk to anyone doing this procedure.

**Breathing Tests**

Diffusing Capacity tests how well oxygen (the good air) and carbon dioxide (the bad air) are exchanged when you breathe.

Spirometry tests how much and how fast you can blow out a breath of air.

Lung Volumes test how much air is inside your chest at different times in your breathing cycle.

There are no risks or complications to these tests.

**Echocardiogram**

A picture of your heart will be taken by an ultrasound camera, similar to the "sonar" used by fishermen to locate fish underwater. There is no radiation and no risk.

**Isotope Scans: Technetium Pyrophosphate Scintigrams**

A small quantity of radioactive substance will be mixed with some of your blood and then injected into a vein. This material will cause the heart to be visible with a special camera with which pictures of your heart muscle and heart chamber size and wall motion can be recorded. The amount of radiation per test is about that received from a routine chest x-ray. This test is identical to the one used in many community hospitals throughout the country to assess heart function. There are no known risks from the amount of radiation used in these tests. Large doses of radiation have been known to cause serious medical problems and smaller doses may theoretically have smaller risks of producing similar problems. Current data indicate this is a matter of concern only during pregnancy. If you are or may be pregnant, please inform us immediately as you should not have this test.
Muscle Biopsy

A small piece (about 50 milligrams or much less than one grain) of muscle will be taken for examination. This is done by numbing about a 1/4 inch spot on your thigh/upper arm with Lidocaine, a local anesthetic similar to Novacaine. A nick in the numbed skin will be made, a special sharp pencil-shaped tube will be inserted a short distance into the thigh/upper arm and a tiny piece of muscle removed. A small (1/4") scar may result. Rarely, slight bleeding occurs and requires a larger incision to find and tie off the bleeding vessel. After the Lidocaine effect wears off, the thigh/arm will be sore for 1-2 days. This discomfort is mild and usually does not interfere with normal activities.

EMG-Cybex Fatigue Test

You will be asked to perform a certain amount of work on the Cybex knee extension machine while we measure the electrical signals in your exercising thigh. This involves placing electrodes on the skin over the thigh muscle and recording from them. There is no risk or discomfort associated with placement of the cutaneous electrodes.

Possible Benefits:

The purpose of these tests is to develop a better understanding of the function of organ systems contributing to high level physical performance, and the extent to which these systems adapt in response to several years of hard training. Our present knowledge suggests that under normal conditions, high level continual training improves athletic performance, and we expect this study to elucidate those variables responsible for the effects. Any undetected pathology that may be present is more likely to be revealed by the comprehensive cardiovascular test described, and the appropriate medical management initiated. In terms of cardiovascular risk factors, this study will provide far more diagnostic information than is currently available in any preventive heart disease program. We cannot and do not guarantee or promise that you will receive any benefits from this study.

You have a right to privacy, and all information that is obtained in connection with this study and that can be identified with you will remain confidential. No information gained from this study that can be identified with you will be released to anyone other than the investigators.
The results of this study may be published in scientific journals without identifying you by name.

We will make every effort at preventing any injury that could result from this research. Compensation for injuries incurred as a result of participating in this research is not available. The investigators are prepared to advise you about medical treatment in case of adverse effects of these procedures which you should report to them immediately. Dr. Stray-Gundersen may be reached at (office: 214/688-3274 or home: 214/253-4905). If you have any questions about the research or about your rights as a subject, we expect you to ask us. If you have questions later, or if you wish to report a research-related injury, you may reach Dr. Stray-Gundersen at the above phone numbers.

Participation in this research study is entirely voluntary. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time without affecting your status as a patient or the medical care you will receive.

You will be given a copy of this document to keep.

YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE IN THIS STUDY. YOUR SIGNATURE INDICATES THAT YOU HAVE DECIDED TO PARTICIPATE HAVING READ (OR BEEN READ) THE INFORMATION PROVIDED ABOVE.

_________________________________________ /______________
Signature of Subject          Date          Time

(Relationship to Subject)      __________________________________________
Signature of Witness

_________________________________________ /______________
Signature of Investigator       Date
## APPENDIX B

### Raw Heart Rate Deflection Point Data

<table>
<thead>
<tr>
<th>Subject</th>
<th>Sex</th>
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<th>Run</th>
<th>Cycle</th>
<th>Rollerski - Run</th>
<th>Run - Cycle</th>
<th>Cycle - Rollerski</th>
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<tbody>
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<td>154</td>
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<td>134</td>
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<td>---</td>
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<tr>
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- $\overline{X}$: 167.4, 164.5, 155.5
- S.D.: 10.18, 13.78, 15.10

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- $\overline{X}$: 168.5, 172.7, 160.7
- S.D.: 4.94, 2.51, 11.01

**TOTAL $\overline{X}$**: 167.63, 166.29, 156.64
- **TOTAL S.D.**: 9.25, 12.61, 14.10

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APPENDIX C

Typical Heart Rate Graph Showing Deflection Point

Note: Heart rates for a 1.25 minute segment are noted above (151, 153, 153, 153, and 154 beats per minute).
REFERENCES


