A PHYSIOLOGICAL AND BIOMECHANICAL PROFILE OF THE ATHLETES COMPETING IN A WORLD CUP CROSS COUNTRY SKI RELAY EVENT

BY: Mark Thomas ©

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Abstract

A variety of studies have been conducted which have attempted to relate biomechanical and physiological variables to cross-country skiing performance. These investigations have taken place in different settings including in the laboratory, outside on roller skis, or on-snow on skis during time trials and competitions. The design of these studies undoubtedly provided the researchers with considerable control over a variety of confounding variables. However, these attempts at controlling variables may have inadvertently created artificial situations with little or no relevance to actual racing situations. Forsberg (1992) pointed out that no one variable can fully account for the observed differences in skiing performance. A more integrated approach to studying the sport was suggested by Hoffman & Clifford (1992) combining physiological and biomechanical measurements in order to achieve a better understanding of which variables affect performance. The primary purpose of this study was to develop a physiological and biomechanical profile of the athletes competing in the free technique legs of the 1994 World Cup Men's Cross-

Country Ski Relay event in Thunder Bay, Ontario, Canada. The secondary purpose was to describe the statistical contributions of specific kinematic and temporal variables to the race velocity of World Cup level cross-country skiers. The tertiary purpose of this study was to compare the top international skiers to the Canadian skiers on the basis of specific physiological and kinematic variables.

The study involved the collection of physiological data from six male members of the Canadian National Cross-Country Ski Team four months prior to the relay event and the collection of physiological, biomechanical, and timing study data during the event. Further biomechanical and timing study data were collected from the remaining 18 international competitors in the skating legs of the relay.

The lab testing involved VO_2peak testing and monitoring of heart rates. The race site testing included the monitoring of heart rates during the race, of whole blood lactates immediately before and after the race, of kinematic and temporal analysis of the offset skating technique on a steep uphill, of skating techniques used on different terrain, and of times taken to ski different parts of the race course. The

physiological, technique census, and timing study data were analyzed using descriptive statistics. The kinematic and temporal data were analyzed using a combination of descriptive, multiple correlation, and multiple regression statistics.

The kinematic and temporal analysis revealed several significant relationships with race velocity. Cycle length was positively correlated with race velocity at the $p<.01$ level of significance. Cycle velocity and percentage of the full cycle skating on the downhill ski were positively correlated with race velocity at the $p<.05$ level of significance. Further significant correlations were found among the remaining selected variables. Cycle length was negatively correlated ($p<.05$ level) with the percentage of the full cycle skating on the downhill ski. Cycle time was negatively correlated ($p<.05$ level) with the percentage of the full cycle time skating on the uphill ski. Percentage of the full cycle time skating on the uphill ski was negatively correlated ($p<.05$ level) with percentage of the full cycle time skating on the downhill ski. A multiple regression equation revealed that cycle length was the best predictor of race velocity.

The Canadian skiers were found to differ in terms of their physiological and biomechanical profiles as they related to race performance.

The physiological analysis of the Canadian subjects revealed several interesting relationships between heart rates and whole blood lactate values and race velocity. The subjects anaerobic thresholds were a good indicator of their relay race performance. The faster subjects raced close to 90 percent of their maximum heart rate. Pre-race and post-race whole blood lactate values were similar to values reported by other studies for top skiers. The peak post-race lactate values did not show any trend in relation to race velocity. However, the fastest subjects had the highest whole blood lactate clearance rates.

A comparison of the Canadian subjects on the basis of several kinematic and temporal variables did not show any trends in relation to their race performance. However, a closer look at their skating technique preferences on different terrain showed some variation. The fastest subject preferred to use the 2-skate technique on 1-5 degree slopes, but the other subjects used a combination of the 1-skate, 2-skate, or offset skate techniques.

There were some distinct differences between the top skiers and the Canadian skiers in terms of their physiology, skating technique, and mean race velocities for different parts of the race course. The relatively low peak VO_2 values for the Canadian skiers compared to previous values reported for top skiers may have set an upper limit to their anaerobic thresholds. The top skiers had higher mean race velocities throughout the course, higher cycle velocities, longer cycle lengths, a more balanced skate off either ski, and a smaller uphill pole angle at the moment of pole plant as compared to the Canadian skiers. The full cycle times and the percentage of the full cycle poling were similar between the two groups. The top skiers preferred to use the 2-skate technique on the 1-5 degree slopes while the Canadians used a variety of techniques. Both groups of skiers used the offset skate on slopes greater than five degrees.

The intent of this study was to develop a physiological and biomechancial profile of World Cup level cross-country skiers. Clearly the lack of physiological data on the competitors other than the Canadian subjects limited the inferences that were made regarding the two groups. Despite these limitations this study has revealed some interesting physiological and biomechanical differences between the top skiers and the Canadian skiers. Further studies need to be conducted on the physiological and biomechanical demands of cross-country ski skating on elite level athletes.

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A sincere thank you goes out to the Canadian athletes who allowed the collection of the physiological data from them before, during, and after the 1994 World Cup Cross Country Ski Relay Race in Thunder Bay. Their cooperation was critical to fulfilling the unique dual nature of the study.

The cooperation of Cross Country Canada and the Big Thunder Sports Park in the collection of data was also gratefully appreciated.

A final thank you goes to the 30 volunteers who helped the author collect the data from the athletes during the relay race. A special mention goes to my thesis advisors, Dr. McPherson and Dr. Thayer, and my fellow graduate students Chen Shao-ming and Wayland Pulkkinen who played key roles in the collection of data.

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Chapter 1

Introduction

A variety of studies have been conducted which have attempted to relate biomechanical and physiological variables to cross-country skiing performance or to the classical or free techniques. These investigations have taken place in different settings, including in the laboratory on a motorized treadmill, outside on rollerskis on level tracks, or on-snow on skis during time trials and competitions. The treadmill and even the rollerski studies allowed the researchers considerable control over what they perceived as confounding variables such as differences in ski technique, ski equipment, snow conditions, or pace chosen by the skier. The results, however, have questionable application to skiing on-snow. The technical skill of the skier affects skiing performance, but treadmill testing procedures do not reflect the use of different techniques during a competition (Bergh & Forsberg, 1992a). The on-snow studies were more sport specific, but the large number of confounding variables have presented some serious concerns to researchers and coaches. The varying terrain, snow conditions, waxing methods, skiing equipment, and individual choice of techniques made it difficult to establish high correlations between physiological or biomechanical factors and race performance.

Never-the-less athletes must contend with these variables every time they race. The researchers' past attempts to control one or more of these variables may have inadvertently created artificial situations with little or no relevance to actual racing. Bergh & Forsberg (1992b) pointed out that no one variable can fully account for the observed differences in skiing performance.

A more integrated approach to studying the sport during competitive performances is needed to combine the physiological and biomechanical measurements in order to achieve a better understanding of which variables affect performance.

Purpose

It was clear from the review of literature that there have been few studies conducted which attempted to examine the inter-relationships between physiological or kinematic variables under actual race conditions. The primary purpose of this study was to develop a physiological and biomechanical profile of the athletes competing in the free technique legs of the 1994 World Cup Men's 4X10 Kilometer Cross-Country Ski Relay event held in Thunder Bay, Ontario, Canada. The secondary purpose of this study was to describe the statistical contributions of specific kinematic variables to the race velocity of World Cup level cross-country skiers. A tertiary purpose of this study was to compare the top international skiers to Canadian skiers on the basis of specific physiological and kinematic variables.

Limitations & Delimitations

Part of the study took place during an actual World Cup relay race. However, some of the interpretation of the physiological test results from the relay was based on previous laboratory testing conducted by the Canadian National Cross-Country Ski Team. Consequently, the list of limitations and delimitations have been divided into the following sections: A) limitations & delimitations for laboratory testing, and B) limitations & delimitations for race site testing.

A. Limitations & Delimitations for Laboratory Testing

The lab testing was limited by the following factors:

1.) The maximal aerobic exercise testing was conducted in three different labs: University of Calgary, Lakehead University, and University of Laval.

The delimitations included:

1.) The physiological lab testing results used to support the field results were only available from the six male members of the Canadian National Cross-Country Ski Team who participated in the skating legs of the 1994 World Cup Men's 4×10 Km Relay Race in Thunder Bay.

B. Limitations & Delimitations for Race Site Testing

The race site testing was limited to the following factors:

1.) Changing weather conditions (temperature, humidity, and wind speed) throughout the two legs of the relay event may have required changes in the wax applications to the subjects' skis which in turn may have affected the glide speed of the skis.

2.) The mass start relay format created problems for the timers, spotters, and the camera crews when groups of skiers passed by their stations. The timers and the spotters precision may have been limited by one or more skiers blocking the view of another. Similarly, some of the skiers were obscured by other skiers on the video recordings.

3.) The precision and reliability of the researcher in digitizing the anatomical endpoints of the body segments for kinematic analysis.

4.) The video camera recording speed was limited to 30 frames per second. The splitting of the image by the PEAK 2D Motion Analysis System to achieve a sampling rate equivalent to 60 frames per second might not have been sufficient to capture precisely each of the key event frames.

The race site testing was delimited to the following factors:

1.) Blood sampling at the race site for lactate analysis immediately before and immediately after the race was delimited to six of the Canadian National Team athletes, participating in the skating legs of the relay.

2.) Video taping of the skiers for the kinematic analysis was delimited to a side view of the skating legs of the relay.

3.) Kinematic analysis was delimited to specific parameters of the offset skating technique on a nine degree slope. These parameters included, cycle time, cycle rate, cycle length, cycle velocity, percentage of the skating cycle poling, percentage of the cycle skating on either leg, pole angle at pole plant, and the distance between the pole tip and ankle at pole plant.

4.) The timing study was delimited to the recording of racers' elapsed times at six locations along the course representing rolling, uphill, and downhill sections of the course.

Research Hypotheses

1. A relationship exists between the variable race

velocity and other specific kinematic variables. The specific kinematic variables include cycle time, cycle rate, cycle length, cycle velocity, percentage of the cycle poling, percentage of cycle skating on either leg, pole angle at pole plant, and distance between the pole tip and ankle at pole plant.

2. There is an order to the relative importance of these selected kinematic variables in predicting the race velocity.

3. There are relationships between the variable race velocity and selected physiological variables. The physiological variables include percentage of maximum heart rate, pre and post-race whole blood lactates, and lactate clearance rates.

4. The faster World Cup level skiers demonstrate different biomechanical characteristics as compared to the Canadian skiers. These differences can be interpreted using physiological data obtained from the Canadian skiers.

Definition of Terms

Percentage of Maximum Heart Rate

Individual heart rates recorded throughout the race were expressed as a percentage of the individual's maximum heart rate recorded during the most recent VO_2peak running treadmill test.

Whole Blood Lactate Values

Whole blood collected pre and post race from the Canadian athletes was analyzed to determine the lactate concentration in mMole/l. Lactate or lactic acid is produced in the working muscles when glucose or stored muscle glycogen is metabolized during anaerobic glycolysis (McArdle, Katch, & Katch; 1991).

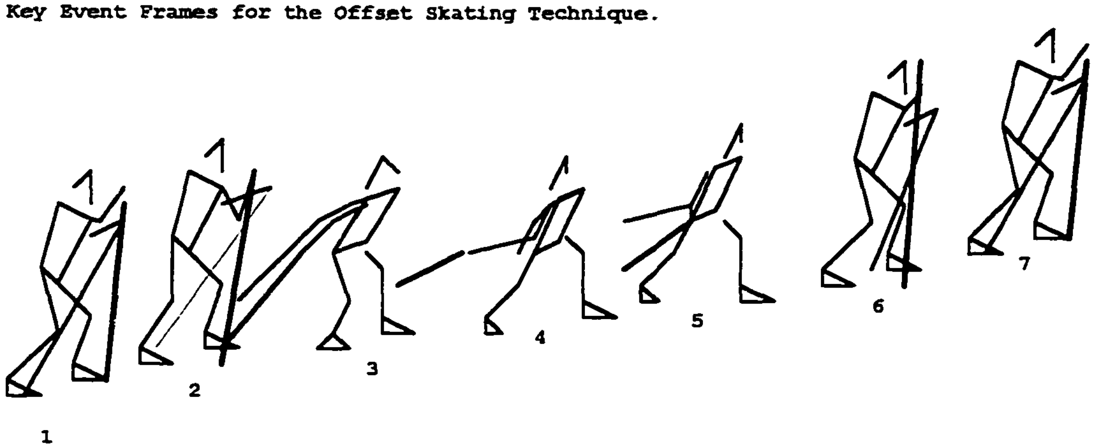
Lactate Clearance Rate

The lactate clearance rate was calculated by determining the rate of reduction in lactate values from peak post race values to the final recorded lactate value.

Offset Skating Technique Cycle

The offset skating technique cycle refers to the sequence of body movements which comprised the offset skating skill. In order to recognize one complete cycle, key events were established. The key events included uphill pole plant, uphill foot plant, high pole release, uphill foot toe off, downhill foot plant, downhill foot toe off, and uphill pole plant (see Figure 1). Thus one complete cycle was from high pole plant to high pole plant.

Figure 1
Key Event Frames for the Offset Skating Technique.



Cycle Time

The cycle time was the time in seconds required to complete one complete cycle of the offset skating technique, measured from pole plant to pole plant.

Cycle Rate

The cycle rate was the number of offset skating technique cycles completed per second.

Cycle Length

Cycle length (CL) was determined from the difference between the resultant displacements of the centre of mass (C/M) from the beginning to the end of the cycle. The skiers' C/M was calculated by the Peak 2D system from body segment parameter estimates (Dempster, 1955).

Cycle Velocity

Cycle velocity was the product of cycle rate and cycle length measured in meter/second.

Percentage of the Cycle Poling

The percentage of the cycle poling was calculated by dividing the number of video frames from uphill pole plant to uphill pole release by the total number of frames to complete one cycle.

Percentage of the Cycle Skating on the Uphill Leg

The percentage of the cycle skating on the uphill leg was calculated by dividing the number of video frames skating on the uphill leg from foot plant to toe off divided by the total number of frames to complete one cycle (see Figure 1). The uphill leg has also been referred to in the literature as the 'strong side' leg.

Percentage of the Cycle Skating on the Downhill Leg

The percentage of the cycle skating on the downhill leg was calculated by dividing the number of video frames skating on the downhill leg from foot plant to toe off divided by the total number of frames to complete one cycle (see Figure 1). The downhill leg has also been referred to in the literature as the 'weak side' leg.

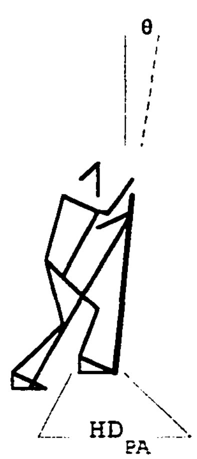
Horizontal Distance Between the Uphill Pole Tip and Ankle at Pole Plant

The resultant distance between the uphill pole tip and the adjacent ankle at the instant of pole plant was calculated from the difference of squares of the horizontal and vertical coordinates (see Figure 2).

Uphill Pole Angle

The only angular variable recorded was backward pole angle relative to vertical pole angle at the moment of uphill pole contact with the snow (see Figure 2). All other angles could not be accurately measured without three dimensional analysis.

Figure 2
Kinematic Variables Measured at the Moment of Pole Plant for the Offset Skating Technique.



HD_{PA} Horizontal Distance Between the Pole Tip and the Adjacent Ankle.

θ Pole Angle Relative to Vertical.

Chapter 2
Review Of Literature

In order to thoroughly review the related literature this chapter has been divided into the following sections: A) Cross-Country ski skating techniques, B) kinematics and temporal studies, C) physiological demands of the sport, D) physiological demands of the skating techniques, E) timing studies on cross-country ski skating competitions, and F) census of skating techniques.

A. Cross-Country Ski Techniques

The Men's 1994 World Cup 4X10 Km Cross-Country Ski Relay event in Thunder Bay, included both classical and free technique (skating permitted) legs. This study focused on the skating laps. The skating races were held on a groomed trail with the track set only on the downhills, following the best line (shortest distance from corner to corner).

The ski-skating techniques resemble speed skating on snow with the addition of the double poling action. Several authors have attempted to define the three skating techniques most commonly used (Silletta and

Scheier, 1995; Kelly, 1990; Svensson, 1994). The author has chosen the terminology used by Cross Country Canada (Silletta and Scheier, 1995). They include, 1-skate, 2-skate, and offset skating techniques. Forward skating movement is achieved by combining a leg push off the inside edge of one ski, with a double pole push while gliding on the other ski. The names of these techniques are derived from the timing of the skating and the poling action (Silletta and Scheier, 1995). The 1-skate refers to the double poling action with every skate (Silletta and Scheier, 1995). It is used on the flats and slight uphills and downhills. The 2-skate refers to the double poling action timed with every other skate (Silletta and Scheier, 1995). It is also used over the same terrain as the 1-skate. The offset skate is similar to the 2-skate, except for the apparent offset poling action caused by planting the poles parallel to the uphill ski (Silletta and Scheier, 1995) and the more pronounced hip rotation to the uphill side (see Figure 1). It is mainly used as an uphill technique.

The variation in terrain and snow conditions make it necessary for the skier to change his technique frequently to maximize his speed (Silletta and Scheier, 1995). All highly skilled skiers should exhibit the same fundamental technical characteristics (Silletta and Scheier, 1995). Analysis of kinematics and temporal variables can help identify the most important factors associated with highly skilled performances.

B. Kinematics and Temporal Studies on Ski-Skating Techniques

The skating techniques are a relatively recent addition to the sport of cross-country skiing and are continuing to evolve. The studies on ski-skating techniques have until recently tended to investigate the kinematics of the offset skating techniques only. Smith, McNitt-Gray, & Nelson (1988) conducted a kinematics analysis of the skating technique used by competitors in the 1986 World Cup races in Holmenkollen, Norway. They reported that the fastest skiers skated with longer cycle lengths, but with cycle rates similar to the slower skiers. The stride length variation was attributed to the faster skier's ability to direct their centre of mass (C/M) in line with the forward direction. In a follow up study, Smith & Nelson (1988) conducted a kinematics study of the offset skating technique at three different intensities. They discovered that while the velocity increased for a given skier, the cycle rate continued to increase as well, but the cycle length remained constant. The cycle phase proportions also remained constant with an increased velocity even though the cycle time decreased. The faster skiers skated with longer cycle lengths at a given velocity.

A more detailed study of the offset technique was conducted by Smith, Nelson, Feldman, & Rankinen (1989) during the 1988 Winter Olympic Games in Calgary, Canada. Temporal characteristics of the offset technique were found to be affected by the degree of slope on the trail: cycle time decreased, cycle rate increased, and the length of the poling phase increased. Kinematic analysis revealed that the cycle velocity was maintained either by increasing the cycle length and decreasing the cycle rate or vice versa. The faster skiers exhibited less displacement of their C/M. The cycle length tended to increase as the C/M displacement increased.

Aro, Smith, & Nelson (1990) compared the offset skate kinematics of 18 male and 13 female cross-country skiers during the 1988 Winter Olympics on slopes of 5-6 degrees and 10-11 degrees. They found that on steeper terrain skiers increase their cycle rate, ski edging angle, stance width, and forward step displacement, but decrease their lateral movement, cycle length, and cycle velocity.

The most recent study on the offset skating technique was conducted during the Women's 30 km free technique cross-country ski race in 1992 Winter Olympics by Gregory, Humphreys, & Street (1994). They examined the offset skating technique on level terrain of eight skiers placing within the top half and another eight skiers placing in the bottom half of the field. They found high correlations between race velocity and cycle velocity. Cycle length and cycle rate showed a high negative correlation. Cycle velocity was neither correlated with cycle length nor cycle rate.

The differences in race velocities between the two groups were attributed to several factors. They found that the body segment, ski and pole angles differed between the two groups. The minimum and maximum elbow, knee, and trunk angles were significantly different. The faster skiers flexed their weak side elbow more at pole plant, but did not extend as much at the end of poling. There was a significant difference in the minimum weak side knee angles between the two groups. The faster skiers skated with a lower body position.

The minimum trunk angles were significantly different. The faster skiers had similar trunk angles to the slower skiers at the onset of poling, but finished with more trunk flexion at the end of poling. The ski and pole orientation angles were similar for both groups. The strong side ski was angled more relative to the direction of travel of the skier. However, the weak side pole was angled more as compared to the strong side pole relative to the direction of travel.

The poling and skating phase times were found to be the same for both groups whether they were expressed as either absolute time or as a percentage of the full cycle time.

The authors attributed the greater cycle velocity of the faster skiers in group 1 to the smaller resistive forces on their skis, to more effective application of propulsive forces, and to greater propulsive forces which would increase either cycle rate or length.

The offset technique used to be the most prevalent skating technique used by World Cup skiers. However, studies by McPherson (1991, 1993) have revealed more frequent use of the 1-skate and the 2-skate on gradual slopes, where the offset would have been used in the past. McPherson conducted a temporal and kinematic study of the skating techniques performed during the 1991 and 1993 Nordic World Championships. The author compared the cycle characteristics of the fastest skaters and found that there were no significant strong correlations between cycle velocity and cycle rate nor cycle length. The top five skaters demonstrated two different strategies for skiing fast. Three of the five fastest skiers had longer cycle lengths. The other two skiers had faster cycle rates but shorter cycle lengths. An increase in offset skating cycle length was found to be associated with a greater percentage of the full cycle spent skating off the weak side and smaller displacement of the centre of mass.

In a recent three dimensional study conducted during the 1992 Olympic Winter Games, Smith and Heagey (1994) investigated the descriptive kinematics of the 2-skate technique on flat terrain. Cycle velocity was positively correlated with race velocity, cycle length, and strong side knee range of motion. Cycle rate was not significantly related to cycle velocity. The poling phase contributed 20% of the complete cycle as compared to 55% for the skating phase.

The ski and pole angles for the 2-skate were found to differ from the offset skating technique angles. The skis were angled 6-8 degrees relative to the forward direction. Similarly, the mean velocity vector of the C/M from the forward direction was only 4 degrees. All skiers began edging their skis as soon as they contacted the snow and continued throughout the glide phase. However, significant correlations were neither found between ski edging angle and cycle velocity nor race velocity.

The researchers also found that the poles were oriented 10-20 degrees from the forward direction during the poling phase. The poles were planted (angled back) 15-20 degrees relative to vertical. In other words the poles were angled more in line with the forward direction of travel as opposed to the gliding ski with the offset technique.

Investigators have tended to look for biomechanical or physiological reasons for the differences in race velocities between the faster and slower skiers. Athletes and coaches believe that the glide characteristics also play an important role in helping a skier go fast. Street and Gregory (1994) studied the relationship between finish times and glide speed during the men's 50 km free technique race at the

1992 Winter Olympics. The skiers' glide speeds while in a tight tuck position were recorded on a flat section immediately following a steep downhill. The researchers found significant correlations between glide speed and finish times. The top 10 skiers had a 13% faster glide speed compared to the bottom 10 skiers. These differences were attributed to differences in kinetic friction, body weight, air resistance, or initial speed at the top of the hill. However significant relationships were neither found between skier mass and finish time nor glide speed. Also, air resistance was not considered an important contributing factor since all skiers maintained a tight tuck with small frontal area and they all wore skin tight lycra racing suits with minimal air drag. The authors concluded that the kinetic friction was the most important factor contributing to a skier's glide speed. In other words the fastest skiers had skis with better gliding characteristics than the slowest skiers.

In his recent book, Svensson (1994) summarizes much of the current information on ski skating mechanics. The author discusses poling and skating technique, downhill dynamics, and level and uphill dynamics in terms of force lines, and makes several recommendations regarding the poling phase. The poles should be planted backward at an angle less than 90 degrees to minimize the dissipation of force into the ground. The C/M should move through a minimal range of motion to save energy from working against gravity by raising and lowering the upper body. The large muscle groups of the trunk should be used as much as possible.

The investigator's recommendations for optimizing skating speed are as follows (Svensson, 1994). Increase cycle length and cycle rate. The trunk angle relative to vertical should not be greater than 45 degrees. The knee angles should range between 115 and 175 degrees. The lateral and vertical movements of the C/M should be minimized. The skating ski angle should also be minimized since the skiing distance down the trail is the product of the length of the skate ski glide and the cosine to the skate ski angle. The greater the angle the shorter the skating distance.

C. Physiological Demands of Cross-Country Ski Racing

In order to gain an understanding of the physiological factors affecting performance an examination of racing trail profiles and the physiology of cross-country skiing are required.

Cross-Country skiing has been shown to be the most demanding of all endurance sports (Bergh & Forsberg, 1992). The 1994 World Cup event held in Thunder Bay, Canada provided a good example of the distances and the types of terrain the men are expected to race. The men competed in a 50 kilometer free technique race on the Saturday, followed by a 4×10 km relay race on the Sunday. The 50 km race consisted of three laps of a hilly 16.7 km course with a total climb (MT) of 593.5 meters. The relay race consisted of two classic legs followed by two skating legs. The classic and skating legs were held on separate, equally challenging courses. Each competitor skied two laps of a 5 km course. The classic leg had a MT of 418 m compared to the MT of the free technique leg of 415 m.

Skiers characteristically have a wide variation in body mass, high VO_2max. values (Bergh et al., 1992), a higher percentage of slow twitch muscle fibre type in their legs (Rusko, 1992), and low lactate production while exercising (Eisenman, Johnson, Bainbridge, & Zupan; 1989).

Body mass has been reported to be less important in cross-country skiing as compared to running (Eisenman et al., 1989). Skiers however, tended to exhibit greater lean body mass than runners which satisfies a need for greater power output (Kelly, 1990).

The main source of energy in cross-country skiing has been shown to be provided by the aerobic system (Eisenman et al., 1989). Kelly (1990) reported that cross-country skiers have the highest VO_2max. values in humans, ranging from 75-94 ml/kg/min. (Bergh, 1982). In addition, the best skiers were able to race at 85-90% of their VO_2max. (Eisenman et al., 1989). Similar values have been shown by Sharkey and Heidel (1981) and Sharkey (1984). Consequently, VO_2max. and skiing velocity at a given %VO_2max. were highly correlated with performance (Ingjer, 1991; Bergh et al., 1992).

The percentage of slow-twitch muscle fibres (ST) has been correlated with a higher performance in skiers (Rusko, 1992), which is probably due to the high oxidative capacity of ST fibres (Bergh et al., 1992) and their ability to spare glycogen by utilizing more fat as a source of energy.

The importance of low lactate production in cross country skiers was identified by Eisenman et al. (1989). In a study on the importance of lactate production and removal during progressive exercise in humans; MacRae, Dennis, Bosch, & Noakes (1992) concluded that reduced lactate concentrations during sub-maximal work were a result of a combination of reduced lactate production and increased lactate clearance, but during higher work rates, the lower lactate concentrations were more a result of increased lactate clearance.

Rusko (1987) conducted a four year training study which involved 129 trained, young Finnish cross-country skiers. He observed that cycling VO_2max. and lactate threshold (LT) increased significantly with age even beyond 20 years of age. Weltman (1995) defined the LT as the breakpoint at which "the highest VO2 can be attained before an elevation in blood lactate is observed". Skiers who were selected to the Finnish National Team were able to increase their VO_2max. most effectively by intense training and increased their LT by continuous low intensity training. These findings were supported by earlier studies which showed that training intensity was the most important factor in raising VO_2max. in different groups varying in their fitness levels (Rusko & Rahkila; 1981; Mikesell & Dudley, 1984; Poole & Gaesser, 1985; and Wenger & Bell, 1986). In a follow up training study Rusko (1992) reported that a group of cross-country skiers and biathletes, who trained emphasizing high speed work increased their VO_2max. and LT after a period of four months. A second group, who trained by emphasizing distance training increased their LT expressed as $\%VO_2max$. After 2.4 years following the study, LT as a $\%VO_2max$. increased in the distance trained group and decreased in the high intensity group. Underwood (1990) described two types of skiers, those who trained hard and fast, and learned to tolerate high amounts of lactic acid (LA) in their muscles, and those who trained long and slow, and produced low amounts of LA in their muscles. The high LA group typically showed a drop in pace on the second lap, compared to the even pace of the low LA group. He suggested that the most successful skiers were characterized by low production of lactic acid.

A recent review by Loat & Rhodes (1993) reported that high correlations have been observed between LT and running velocity which emphasizes that LT is an important factor in successful endurance performance.

Researchers have used both the ventilatory (VT) and LT to predict anaerobic threshold. Wasserman (1984), Wasserman (1973), and Wasserman & Koike (1992) have suggested that nonlinear increases in VE and VCO_2 and the changes in the relationship between VE/VO_2 and VE/VCO_2 are accurate determinants of the anaerobic threshold, hence the term "ventilatory threshold".

However, a controversy exists as to whether VT and LT are measures of the same phenomenon (Weltman, 1995). Weltman (1995) concluded that the VT and LT are determined by different mechanisms and represent different phenomena. Unfortunately, blood lactate testing is invasive, requires more skilled technicians to operate the equipment, and costs more than non invasive methods for measuring the anaerobic threshold. Consequently, coaches and athletes have often chosen the non invasive methods to determine anaerobic threshold.

Droghetti, Borsetto, Casoni, Cellini, Ferrari, Paolini, Ziglio, and Conconi (1985) reported a strong correlation between a non invasive measure of anaerobic threshold and average race velocity for members of the Italian National Ski Team.

Conconi, Ferrari, Ziglio, Droghetti, and Codeca (1982) conducted a study with 210 runners. The researchers reported that the LT occurred when the heart rate and running speed relationship was no longer linear. Similar findings were reported by other studies (Ballarin, Borsetto, Cellini, Patracchini, Vitiello, Ziglio, Conconiet, 1989; Cellini, Vitiello, Nagliatti, Ziglio, Martinelli, Conconi, 1986; Droghetti et al., Conconi, 1985). These studies provided coaches and athletes with non invasive field tests for determining the anaerobic threshold using a heart rate monitor. Janssen (1995) described the heart rate-lactate relationship and how it can be used for prescribing training. The heart rate-lactate curve established a specific heart rate response at the anaerobic threshold. Once this point was established, the intensity of endurance training could be prescribed based on the individual's heart rate response (Janssen, 1995). The Canadians base their national cross country ski team training intensity models on the heart rate-lactate relationship (Siletta and Scheier, 1995).

D. Physiological Demands of Ski-Skating Techniques

A number of studies have been conducted to determine the physiological demands of skating as compared to the classical techniques both on snow skis and roller skis. Kubica, Wilk, Karvonen, Krasicki, & Kalli (1988) found that skating on snow has a lower energy cost than the diagonal stride at both sub maximal and maximal VO_2 for a given pace. The VO_2 values were estimated from regression curves obtained in the lab.

Karvonen, Kubica, Wilk, Wnorowski, Krasicki, & Kalli (1989) demonstrated that for the same speed, skating as compared to classical skiing showed lower heart rates, but at maximal effort there was no difference in the heart rates. In addition, lactate concentrations were lower for skating at sub maximal efforts, but were higher at maximal efforts. Similar lactate values were reported by Stray-Gundersen & Ryschon (1989). However, Bilodeau, Roy, & Boulay (1991) revealed no difference in heart rate and VO_2max. response between skating and classical techniques during a series of ski time trials on snow. Furthermore, the velocity for the skating technique time trials was 16% greater than for the classical technique. In general, skating is considered to be approximately 10% more efficient metabolically and to produce higher velocities for a given blood lactate concentration than classical skiing (Bergh & Forsberg, 1992a).

A series of investigations have studied the physiological response to different ski techniques while roller skiing. Hoffman, Clifford, Foley, & Brice (1990) determined that there were no significant differences between the offset skate, the double pole, and the kick double pole in regards to heart rates, ventilation, VO_2, rating of perceived exertion (RPE), and blood lactates. Hoffman & Clifford (1990), expanded the investigation on the influence of various techniques and included the diagonal stride, double pole, kick double pole, and the marathon skate. The diagonal stride showed the greatest physiological demands. The offset skate, marathon skate, kick double pole, and double pole techniques elicited similar heart rates and VO_2 responses, but lower values than the diagonal stride. Similarly, Bilodeau et al. (1991) reported no significant difference in heart rate values for three different skating techniques.

In another study however, by Hoffman, Clifford, Jones, Bota, & Mandli (1991), the kick double pole technique displayed the highest VO_2, HR, and ventilatory equivalent (VE). The double pole technique revealed the lowest VO_2 and the offset technique had the lowest RPE and respiratory exchange ratio. In a related study, Hoffman, Jones, Bota, Mandli, & Clifford

(1992) investigated the relationship between HR, VE, and RER with respect to VO_2 using regression analysis. The VO_2 for double poling was 12% lower than the skating techniques.

An investigation was conducted with competitive swimmers looking at the physiological effects of different swim strokes. A study by Kelly, Gibney, Mullins, Ward, Donne, and O'Brien (1990) examined the relationship between lactate profiles and heart rate responses in all four basic swim strokes and in an individual medley swim for eleven competitive swimmers. They revealed a variation in swim speeds at the initial onset of blood lactate accumulation (OBLA) and differences between lactate values at OBLA and maximum heart rates for different swim strokes. Heart rates varied considerably for different swim strokes. The authors concluded that swimmers should base their training for a given stroke on their lactate profiles for that specific stroke. The results of this study might be applicable to cross country skiing. Perhaps different skiing speeds should be prescribed for specific techniques in training to produce the fastest aerobic and anaerobic improvement for a given technique.

E. Timing Studies on Ski-Skating Events

Cross-Country ski competitors have been kept informed by their coaches on the their position relative to the rest the race field during the race through "split times" (Silletta & Scheier, 1995) However, split timing information has often been limited to just giving the skier concerned their ranking and time behind or ahead of the leader at a particular point on the trail. A timing study provides more complete information to athletes and coaches on how fast a particular individual has skied relative to the entire field. Time recording stations are usually positioned around the entire trail. The times to negotiate each section of the trail can be calculated for every competitor in the race. A timing study can provide important information to the coach on the current strengths and weaknesses of the athlete and of the training plan. Unfortunately, timing studies are seldom published in a public forum due their potentially strategic importance to the country that commissions them.

F. Census of Ski-Skating Techniques

There have been many kinematics and temporal studies published on the skating techniques, but none of these studies have addressed the question often asked by coaches, "what techniques are faster on a given type of terrain." The author of this study was unaware of any other published studies that have attempted to determine what technique the faster skiers use on a given type of terrain as compared to the slower skiers.

Summary

The review of literature addressed five different aspects of cross country ski skating: description of skating techniques, kinematics and temporal studies, physiological demands of the sport, physiological demands of skate skiing, timing studies, and census of skating techniques. In the first section on skating techniques three distinct skating techniques were identified. This study adopted the terminology used by Cross Country Canada, the national sport governing body for cross country skiing in Canada. The skating techniques discussed in this study included the 1-skate, 2-skate, and the offset skate. The names of these techniques were derived from the timing of the skating and the poling action. The 1-skate and the 2-

skate techniques are used on the flat, slight uphill, and dowhill sections of a ski trail. The offset skate is primarily an uphill technique.

The kinematic and temporal studies on ski skating in this section tended to focus on the offset skating technique. The most important factors reported in these studies regarding the offset skate are as follows:

1. The fastest skiers skated with longer cycle lengths at a given velocity. However, a few of the faster skiers skied with a shorter cycle length but were able to compensate by skiing with a higher cycle rate.

2. Race velocity increased as cycle velocity and cycle rate increased.

3. Cycle rate tended to increase with an increase in velocity on a given slope, but cycle length tended to remain constant.

4. Certain cycle characteristics were affected by the degree of slope on the trail. As the slope became steeper, the cycle rate and the length of the poling phase increased, but the cycle length and cycle velocity decreased. Also the cycle length increased as the percentage of the full cycle spent skating on the weaker side increased.

5. The faster offset skaters on level terrain skied with different body and pole segment angles as compared to the slower skiers. The faster skiers appeared to move their limbs through a greater range of motion by flexing their trunks, knees, and elbows more than the slower skiers.

The studies on the other skating techniques (1-skate and 2-skate) revealed similar findings as those for the offset technique. They are summarized as follows:

1. The fastest skiers had a higher cycle velocity, a greater cycle length, a greater cycle rate, a longer poling phase, and a minimal displacement of their C/M.

2. Race velocity increased as the cycle velocity increased. Cycle velocity increased when the cycle length and the strong side knee range of motion increased.

3.During the 2-skate the ski poles were planted at an angle more in line with the forward direction of travel as opposed to the direction of the gliding ski.

While there is strong evidence from some studies attributing poor race performance to biomechanical differences between the slower and the faster skiers, a recent study has attributed poor race performances to ski glide characteristics. Race finish times were found to decrease with increasing glide speed on a flat section following a steep downhill. Kinetic friction was found to be the most important contributing factor affecting glide speed.

A variety of studies have been conducted on the physiological demands of cross country skiing on the body. Although their were a wide range of body types reported to have competed at the elite level in the sport, it was clear that the top skiers had high aerobic capacities, greater lean body mass, high percentage of slow twitch muscle fibres, lower blood lactate production and lower lactate clearance rates while exercising. In addition the top skiers were able to race at a high percentage of their anaerobic threshold.

The lactate-heart rate response relationship is a well established method for prescribing and monitoring training intensities amongst cross country skiers.

The physiological demands of skate skiing are different from those of classical skiing.

1. Skate skiing expends less energy at a given speed as compared to classical skiing.

2. Skate skiing produces higher velocities for a given lactate value.

3. Lactate values during sub maximal efforts are lower when skate skiing as compared to classical skiing, but lactate values are higher at maximal efforts.

4. Heart rate, ventilatory equivalent, and VO_2 response varied between the skating and classical techniques.

5. A swimming study revealed variations in heart rate response and lactate production among the four basic swim strokes. This may have implications for training cross country skiers because like swimming, different techniques are used in cross country skiing. Similar studies remain to be conducted with ski skating to compare the physiological response to the different skating techniques.

National team coaches and sport governing bodies regularly commission timing studies at major skiing events. The author of this study was unaware of any other published studies that have attempted a census of the skating techniques used by the faster skiers on a given type of terrain as compared to the slower skiers.

Finally, the author of this study was unable to find any studies that attempted to develop a physiological and biomechanical profile of international level skate skiers under actual race conditions.

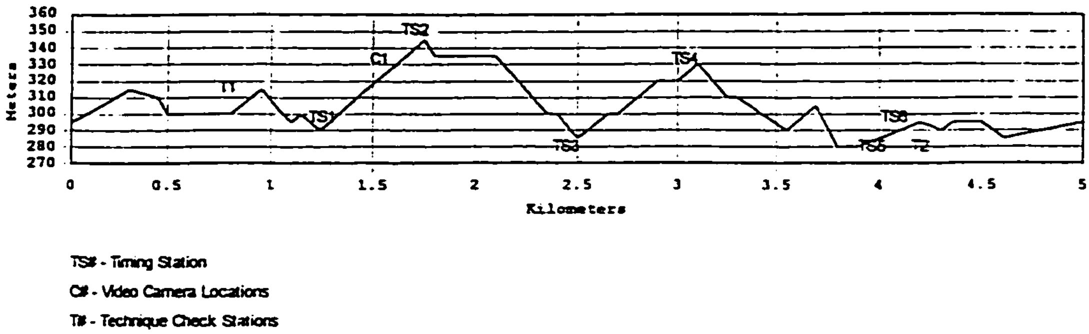
Chapter 3

Methods And Procedures

Subjects

The study was conducted during the skating legs of the Men's 4X10 Kilometer Cross-Country Ski Relay event at the 1994 World Cup at the Big Thunder National Ski Training Centre in Thunder Bay, Ontario, Canada. The study involved the collection of physiological data from six male members of the Canadian National Cross Country Ski Team, approximately four months prior to the competition. Biomechanical and timing study data were collected during the relay race. Other international teams were not requested to participate in the physiological testing, and consequently only biomechanical and timing study data were collected on the remaining 18 athletes in the relay event. These additional subjects increased the sample size and provided the basis for a technique comparison between the Canadians and the fastest international athletes. The competitors skied two laps of a five Kilometer free technique course as shown in the trail profile (see Figure 3).

Figure 3
Vertical Profile of the Skating Relay Course: Video Camera Location, Timing Study Stations, and Technique Census Stations.



Procedures

The nature of this study required that data be collected both within the laboratory and at the cross-country relay race site. Consequently, the procedures were divided into two sections: procedures in the laboratory and procedures at the race site.

Procedures in the Laboratory

The procedures in the laboratory are described under the following headings: VO_2peak testing and monitoring of heart rates. Descriptive statistics were used to summarize the data.

VO_2peak Testing

Approximately four months prior to the start of the race, the Canadian National Team members performed a VO_2peak aerobic exercise test on a motorized running treadmill as part of their regular testing program. The athletes had the option of being tested at one of three centres, either the University of Calgary, Lakehead University, or Laval University.

The testing centres followed the protocol used by Cross Country Canada's National Ski Team. The treadmill was set at 6.5 mph for seven minutes to provide the athletes with a warm-up. After the warm-up, the treadmill speed was increased to 8 mph, where the speed remained unchanged until the end of the test. Progressive increases in the workload were achieved by raising the elevation of treadmill by two percent (0, 2, 4, ...grade) every three minutes until the athlete reached exhaustion.

During the treadmill testing each athlete was attached to a Beckman MMC Horizon System for monitoring, peak values for oxygen uptake (VO_2peak) and ventilation (VE) as described by Watts, Hoffman, Sulentic, Drobish, Gibbons, Newbury, Mittlestadt, O'Hagan, & Clifford (1993). The athletes' anaerobic thresholds were estimated using their ventilatory and/or lactate threshold.

Monitoring of Heart Rates

Each of the six Canadian athletes were fitted with a Polar Vantage XL heart rate monitor prior to starting the treadmill. They were asked to set the heart rate function on their monitors to record information every minute. The monitors were activated by each individual a few seconds before the start of their test. The monitors were stopped as they were collected from the athletes, immediately following their test. The stored memory files were downloaded a few hours later using the Polar Computer Interface unit and Polar Heart Rate Analysis Software. A heart rate profile was generated for each athlete including the maximum heart rate.

The recording of heart rates and of whole blood lactate concentrations during training and competitions were a routine procedure for members of the Canadian National Ski Team. They were used as indices for monitoring aerobic fitness and for prescribing optimum training intensities.

Procedures at the Race Site

Physiological, kinematic, and temporal data were recorded during the relay event. Physiological data included monitoring heart rates during the race, and whole blood lactates immediately before and after the race for the six Canadian athletes.

A kinematic and temporal analysis of the offset skating technique used by 24 of the competitors was conducted using video footage recorded from the skating legs of the relay.

A timing study and a census of techniques used on different uphill grades were used to provide additional descriptive information in order to enhance the interpretation of the findings.

A more detailed description of the race site procedures can be found under the following headings: physiological analysis, kinematics and temporal analysis, timing study, and census of skating techniques used on different terrain.

Physiological Analysis

The physiological analysis included the recording of heart rates during the race and the determination of whole blood lactate concentration before and after the finish of the race.

Monitoring of Heart Rates

Each of the six Canadian athletes were fitted with a Polar Vantage XL heart rate monitor prior to the start of the race. Athletes were asked to set the heart rate function on their monitors to record information every minute. The monitors were started by each individual a few seconds before the start of their relay leg. The monitors were stopped as they were collected from the athletes, immediately following their relay leg. The stored memory files were downloaded a few hours later using the Polar Computer Interface unit and Polar Heart Rate Analysis Software. A race heart rate profile was generated for each athlete. These profiles were matched with intermediate times obtained from the timing study, (conducted during the race) to determine the heart rate response to a given section of the course. The individual heart rate data from the race combined with their maximum heart rate recorded during previous lab tests were used to determine the percentage of the race time spent near their maximum heart rate.

Blood Lactate Sampling

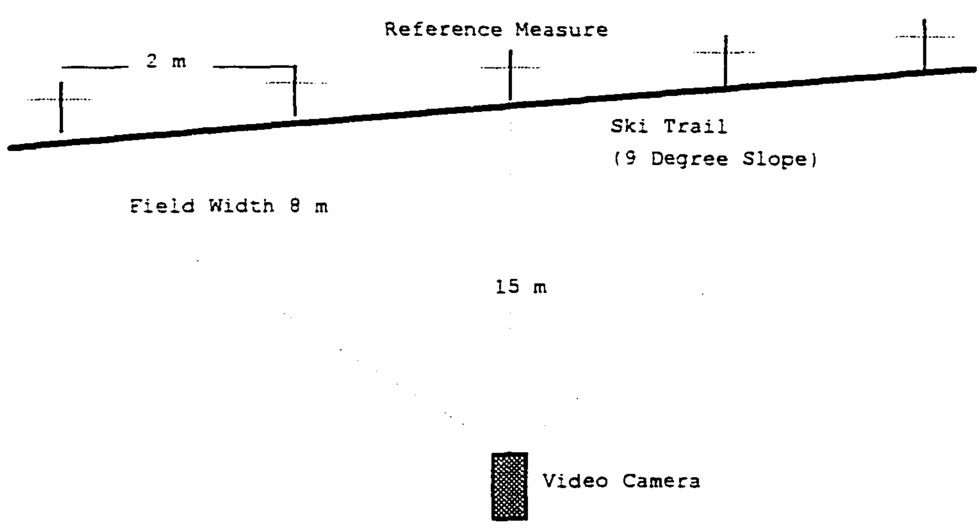
Whole blood samples were collected from the finger tips of the six Canadian athletes. Samples were taken while the subject was sitting, 10 minutes before the start of the race, and two, three, and four minutes immediately after they finished the race. Penlet II Automatic Blood Samplers were used to puncture the skin. A new, sterile lancet and a new Penlet cap were used to collect every sample. A 40 µl sample of blood was drawn into a capillary tube from which a 25 µl sample was removed with a micro pipette. This sample was then added to a YSI 2372 Blood Lactate Preservative Tube containing 100 µl of double distilled water. These tubes were carefully labeled and then stored in a cooler until they were analyzed two hours after the finish of the event. The preserved samples were analyzed at the Lakehead University Human Performance Laboratory using a 1500 YSI Sport Lactate Analyzer. The dilution of the whole blood was corrected for by multiplying the values obtained by a factor of four.

Individual lactate profiles were determined for each of the Canadian athletes. The peak post race lactate concentrations and the rate of change in the lactate concentrations during the collection period were compared to other post race lactate studies involving cross-country skiers.

Kinematic and Temporal Analysis

Kinematic and temporal data were collected on 24 athletes, including the six Canadian skiers, who were competing in the free technique laps of the relay race. A Panasonic SVHS video camera was positioned at the 1.7 kilometer mark on the course (see Figure 3) to record a side view of the skiers offset skating on a nine degree slope, as shown in Figure 4.

Figure 4
Side View of the Video Camera Recording Station.

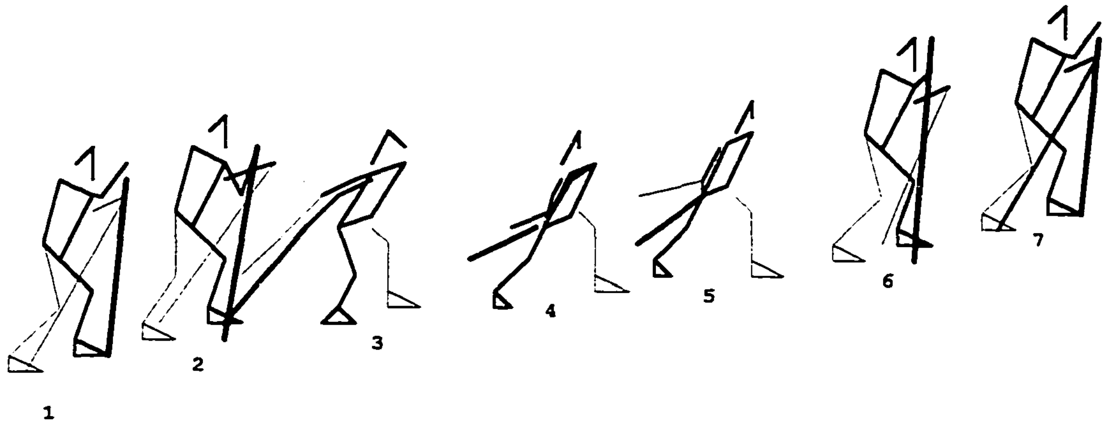


The camera was positioned approximately 15 meters, perpendicular to the trail and leveled. The field width was 8 meters. The camera recorded video images at a rate of 30 frames/second. However, the Peak 2D Motion Analysis System software enhanced the video signal to produce a sampling rate equivalent to 60 frames/second. The shutter on the camera was set at 1/1000 to match the lighting conditions and to minimize the exposure time.

Quantitative Analysis

The kinematic data were analyzed quantitatively using the Peak 2D Motion Analysis System located at the Biomechanics Laboratory at Lakehead University. Key event frames were digitized for one complete cycle of the skating techniques used by each of the athletes. The key events for the offset technique included high pole plant, high foot plant, high pole release, toe-off, foot plant, toe-off, and high pole plant (see Figure 5). These key events were chosen based on a review of the literature, as well as for practical reasons. The events represented the beginning or ending of each of the poling and skating phases. In addition,

Figure 5
Key Event Frames for the Offset Skating Technique.



Key event Frames:
1.High Pole Plant
2.High Foot Plant
3.Pole Release
4.Toe Release
5.Foot Plant
6.Toe Release
7.High Pole Plant

they were easy to recognize during the digitizing process.

The digitized image of the skiers was based on a 23 point spatial model consisting of: limb joint centers, trunk, head, and pole positions (see Appendix 5). The Peak 2D System assigned horizontal and vertical coordinates to each of these points for every frame selected for analysis.

The choice of variables for kinematic analysis was selected on the basis of the review of the literature and was delimited to those which could be accurately assessed in two dimensions. The variables chosen for the study included cycle time, cycle rate, cycle length, cycle velocity, uphill pole angle, and the resultant distance between the uphill pole tip and adjacent ankle at the moment of pole plant.

The temporal data were collected by counting the number of video frames between key events. The temporal variables included percentage of the cycle spent poling, percentage of the cycle spent skating on the uphill leg, and the percentage of the cycle spent skating on the downhill leg.

The kinematic and temporal variables were analyzed using descriptive statistics (means, standard deviations, minimum, and maximum) generated by the Statistical Package for the Social Sciences, Personal Computer version (SPSS/PC). The Pearson product-moment correlation for pairs of variables was used to show the strength of the linear relationship between the variable race velocity and selected kinematic and temporal variables. The strength of the linear relationships among the selected variables were also investigated. The correlation coefficients were calculated using the SPSS/PC. A direct multiple regression model was developed to predict race velocity using the SPSS/PC. A further stepwise multiple regression analysis was performed using the SPSS/PC to identify those variables which accounted for the greatest percentage of variance in predicting race velocity.

Qualitative Analysis

The nine fastest skiers and the six Canadian skiers were compared qualitatively on the basis of their arm positions at the moment of the uphill pole plant and pole release. The faster skiers would be expected to use their arms through a greater range of motion than the slower Canadian skiers. In addition their leg positions at the moment of uphill foot plant and toe off were compared for the same reason as the arm positions.

Timing Study

A timing study was conducted during the relay race on the 5 kilometer free technique course. Six teams of two observers were stationed at the top and the bottom of hills along the free technique course (see Figure 3). They were located at the 1.25 km, 1.75 km, 2.5 km, and 3.1 km marks along the trail. One of the observers called out elapsed times as the skiers raced by the station, and the other person matched the times to the bib numbers. All stopwatches were started at the same time prior to the race. Intermediate times to negotiate different sections of the course were calculated by subtracting the times from the stations immediately before or after a given station. In turn these intermediate times were used to calculate the race velocities for the different sections of the course.

Census of Skating Techniques

Figure 3 shows the location of two technique observers on the course. The first observer was located between the 0.84 and 0.90 km marks. The second observer was located between the 4.1 and 4.2 km marks. They recorded the skating techniques used by each of the competitors within their section (see Appendix 1 and 2). This aspect of the study was used as a census for gauging the choice and frequency of the skating techniques used on different uphill grades. The information gathered was used to help explain other findings of the study.

Chapter 4

Results

The results follow the same format as detailed in the methods section: physiological analysis, kinematics and temporal analysis, timing study analysis, and skating technique census.

Table 1 provides some descriptive information on all 24 of the competitors, including subject names, rankings, team affiliation, and race times.

Physiological Analysis

The physiological analysis involved the six Canadian athletes from the skating part of the relay race. Table 2 shows some descriptive physiological information collected in the lab from the Canadian skiers four months prior to the race. The physiological descriptives included, body weight, age, VO_2peak, anaerobic threshold and maximum heart rate.

The race site physiological results are presented under the headings of heart rate analysis and lactate analysis.

Table 1
Results From the Skating Portion of the 1994 Men's World Cup Cross Country Ski Relay Race.

Relay Leg	Rank By Race Time	Subject	Team	Race Times (min:sec)
3	1	J. Isometsa	Finland	22:32
3	2	B. Daehli	Norway	23:06
3	3	J. Muehlegg	Germany	23:06
3	4	S. Broers	Norway	23:10
3	5	H. Forsberg	Sweden	23:11
3	6	G. Godioz	Italy	24:08
3	7	E. Kristiansen	Mixed	24:09
3	8	**1***	Canada 1	24:17
3	9	P. Vordenberg	USA	24:37
3	10	M. King	Mixed	25:51
3	11	**3***	Canada 2	26:21
3	12	P. Ozadsky	Mixed	26:55
3	13	G. Bond	Mixed	27:19
3	14	**5***	Canada 3	27:44
4	1	T. Alsgaard	Norway	23:35
4	2	T. Mogren	Sweden	24:08
4	3	J. Hartonen	Finland	24:21
4	4	A. Eide	Norway	24:30
4	5	P. Schlickenrieder	Germany	24:58
4	6	S. Barco	Italy	25:04
4	7	C. Swenson	USA	25:10
4	8	M. Hasler	Mixed	25:20
4	9	**2***	Canada 1	25:31
4	10	**4***	Canada 2	27:41
4	11	**6***	Canada 3	28:36

***1-6 represent the Canadian Subjects**

Heart Rate Analysis

The heart rates for five of the six Canadian skiers who competed in the free Technique sections of the relay were expressed as means and percentage of maximum heart rate (MHR) for consecutive sections of the course. One subject neglected to start his heart rate monitor at the start of the race. The MHR was

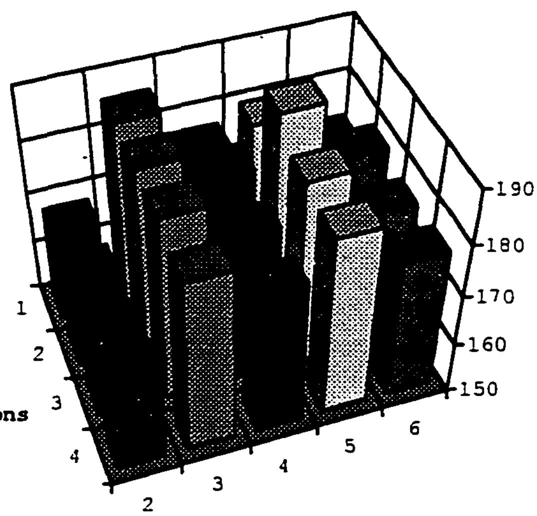
Table 2
Descriptive Physiological Characteristics of the Canadian Skiers.

Subject	Age	Body Weight (Kg)	VO_2peak (ml/kg/min)	AT as a Percentage of VO_2peak	AT as a Percentage of Maximum Heart Rate
1	23	77	66.7	81.8	92.9
2	24	76	-	-	-
3	21	64	66.6	92.6	92.0
4	-	62	68.1	88.2	92.1
5	-	-	-	-	-
6	20	80	72.5	90.2	87.6
Mean	22	71.8	68.47	88.2	91.2
S.D.	1.8	8.2	2.77	4.63	2.4

determined during the earlier laboratory testing. Figure 6 shows the mean heart rate values for each of the skiers on the first four sections of the course from timing station 1 to 4 (refer to Figure 3). These sections were classified according to the amount and type of slope. Section 1 (Start - TS1) was generally rolling. Section 2 (TS1 - TS2) and 4 (TS3 - TS4) were mainly uphill. Section 3 (TS2 - TS3) was predominantly downhill. The skiers with the highest race velocities (2 and 3) had the most consistent (flattest) heart rate profiles throughout the four sections of the trail. The slower skiers (4, 5, 6) showed more variation in their mean heart rate profiles. All three of these skiers showed increases in section 2. Skiers 4 and 5 showed a gradual decrease in their heart rates of 3 and 5 beats/min. respectively through sections 3 and 4.

Figure 6

Mean Heart Rate Values of the Canadian Skiers Recorded in Four Adjacent Sections of the Race Course.

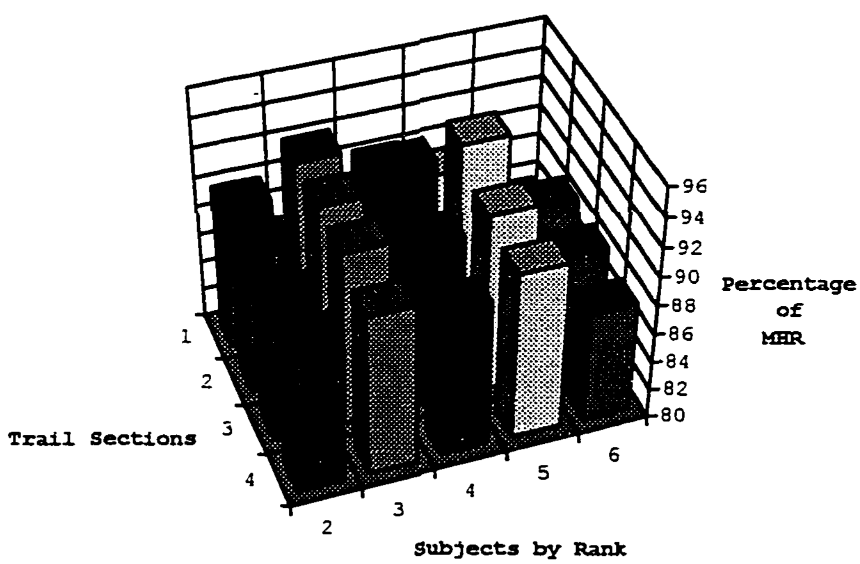


Skier 6's heart rate dropped only 2 beats/min. for sections 3 and 4.

Figure 7 illustrates the mean percentage of maximum heart (%MHR) rate values for the competitors on the different sections of the course. All of these skiers' mean %MHR values were close to 90 percent for all four sections of the course. The skiers with the highest race velocities (3 and 2) maintained their %MHR at 92 and 90 percent respectively, regardless of the terrain.

Figure 7

Mean Percentage of Maximum Heart Rate (MHR) Values for the Canadian Skiers on Four Adjacent Sections of the Course.



The next slowest skiers (4 and 5) showed an increase of 3 and 5 %MHR respectively on the first long uphill (section 2), followed by a gradual decline of 3 %MHR for the next two sections. The slowest skier in the group (6), showed an increase of 3 %MHR in section 2 but, unlike the previous group, he maintained a constant 88 %MHR for the last two sections.

Pre and Post-Race Lactates

Figure 8 demonstrates the pre and post-race whole blood lactate values for six Canadian skiers who were ranked according to their race finish times. The pre-race average lactate value was 1.9 mMoles/l. The S.D. of 0.71 indicated considerable variation in the pre-race values. The skiers attained their peak post-race (PPL) values within two to three minutes. The PPL values ranged from 6.52 to 11.48 mMoles/l. Figure 9 compares the skiers' peak lactate clearance rates post-race. The fastest and the slowest skiers had a lactate clearance rate of 0.26 mMoles/l/min. The highest lactate clearance rates were achieved by the second (1.0 mMole/l/min.) and third (1.38 mMoles/l/min.) ranked skiers. The fourth and fifth ranked skiers had the lowest lactate clearance rates (0.16 and 0.14 mMoles/l/min.).

Figure 8

Lactate Concentrations in Whole Blood Values for the Canadian Skiers Pre and Post-race.

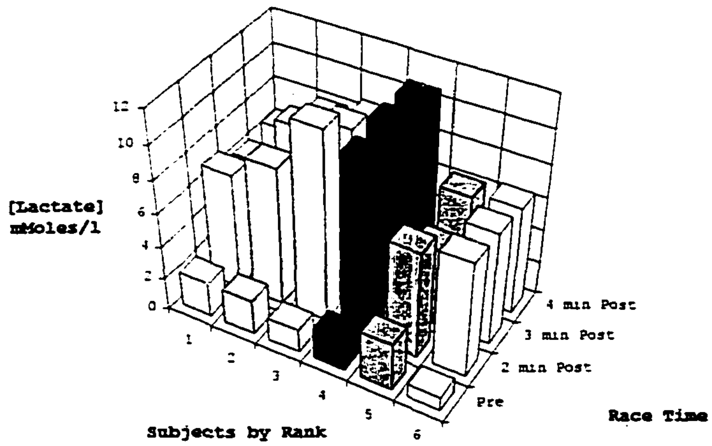
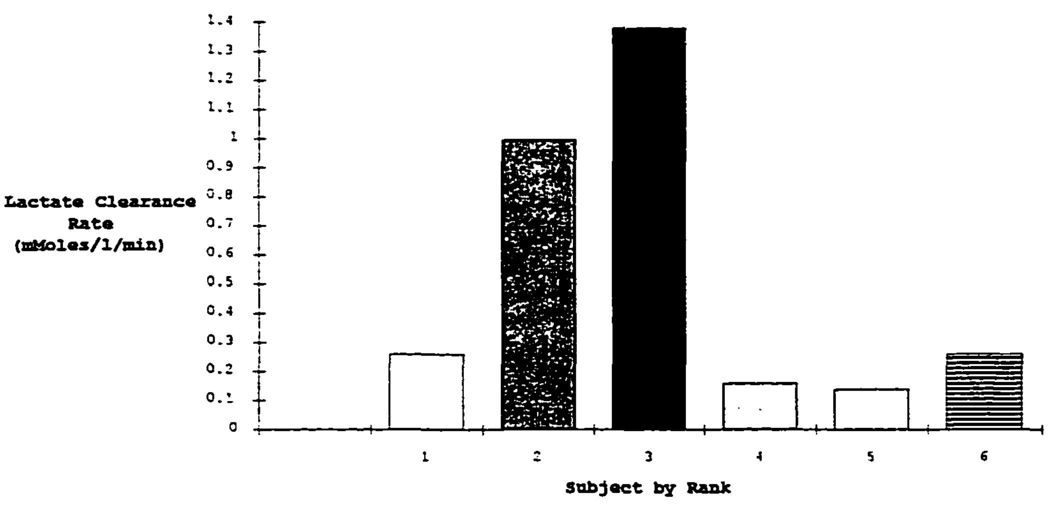


Figure 9

Peak Lactate Clearance Rates Amongst the Canadian Skiers Post-race.



Kinematic & Temporal Analysis

The kinematic results for 24 of the competitors were described in quantitative and qualitative terms.

Quantitative Analysis

The Canadian skiers were compared on the basis of nine kinematic and temporal variables (see Table 3). There appeared to be noticeable differences within the group, and no distinct trends.

The top nine skiers in the race and the six Canadian skiers were then compared on the basis of nine kinematic and temporal variables that were recorded while they were offset skating on a nine degree slope. The mean values for these variables are shown in Table 4. The two groups had some distinct differences for eight of the nine selected variables. The top competitors as compared to the Canadians had a race velocity 0.78 m/s faster, a cycle length 0.71 m longer, a cycle time only 0.02 seconds longer, a cycle velocity 0.43 m/s faster, a percentage of the full cycle time poling 4.12% smaller, a 5.2% smaller difference between the percentage of the full cycle skating on the uphill leg as compared to the downhill leg, and a horizontal distance between the pole tip and adjacent ankle 0.131

meters smaller.

Table 3
Descriptive Kinematic and Temporal Characteristics of the Canadian Skiers.

Variables	Subject #1	2	3	4	5	6	Mean	S.D.
RV	6.85	6.53	6.32	6.14	6.0	5.94	6.28	0.354
CL	5.19	5.01	4.45	4.95	5.14	5.31	4.98	0.139
CT	1.33	1.20	1.17	1.10	1.27	1.1	1.20	0.090
CV	3.89	4.17	3.81	4.5	4.05	4.8	4.21	0.376
PP	45.00	41.66	45.71	48.48	44.73	45.45	45.17	2.19
PUS	47.50	50.00	51.42	45.45	50.00	48.48	48.80	2.13
PDS	45.00	38.89	40.00	45.45	36.84	42.42	41.43	3.44
UPA	3.2	12.4	6.4	6.1	13.2	7.2	8.08	3.9
PAD	0.483	0.162	0.195	0.174	0.671	0.570	0.37	0.226

RV -Race Velocity (meter/second)
CL -Cycle length (meter)
CT -Cycle time (seconds)
CV -Cycle velocity (meter/second)
PP -Percentage of cycle time poling
PUS -Percentage of cycle time on uphill ski
PDS -Percentage of cycle time on downhill ski
UPA -Uphill pole angle at pole plant (degrees)
PAD -Distance between pole tip and adjacent ankle (meter)

A correlation analysis was conducted to determine the contribution of these kinematic variables toward race velocity.

Correlation Analysis

A correlation analysis was conducted on nine selected kinematic variables recorded in the sagittal plane. A description of these variables is shown in Table 5. Seven of these variables demonstrated significant relationships at either the $\underline{P}<.05$ or $\underline{P}<.01$ levels (2-tailed) level of confidence. A correlation coefficient of r=0.4060 was required for significance at the $P<.05$ level compared to an r=0.5168 at the $\underline{P}<.01$ level.

Significant relationships at the $\underline{P}<.05$ level existed between two of the selected variables and the race velocity (see Table 6). Cycle velocity correlated positively with race velocity (r=.4550). The greater the cycle velocity while offset skating the greater the race velocity. The 'percentage of the cycle time spent skating off the downhill leg' was positively correlated with race velocity (r=.5051). The greater the percentage of the cycle time spent offset skating on the downhill leg, the greater the race velocity. A slightly stronger correlation at $\underline{P}<.01$ level was found between race velocity and cycle length (r=.5330). The longer the cycle length while offset skating, the greater the race velocity. Although these variables were positively correlated with cycle velocity they are weak correlations.

Table 4

Mean Values of Kinematic and Temporal Variables for the Top Skiers (N=9) as Compared to the Canadian Skiers (N=6).

Variables	Top Skiers (Mean)	Top Skiers (± S.D.)	Canadian Skiers (Mean)	Canadian Skiers (± S.D.)
RV	7.06	0.229	6.28	0.354
CL	5.69	0.394	4.98	0.319
CT	1.22	0.059	1.20	0.090
CV	4.64	0.320	4.21	0.376
PP	41.05	3.58	45.17	2.19
PUS	45.32	3.99	48.80	2.13
PDS	43.15	3.03	41.43	3.44
UPA	5.11	4.50	8.08	3.90
PAD	0.239	0.094	0.370	0.226

RV -Race Velocity (meter/second)
CL -Cycle length (meter)
CT -Cycle time (seconds)
CV -Cycle velocity (meter/second)
PP -Percentage of cycle time poling
PUS -Percentage of cycle time on uphill ski
PDS -Percentage of cycle time on downhill ski
UPA -Uphill pole angle at pole plant (degrees)
PAD -Distance between pole tip and adjacent ankle (meter)

Table 5
Descriptive Statistics for the Kinematic and Temporal Variables (N=24).

Variable	Mean	S.D.	Minimum	Maximum
RV	6.68	0.42	6.10	7.39
CL	5.37	0.54	4.00	6.38
CT	1.21	0.11	0.97	1.40
CV	4.45	0.47	3.26	5.26
PP	43.48	3.95	34.28	51.72
PUS	47.35	4.09	37.14	55.17
PDS	41.22	3.50	35.13	48.57
UPA	6.22	3.92	0.60	13.50
PAD	0.275	0.157	0.102	0.671

RV -Race Velocity (meter/second)
CL -Cycle length (meter)
CT -Cycle time (seconds)
CV -Cycle velocity (meter/second)
PP -Percentage of cycle time poling
PUS -Percentage of cycle time on uphill ski
PDS -Percentage of cycle time on downhill ski
UPA -Uphill pole angle at pole plant (degrees)
PAD -Distance between pole tip and adjacent ankle (meters)

Additional relationships were revealed among the remaining variables (see Table 6). Cycle velocity increased with increasing cycle length. One of these pairs of variables demonstrated significance at the $p<.01$ level. Cycle length was positively correlated ($r=.6073$) with cycle velocity.

Table 6

Correlation Between the Race Velocity and Selected Kinematic and Temporal Variables (N=24).

Correlation:	**RV**	**CL**	**CT**	**PP**	**CV**
RV	1.0000	.5330*	.0457	-.2293	.4550*
CL	.5330**	1.0000	.3846	-.0987	.6073**
CT	.0457	.3846	1.0000	-.2021	-.4963*
CV	.4550*	.6073**	-.4963*	.0724	1.0000
PP	-.2293	-.0987	-.2021	1.0000	.0724
PUS	-.1681	-.2355	-.4488*	.2612	.1702
PDS	.5051*	.3279	.0402	-.0203	.2428
UPA	-.3586*	-.4387*	-.0635	-.1213	-.3628

2-tailed significance: *$p<.05$. **$p<.01$.

RT -Race time
CL -Cycle length
CT -Cycle time
CV -Cycle velocity
PP -Percentage of cycle time poling
PUS -Percentage of cycle time on uphill ski
PDS -Percentage of cycle time on downhill ski
UPA -Uphill pole angle at pole plant

Table 6 (continued)
Correlation Between the Race Velocity and Selected Kinematic and Temporal Variables (N=24).

Correlation	PUS	PDS	UPA
RV	-.1681	.5051*	-.3586
CL	-.2355	.3279	-.4387*
CT	-.4488*	.0402	-.0635
CV	.1702	.2428	-.3628
PP	.2612	-.0203	-.1213
PUS	1.0000	-.4787*	.0839
PDS	-.4787*	1.0000	-.5022*
UPA	.0839	-.5022*	1.0000

2-tailed significance: *$\underline{P}<.05$. **$\underline{P}<.01$.

RT -Race time
CL -Cycle length
CT -Cycle time
CV -Cycle velocity
PP -Percentage of cycle time poling
PUS -Percentage of cycle time on uphill ski
PDS -Percentage of cycle time on downhill ski
UPA -Uphill pole angle at pole plant

The remaining relationships were revealed at the $\underline{P}<.05$ level of significance. Cycle length had a weak negative correlation with the 'uphill pole angle at pole plant' (r=-.4387). This implied that cycle length increased as the pole angle relative to vertical angle decreased. Cycle time had a weak negative correlation with the 'percentage of the cycle time skating on the uphill ski' (r=-.4488) and the cycle velocity (r=-.4963). This means that the cycle time decreased with increasing cycle time on the uphill ski and increasing cycle velocity. The 'percentage of the cycle time on the downhill skating leg' was negatively correlated (r=-.5022) with the 'uphill pole angle relative to vertical at pole plant' and the 'percentage of the cycle skating on the uphill ski' (r=-.4787). This means that as the percentage of the cycle time on the downhill ski increased, the uphill pole angle and the percentage of the cycle time skating on the uphill leg decreased.

In summary the cycle length and the percentage of the cycle time skating on the downhill ski were shown to be significantly correlated ($\underline{P}<.05$) to race velocity. Although these relationships were statistically weak. In addition, uphill pole angle relative to the vertical at the moment of pole plant had a weak negative correlation with several variables at the $\underline{P}<.05$ level of significance. Consequently, these three variables were used as the basis for comparing the skating characteristics of the top skiers versus the Canadian skiers.

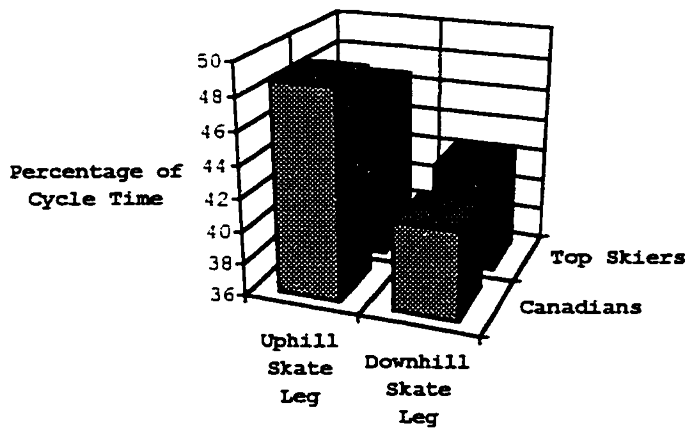
The mean cycle length for the top skiers was 5.69 meters (S.D. 0.394) as compared to the Canadian mean of 4.98 meters (S.D. 0.319).

Figure 10 illustrates the differences in the percentage of the cycle skating on the downhill leg as compared to the uphill leg. A large variation existed between the skating percentage on either leg between and within the two groups. The top skiers had a mean uphill skating leg percentage of 46.59 (S.D. 2.65) and downhill skating leg percentage of 42.28 (S.D. 2.89). The Canadians had a mean uphill leg percentage of 48.8 (S.D. 2.13) and a downhill leg percentage of 41.43 (S.D. 3.44).

The pole angle relative to vertical at the moment of pole plant was negatively correlated to race velocity ($\underline{P}<.05$). This means that the fastest skiers had a more vertical pole plant compared to the slower skiers. The mean uphill ski pole angles at the moment of pole plant of the top skiers as compared to the Canadians varied considerably within the groups. The top skiers had a mean angle of 3.5 degrees (S.D. 4.3) as compared to the Canadian mean angle of 8.08 degrees (S.D. 3.9).

Figure 10

Mean Offset Skating Technique Characteristics for the Top Skiers (N = 9) as Compared to the Canadian Skiers (N = 6).



Multiple Regression Analysis

The previous correlation analysis revealed that the variables cycle length, and percentage of the cycle skating on the downhill ski were significantly correlated with the variable race velocity in the sagittal plane. This subset of predictor variables was used to build a direct multiple regression model to predict race velocity using the method of least squares. The results generated by the SPSSPC program are shown in Table 7.

Table 7
Direct Regression Statistics Used to Predict Race Velocity (N=24).

Variable	B	SE B	Beta	T	Sig T
PDS	.044231	.021272	.370079	2.079	.0500
CL	.318529	.137728	.411626	2.313	.0310
Constant	3.153540	.946448		3.332	.0032

PDS -Percentage of cycle skating on the downhill leg
CL -Cycle length

The prediction equation is shown below. The variables are arranged according to their predictive power.

$$Y = 3.1535 + 0.3185X_1 + 0.0442X_2$$

where:

Y - predicted values of race velocity
3.1535 - the regression constant
0.3185, 0.0442 - regression weights or coefficients
X_1 - predictor variable cycle length (m)
X_2 - predictor variable percentage of cycle skating on the downhill ski

The multiple correlation coefficient for the direct regression model was R=.63741. The F-test statistic of F=7.18555 was significant at $P<.05$ since the level of significance for F=.0042. The hypothesis predicting an order to the relative importance of the selected variables was confirmed at the $P<.05$ level of significance.

A stepwise technique was used to derive the best prediction model from the same subset of predictor variables as in the direct regression model. Table 8 shows the results of the SPSSPC stepwise regression analysis.

Table 8
Stepwise Regression Statistics Used to Predict Race Velocity (N=24).

Variable	B	SE B	Beta	T	Sig T
Cycle Length	.412433	.139596	.532975	2.954	.0073
Constant	4.472351	.753681		5.934	.0000

The resulting regression equation was:

$$Y' = 4.4723 + 0.4124X_1$$

where: Y' - Race velocity

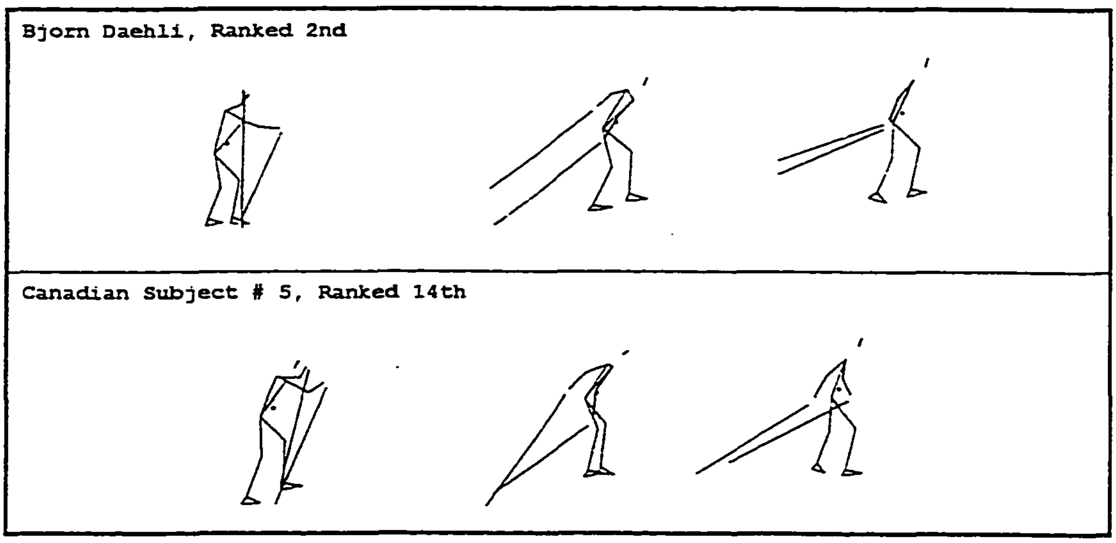
X_1 - Cycle length.

The stepwise analysis removed the predictor variable percentage of cycle skating on the downhill ski. This predictor added little power to the equation. The F-statistic for this predictor variables was non-significant $P \geq .05$. Therefore although the multiple correlation coefficient for the stepwise model was R=.5329, slightly lower than for the direct equation (R=.6374), the stepwise regression model was almost as useful in predicting cycle velocity.

<u>Qualitative Analysis</u>

The 2-D analysis prevented the accurate measurement of most of the body segment angles of the skiers that were captured while they were offset skating on a nine degree slope. However, slow motion and freeze frame analysis of the skiers' key event frames revealed some differences in terms of their arm extensions at the moment of 'pole release'. A top skier and a Canadian skier were selected to illustrate these differences in Figure 11. Neither of the skiers within the two groups fully extended their knees at the end of a skate at 'toe release' nor their elbows at 'pole release' (see Figure 11). However, the top skiers tended to extend their wrists well past their hips during 'pole release' (Figure 11). By contrast four of the six Canadians did not appear to extend their wrists past their hips to the same extent at 'pole release' (Figure 11). There did not appear to be any noticeable difference between the two groups with regards to their amount of leg extension at 'toe release' (Figure 11).

Figure 11
The Arm and Leg Extensions of a Canadian Skier as Compared to a Top Skier at the Moment of 'Pole Release' and 'Toe Release' During the Offset Skating Cycle.



Uphill Pole Plant   Pole Release   Toe release

Timing Study

The average race velocities of the Canadian skiers for four consecutive sections of the course are shown in Table 9.

Table 9
Average Race Velocities of the Canadian Skiers for Four Consecutive Sections of the Race Course.

Canadian Subjects	Race Velocity (m/s) Rolling (0-1.25 Km) Lap 1,Lap 2	Up (1.25-1.75 Km) Lap 1, 2	Down (1.75-2.5 Km) Lap 1, 2	Up (2.5-3.1 Km) Lap 1, 2
1	7.83,	2.98, 3.07	4.65, 4.65	6.52, 6.25
2	7.69,	3.03, 3.17	4.68, 4.62	6.19, 6.59
3	7.55,	2.91, 2.82	4.27, 4.21	5.88, 5.77
4	7.60,	- , 2.70	- , 4.23	5.94, 5.78
5	6.98,	2.66, 2.48	4.12, 4.06	5.41, 5.71
6	7.22,	2.58, 2.58	4.27, 4.49	5.76, 5.45
Mean	7.22,	2.83, 2.80	4.40, 4.38	5.95, 5.92
Std. Dev.	0.32,	0.20, 0.27	0.25, 0.24	0.38, 0.42

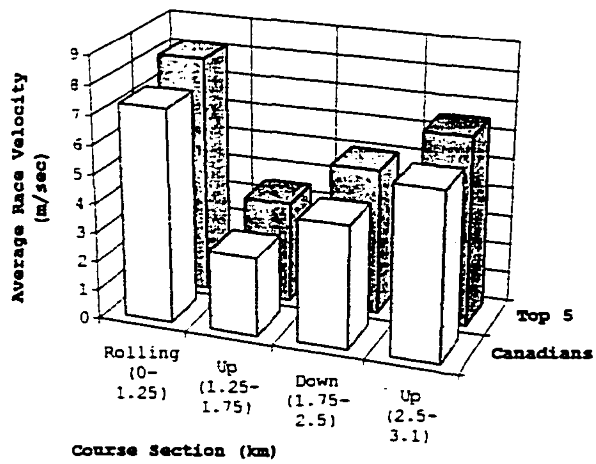
The average race velocity for the Canadian skiers over the entire course was 6.24 m/s with a range of 6.86-5.83 m/s. The average race velocity of the Canadian skiers for four consecutive sections of the race course are shown in Table 9.

The race velocity for section one, lap one ranged from 7.83-6.99 m/s. The subjects were ranked 1-6 in descending order. The race velocity for section two, lap one ranged from 3.03-2.58 m/s. Subject 2 had the highest velocity followed by subjects 1, 3, 6, and 5. On the second lap of section two, subject 2 had the highest velocity followed by subjects 1, 3, 4, 6, and 5. The race velocities ranged from 3.17-2.48 m/s. The race velocities varied considerably on the downhill section for lap one (4.68-4.12 m/s) and lap two (4.65-4.06 m/s) and were not indicative of their final rankings. The velocities on the first and second laps of the second uphill were as variable as the previous downhill section. The race velocity for lap one ranged from 6.52-5.41 m/s as compared to 6.25-5.45 m/s for lap two.

The average velocity for the entire free technique relay race ranged from 5.94-7.39 m/s (N=24). Figure 12 illustrates that the five top skiers showed a similar variation in their average race velocity as five Canadian skiers over four sections of the 5 km course for the first lap. However, the fast group consistently maintained a higher race velocity throughout the four sections when compared to the Canadians.

Figure 12

Mean Race Velocities of the Top Skiers (N=5) as Compared to the Canadian Skiers (N=5) on Four Consecutive Sections of the Race Course.



The mean race velocity for the top five skiers was 7.24 m/s (S.D.=0.083) as compared to the Canadians' 6.1 m/s (S.D.=0.146). The range of values for the top skiers were 7.19-7.39 m/s, as compared to 5.94-6.32 m/s for the Canadians. The greatest difference in race velocity between the two groups occurred in section one, a rolling part of the course.

The mean velocity of the fastest skiers differed from the Canadians by as much as 0.82 m/s. There was a smaller difference in their mean velocities on the other sections of the course (0.74-0.78 m/s).

The top skiers were compared to Canadian skiers on the basis of the percentage of the combined total race time skiing on two uphill sections (section 1 & 3) and two downhill sections (section 2 & 4) by lap (see Tables 10-13).

Table 10
The Percentage of the Total Race Time Skiing two Uphill and two Downhill Sections for the Top Skiers for Lap 1.

Top 5 Rank	Lap 1 Uphill Time(s)	%TT	Downhill Time(s)	%TT	TRT(s)
1	203	15	189	13.97	1353
2	204	14.71	191	13.77	1387
3	213	15.35	195	14.06	1387
4	208	14.7	184	13	1390
5	210	15.11	196	14.1	1415
Mean	207.6	14.97	191	13.78	1386.4
SD	4.159	0.28	4.85	0.45	22.06

Table 11
The Percentage of the Total Race Time Skiing two Uphill and two Downhill Sections for the Canadian Skiers for Lap 1.

Can. Rank	Lap 1 Uphill Time(s)	%TT	Downhill Time(s)	%TT	TRT(s)
2	229	14.96	205	13.39	1531
3	239	15.11	225	14.22	1582
4	247	14.87	221	13.3	1661
5	261	15.67	230	13.81	1665
6	259	15.09	225	13.11	1716
Mean	247	15.14	221.2	13.56	1631
SD	13.49	0.312	9.602	0.446	73.62

<u>Table 12</u>
The Percentage of the Total Race Time (TRT) Skiing two Uphill and two Downhill Sections for the Top Skiers for Lap 2.

Top 5 Rank	Lap 2 Uphill Time(s)	%TT	Downhill Time (s)	%TT	TRT(s)
1	208	15.37	187	13.82	1353
2	200	14.42	194	13.99	1387
3	212	15.28	191	13.77	1387
4	210	15.11	193	13.88	1390
5	201	14.2	201	14.2	1415
Mean	206.2	14.87	193.2	13.93	1386.4
SD	5.4	0.53	5.12	0.17	22.06

<u>Table 13</u>
The Percentage of the Total Race Time (TRT) Skiing two Uphill and two Downhill Sections for the Canadian Skiers for Lap 2.

Can. Rank	Lap 2 Uphill Time(s)	%TT	Downhill Time (s)	%TT	TRT(s)
1	217	14.17	208	13.59	1531
2	246	15.55	228	14.41	1582
3	252	15.17	225	13.54	1661
4	266	15.98	237	14.23	1665
5	265	15.44	235	13.69	1716
Mean	249.2	15.262	226.6	13.892	1631
SD	19.917	0.676	11.502	0.399	73.62

From the tables it can be seen that for lap 1, the top skiers and the Canadians spent similar mean percentages of total race time (%TRT) skiing the two uphills (Top=14.97%, Can=15.14%). The two groups showed similar mean %TRT for the two downhill sections for lap

1 (Top=13.78, Can=13.56). The percentages were similar for the second lap.

Skating Technique Census

The skating technique census illustrated that the top skiers' and the Canadian skiers' choice of technique for the one to five degree slope and the three to eleven degree slope.

The skating technique census (see Appendices 1-4) revealed distinct differences amongst the Canadians in their choice of techniques for different types of terrain. On one to two degree slopes, the fastest Canadian subject (1) preferred to use the 2-skate technique as compared to the others in the group who generally preferred to use the 1-skate technique. On a three degree slope, half of the group 1-skated and the other half 2-skated, including subject 1. The greatest difference occurred on the five degree slope. Subject 1 continued to use the 2-skate, but the other subjects preferred to use the offset technique. All of the subjects used the offset skating technique on the eleven degree slope.

The top skiers and the Canadians preferred to use the 1-skate technique on the 1-2 degree slope (See

Table 14). In contrast on the 5 degree slope the top skiers selected the 1-skate technique and the Canadians selected the offset technique. On the 3 degree section of the steeper slope, the top skiers chose to use the 2-skate more frequently while the Canadians showed an equal split between the 1-skate and the 2- skate (refer to Table 15).

Table 14
Ski Skating Techniques Used by the Top Skiers (N=10) as Compared to the Canadian Skiers (N=6) on a 1-5 Degree Slope.

Slope	Technique	Top Skiers Lap 1	Canadians Lap 1
	1-skate	3	3
1 Degree	2-skate	7	3
	Offset	0	0
	1-skate	6	4
1 Degree	2-skate	4	2
	Offset	0	0
	1-skate	6	4
2 Degrees	2-skate	4	1
	Offset	0	1
	1-skate	6	0
5 Degrees	2-skate	1	1
	Offset	3	5

Table 15
Ski Skating Techniques Used by the Top Skiers (N=10) as Compared to the Canadian Skiers (N=6) on a 3-11 Degree Slope.

Slope	Technique	Top Skiers Lap 1	Canadians Lap 1
	1-skate	3	3
3 Degree	2-skate	7	3
	Offset	0	0
	1-skate	0	0
6 Degree	2-skate	0	0
	Offset	10	6
	1-skate	0	0
11 Degrees	2-skate	0	0
	Offset	10	6

All of the skiers elected to use the offset technique on both the six and eleven degree sections of slope. These results indicated that the Canadian and the top skiers employed similar skating techniques on the steeper slopes, but not on the gentler slopes. The offset technique became the dominant technique when the slopes were approximately five degrees or more. On the gentler one to three degree slopes, the Canadians tended to use either the 1-skate or the 2-skate techniques. The top skiers chose the 2-skate over the 1-skate.

Chapter 5

Discussion

The results will be discussed under the following headings: kinematic and temporal analysis, physiological and biomechanical profile of the Canadian skiers, and a comparison between the top skiers and the Canadian skiers.

Kinematic and Temporal Analysis

The statistical significance of nine selected kinematic and temporal variables were investigated by conducting a correlation and regression analysis. The results of this analysis were used to help develop a biomechanical profile of the Canadian skiers, and to help compare the top skiers to the Canadian skiers.

Significant Correlations

Four offset skating kinematic or temporal variables demonstrated some significant relationships at either the $\underline{P}<.05$ or $\underline{P}<.01$ levels (2-tailed) of confidence (see Table 6) with race velocity. Race velocity was found to be correlated with cycle length, cycle velocity, percentage of full cycle time skating on the downhill leg, and the uphill pole angle relative to the vertical at pole plant.

Race velocity was weakly positively correlated with cycle velocity at the $P<.05$ level of significance. A stronger correlation was reported by Gregory et al. (1994) in their study of offset skaters on level terrain. The difference in the strength of the relationship may be related to the difference in terrain. The current study was conducted on a steep uphill where as the study by Gregory et al. (1994) was conducted on flat terrain. Smith & Heagey (1994) also found a strong correlation between race velocity and cycle velocity in their study on the 2-skate on level terrain.

A weak positive correlation at the $P<.05$ level of significance was also found in the current study between race velocity and the percentage of the full cycle spent skating on the downhill leg. This meant that the race velocity increased as the the percentage of the full cycle spent skating on the downhill leg increased. The significance of the percentage of the full cycle spent skating on the downhill leg was identified by McPherson (1991, 1993). An increase in the cycle length was found to be associated with a greater percentage of the full cycle spent skating on the downhill leg.

Clearly, the mean percentage of the full cycle spent skating on the uphill leg versus the percentage of the full cycle spent skating on the downhill leg was more balanced for the top skiers (46.6% vs. 42.6%) as compared to the slower Canadian (48.8% vs. 41.43%) skiers (see Figure 10). The top skiers appeared to skate more evenly on either leg even while offset skating on a steep 9 degree slope. Smith et al. (1989) reported a greater variation between the uphill and downhill skating legs (63.9% vs. 54.4%) on an 11 degree slope, and slightly closer values (61.0% vs. 54.1%) on a six degree slope. The discrepancy between the current study values and the previous study values may be attributed to the evolution of the offset skating technique over the years. Skiers have probably become more efficient offset skaters since the first introduction of the free technique racing format.

Most of the skiers had a strong (high) side and a weak (low) side depending on which side they offset on. However, the skiers who possessed a more balanced skate off either leg were probably achieving a more forceful backward leg push and consequently a longer and faster glide in the forward direction instead of moving back and forth across the trail with an unbalanced leg push (Svensson, 1994).

The strongest correlation at the $\underline{P}<.01$ level of significance was found between race velocity and cycle length. Offset skating race velocity increased as the cycle length increased. This finding was supported by previous studies (Smith & Nelson, 1988, Smith et al. 1989, and McPherson, 1993). Smith et al. (1989) reported a mean cycle length value of 2.99 m on a 10-11 degree slope. The large discrepancy between the values reported by Smith et al (1989) and the current study was probably related to a combination of slower snow conditions and the steeper slope in the previous study (9 vs. 11 degrees).

The uphill pole plant angle relative to vertical was negatively correlated with race velocity (see Table 6). The mean uphill pole plant angle relative to vertical of the top skiers was compared to the Canadians' mean value (see Table 4). The mean uphill pole plant angle relative to vertical of the top skiers of 5.11 degrees was smaller than the Canadian's mean of 8.08 degrees. Smith et al. (1989) reported a mean uphill pole plant angle relative to vertical of 15 degrees relative to vertical on slopes of 6-11 degrees. Smith et al. (1989) showed that the percentage of the full cycle poling increased as the slope increased, consequently the uphill pole should be planted as far forward as possible (near vertical), while still being angled backward and the arms extended as far back as possible at the end of poling. A closer to vertical uphill pole plant angle relative to vertical would help increase the poling time and a more complete arm extension would provide a greater pushing force. The discrepancy in the uphill pole plant angle relative to vertical between the current study and the previous study may be related to the evolution of the skating techniques during the elapsed time between the studies. The better skiers had probably developed stronger arms and may have been more capable of using them in forward propulsion.

There were other relationships revealed among the remaining kinematics variables. Cycle length and the percentage of the full cycle time spent skating on the downhill leg were negatively correlated at the $p<.05$ level of significance with the uphill pole plant angle relative to vertical. Cycle length and the percentage of the full cycle time spent skating on the downhill leg increased when the uphill pole was planted with a small backward angle relative to vertical. Cycle length would be expected to be inversely related to the uphill pole angle relative to vertical because they are both affected by the degree of the slope. A study conducted by Aro et al. (1990) revealed that the cycle length of offset skaters decreased as the slope became steeper. Furthermore, a study by Smith et al. (1989) showed that the length of the poling phase increased as the slope became steeper. By planting the poles more forward with a close to vertical angle the poles would naturally be in contact with the snow for a longer duration and would result in a longer poling phase.

Cycle time was negatively correlated with the percentage of the full cycle time spent skating on the uphill leg and cycle velocity at the $\underline{P}<.05$ level of significance. The cycle time decreased as the percentage of the full cycle time spent skating on the uphill leg increased. The relationship with percentage of the full cycle time spent skating on the uphill leg could be explained by the tendency of most offset skaters to spend more time skating on the uphill leg due to the planting of the uphill pole on the same side as the uphill leg. Consequently, the skate off the uphill leg had a negative influence on the overall cycle time.

Lastly a negative correlation existed between the variables percentage of the full cycle time spent skating on the uphill leg and the percentage of the full cycle time spent skating on the downhill leg. This relationship arose because of the natural tendency for the percentage of time on one leg to increase as the percentage of time decreases on the other leg and vice versa.

Multiple Regression Model

A multiple regression model was developed to predict the race velocity of offset skate skiers at the $\underline{P}<.05$ level of significance. The model consisted of a full regression equation and a stepwise regression equation.

The full regression equation had a high correlation of R=.63741 and provided some general information on the contribution of the selected kinematics variables (refer to Table 7). The resulting equation predicted that a cross country ski skater could improve his race velocity by optimizing the offset skating CL and the PSD.

The stepwise regression equation with a correlation coefficient of R=.5329 was almost as useful as the direct regression equation in predicting race velocity (see Table 8). The predictor variable, PSD was removed because it added little power to the equation. The resulting equation predicted that cross country ski skaters could improve their offset skating velocity on a nine degree slope by optimizing their CL. The author of this study was unaware of any previous studies that have developed a multiple regression model for predicting the race velocity of offset skaters on a steep slope.

Physiological and Biomechanical Profile of the Canadian Skiers

The Canadian skiers were compared on the basis of the timing study results, heart rate and lactate responses to the race, offset skating kinematics, and skating technique census.

The timing study results clearly showed the variation in the average race velocities within the group throughout the four sections of the trail (see Table 9). Subjects 1 and 2 were consistently faster than the subjects 3, 4, 5, and 6 throughout the race course. The question arose as to whether the difference in the race velocities could be explained by the skiers' physiological and/or kinematics profiles.

Previous physiological testing in the lab (see Table 2) revealed an unexpected trend. It appeared from the results of the current study that as the VO_2peak increased, the average race velocity decreased. Stromme, Ingjer, and Meen (1977) claimed that VO_2max. values during skiing were twelve percent higher than during running for the same individual. The Canadian skiers values were recorded while they were running on a treadmill. Further, Rusko (1976) has reported seasonal changes in VO_2max., as much as five percent. Thus, it should be expected that the VO_2max. values would have changed due to training after the four months elapsed between the lab testing and the relay race. Clearly in the present study, the VO_2max. results were probably poor predictors of performance.

The anaerobic threshold values, expressed as a percentage of VO_2peak (%VO_2peak), showed a similar trend as the VO_2peak values (see Table 9). The slowest skiers tended to have the highest anaerobic threshold values, expressed as a %VO_2peak. In contrast, the anaerobic threshold expressed as a percentage of the maximum heart rate could have been used as a predictor of the outcome (rankings) of the race. A high correlation between anaerobic threshold and running velocity was reported by Loat & Rhodes (1993). However, the anaerobic threshold values would have changed with the variation in training intensity. As the peak racing phase approached, the training intensity increased and the distance training decreased (Silletta & Scheier, 1995). Rusko (1987) reported that an increase in distance training volume results in higher oxidative enzyme activity in the skiing muscles and a higher anaerobic threshold. The normal drop in distance training carried out by the Canadians through the competition period would have caused a decrease in the oxidative capacity of their skiing muscles (Rusko, 1976; Bergh et al., 1978; and Machova, Bass, Sprynarova, Teisinger, Vondra, and Bojanovsky, 1982) and a decrease in their anaerobic thresholds.

In summary the VO_2peak and anaerobic threshold values for the Canadians at the time of the relay race were probably different from the VO_2peak and anaerobic threshold values recorded in the lab four months earlier. However, the anaerobic threshold expressed as a percentage of maximum heart rate recorded in the lab appeared to be a good predictor of future performances.

The individual heart rates and whole blood lactate values recorded at the race site were expected to show some relationships toward performance. Subjects 2 and 3, as seen in Figure 6, had the most consistent mean heart rate profiles throughout the race as compared to the more irregular profiles of subjects 4, 5, and 6. Janssen (1995) and Underwood (1992a) described the top endurance athlete as the one who was able to sustain a pace at an intensity close to anaerobic threshold throughout the race. However, the timing study results (see Tables 9, 11, and 13) revealed that the Canadian skiers' pace varied throughout the course. This apparent contradiction with the heart rate response was related to the variation in the skiing terrain. The faster skiers probably adjusted their pace according to their level of perceived exertion.

When the mean heart rate values were expressed as a percentage of their maximum (see Figure 7), it appeared that the faster Subjects (2 and 3) were able to ski at 90 and 92 percent of their maximum heart rates respectively, regardless of the terrain. The percentage of the maximum heart rate for subject 3 during the race was similar to his anaerobic threshold expressed as a percentage of his maximum heart rate recorded during the lab testing (see Table 2). Thus, subject 3 appeared to be racing near his anaerobic threshold throughout the race. The next slowest subjects (4 and 5) showed a slight increase of 3-5 percent of his maximum heart rate on the first uphill and a decrease of 3 percent of his maximum heart rate over the remaining sections of the course. The slowest subject (6) showed an increase of 3 percent of his maximum heart rate on the first uphill, and maintained an intensity of 88 percent of his maximum heart rate for the remaining three sections of the course. The timing study results (see Table 9, 11, and 13) did not support the possibility that the slower skiers' performances could be attributed to going above their anaerobic threshold. The race velocities of all the skiers did not decrease appreciably from the first to the second lap as might be expected if the accumulation of lactic acid was hindering their performance (Underwood, 1992b).

Unfortunately, whole blood lactate values were not recorded during the race for practical reasons. The skiers' lactate profiles for the race would have provided more conclusive evidence of their level of effort. However, the pre and post-race whole blood lactate values were recorded in order to get some indication of their lactate response to racing (see Figure 8). The mean pre-race lactate value for the group was 1.9 mMoles/l (S.D. +/- 0.71). Underwood (1992a) reported similar pre-race values for top skiers. The peak whole blood lactate values post-race varied within the group (6.52-11.48 mMoles/l) and did not show any trend. The mean peak post-race value for the group of 8.66 mMoles/l was close to the values reported by Underwood (1992a) of 10-11 mMoles/l for top skiers post-race.

Figure 9 depicts the post-race lactate clearance rates for the group. The mean peak lactate clearance rate for the group of 0.59 mMoles/l/min. was similar to the average values of 0.5-0.6 mMoles/l/min. reported by Underwood (1992a) for top skiers. Clearly, two of the faster subjects (2 and 3) had the highest clearance rates of 1.0 and 1.38 mMoles/l/min. (see Figure 9). MacRae et al. (1992) reported that the reduced blood lactate concentrations after sub maximal endurance efforts were attributed to decreased rate of production and an increased rate of lactate clearance. Further, at maximal efforts, reduced blood lactate concentrations were attributed largely to improved lactate clearance (MacRae et al., 1992). The increased effort of a skier brought on by the hilly terrain over a typical race course, raises the skier's blood lactate levels frequently above their anaerobic threshold for short periods of time (Underwood, 1992a). Thus, a skier's lactate clearance rate could be an important contributing factor to their race performance (Underwood, 1992a).

The results from this study show that the fastest Canadian skiers had the highest peak post-race lactate clearance rates and the highest anaerobic threshold as compared to the slower skiers in the group. Further, their mean peak post-race lactate values and mean post-race lactate clearance rates were comparable to the top skiers in the world.

In addition to their physiological profiles, it was hoped that their kinematic and temporal profiles of their offset skating technique, and the census of their choice of skating techniques on different terrain could also be used to help explain the Canadian subjects' performances.

A comparison amongst the Canadian subjects on the basis of nine descriptive kinematic and temporal variables did not reveal any noticeable trends in relation to their final race rankings (see Table 3). This was probably due to the small size and homogeneous nature of the group. Statistical analysis of the kinematic and temporal results from the entire race field (N=24) would have been required to produce any significant results.

A comparison of the degree of arm extension while offset skating was made among the Canadian subjects (see Figure 11). Subject 3 and 5 did not extend their wrists past their hips as compared to subjects 1, 2, 4, and 6 at the moment of pole release. However, there did not appear to be any trends in relation to the final race results.

The Canadian subjects were compared on the basis of their choice of skating technique on slopes of varying degree (see Appendices 1-4). The fastest subject (1) preferred to use the 2-skate on 1-5 degree slopes and the offset skate on the 6-11 degree slopes. The other members of the group used either the 1-skate or 2-skate techniques on the 1-3 degree slopes, and the offset skating technique on the 5-11 degree slopes.

Skiers probably used a given technique for a variety of reasons including perceived exertion, racing strategy, and perhaps because other skiers around them were using the technique.

If a skier frequently used a given skating technique on the same kind of terrain in practice because it felt easier, then it was likely that the skier used the same technique on the same terrain during the race, regardless of whether it was the most efficient or fastest technique for that terrain. Further, if a skier did not practice a skating technique on similar terrain as the race course, then the skier might have perceived that skating techniqe to be too difficult to sustain and switched to another perhaps slower skating technique.

The study by Kelly et al. (1990) on the physiological responses to different swim strokes may have implications for cross country skiing. Perhaps there are specific physiological responses to different skating techniques such as lower heart rates and energy demands at a given speed.

The frequency of use of a skating technique and the intensity of the skating technique practiced by a skier might have developed specific peripheral physiological and neuromuscular adaptations in the skier. The degree of development of these adaptations may have allowed the skier to sustain a technique only on certain kinds of terrain. In other words both physiological and technical ability probably determined which technique a skier used on a given type of terrain. Unfortunately, this author was unaware of any studies which have compared the physiological demands of the different skating techniques over the same terrain. Consequently, it was difficult to draw any conclusions on an individual basis from the skating census results.

Comparison Between the Top skiers and the Canadian Skiers

The mean race velocity of the fastest ski skaters was compared to the mean of the Canadian skiers over several sections of the five kilometer course as shown in Figure 16. The top group's average race velocities were consistently faster than the Canadian's. The greatest difference between the two groups occurred in the rolling first section (0.82 m/s). The difference was smaller on the remaining two steep uphill sections and a downhill (0.74-0.78 m/s). There are several possible reasons for this difference including, physiological and biomechanical characteristics.

Although some of the Canadians in the study had post race lactate clearance rates that were lower than the average top skiers, in general their lactate and heart rate profiles were similar to previously reported values for top skiers (Underwood, 1992a). It appeared that the Canadians were well trained aerobic athletes, but they did not have the aerobic capacities of the top skiers, as reported in previous studies (Bergh, 1982; Kelly, 1990). Duggan and Tebbut (1990) suggested that VO_2max. sets the upper limit for lactate threshold. Consequently, even though the Canadian skiers were skiing close to their anaerobic thresholds during the relay race, their aerobic capacities may have been too low to be competitive with the top skiers.

The previous kinematic and temporal analysis revealed that four variables were correlated with race velocity including, cycle length, percentage of the full cycle spent skating on the downhill ski, uphill pole angle relative to vertical at the moment of pole plant, and cycle velocity.

The multiple regression equation revealed that the cycle length was the most important factor in predicting race velocity. The mean cycle length for the Canadian skiers was 4.98 m as compared to the top skiers mean value of 5.69 m (see Table 4). This means that the faster skiers were traveling 0.71 m further than the Canadian skiers for a complete cycle of the offset skating technique. The Canadian subjects' cycle length difference as compared to the top skiers ranged from 0.38-1.24 m (compare Tables 3 & 4). Clearly, the shorter cycle length of the Canadian subjects could have helped to explain the slower race velocities on the steep uphill sections of the course.

The direct regression equation included percentage of the full cycle skating on the downhill ski as a predictor of race velocity in addition to cycle length. The mean percentage of the full cycle skating on the downhill ski for the top skiers was 43.15% as compared to 41.43% for the Canadian skiers (see Table 4). Further, the previous correlation analysis indicated that percentage of the full cycle skating on the downhill ski was negatively correlated to the percentage of the full cycle skating on the uphill ski. When the two groups of skiers were compared on the basis of their percentage of the full cycle skating on the downhill ski versus percentage of the full cycle skating on the uphill ski (see Figure 10), the top skiers skated more evenly (43.15% vs. 45.32%) on either leg as compared to the Canadians (41.43% vs.48.80%). The fastest Canadian subject (45.0% vs. 47.5%) and the fourth fastest Canadian subject (45.45% vs. 45.45%) had relatively balanced values as compared to the top skiers' mean values. The remaining Canadian subjects showed much wider differences between percentage of the full cycle skating on the downhill ski and percentage of the full cycle skating on the uphill ski. Thus an increase in the percentage of the full cycle skating on the downhill ski for some Canadian subjects may have increased their race velocity.

The uphill pole angle relative to vertical at pole plant was found to decrease as the race velocity increased. The Canadian skiers planted their uphill poles backward with a larger angle relative to vertical as compared to the top skiers. The timing study indicated that the Canadian skiers were slower on the uphill sections (see Table 9). Thus, the Canadian skiers might have been able to offset skate faster on the uphill sections if they had planted their uphill pole at an angle closer to vertical.

Cycle velocity was weakly correlated with race velocity. The mean cycle velocity of the top skiers was 4.64 m/s. as compared to 4.21 m/s. for the Canadian skiers (see Table 4). Although the Canadian subjects' cycle velocity values did not show any trend in relation to their race velocity (see Table 3), it was clear that by increasing their offset skating cycle velocity, the Canadian skiers would probably ski the uphill sections faster.

The top skiers and the Canadian skiers were also compared on the basis of four other non significant variables including, cycle time, percentage of the full cycle poling, and horizontal distance between the pole tip and adjacent ankle. The mean cycle times for the top skiers vs. the Canadian skiers were similar (1.22 s. vs. 1.20 s.). The individual cycle times for the Canadians did not show any trend in relation to rankings (Table 3). This supported the earlier correlation results that showed no significant relationship between cycle time and race velocity. Further, cycle time was probably not an important contributing factor to the race velocity of the Canadian skiers.

It appeared that the offset skating cycle length rather than the cycle time was the more important factor contributing to a skier's race velocity.

The mean percentage of the full cycle poling for the top skiers (41.05%) and the Canadian skiers (45.17%) differed by only 4.12%. The standard deviations for the two groups of skiers were also similarly small (3.58% and 2.19%), indicating the lesser contribution of percentage of the full cycle poling toward the cycle velocity.

Finally, the mean horizontal distance between the pole tip and adjacent ankle for the top skiers was 0.239 m as compared to the mean value of 0.370 m for the Canadian skiers. Once again there did not appear to be any trend amongst the skiers in relation to mean horizontal distance between the pole tip and adjacent ankle and ranking. These results suggested that the mean horizontal distance between the pole tip and adjacent ankle was probably not a contributing factor to the Canadian skiers race velocity.

The conclusions drawn from the kinematic and temporal analysis were limited to the offset skating technique. It was hoped that the skating technique census might have revealed some differences between the top skiers and the Canadian skiers in regards to techniques used on different degree slopes.

The skating technique census and the key event stick figure plots revealed some distinct differences between the top skiers and the Canadians in terms of their choice of skating techniques and their skating kinematics. The two groups of skiers preferred the offset technique on a slope steeper than five degrees but, on slopes between 1 and 5 degrees the groups differed (see Tables 14 & 15). The top skiers preferred to use the 2-skate, while the Canadians used either the 1-skate, offset, or the 2-skate technique. Thus, it is possible that the slower race velocities of the Canadian subjects could be attributed to their individual racing strategies, particularly on the rolling section of the trail where the top skiers would use the 2-skate technique more frequently as opposed to the 1-skate or the offset skate techniques. Although there were obvious differences between the two groups of skiers in terms of their preference of skating technique on a given type of terrain, it was difficult to conclude that one technique was faster or physiologically more efficient than another without actually measuring and comparing the physiological demands of all the skating techniques. Bilodeau et al. (1991) reported no significant difference in heart rate values for three different skating techniques. It is possible that the best skiers were able to maintain or increase their velocity by adopting a more efficient skating technique.

The key event frame plots of the top skiers and the Canadian skiers offset skating revealed some differences in terms of their arm extensions (see Figures 11). The top skiers extended their wrists well past their hips during pole release as compared to the Canadian skiers. This revealed that the Canadian skiers were not using all of their arm joints and muscles effectively. If their shoulders were not protracted fully at the moment of pole plant, it followed that the use of only their elbow and wrist joints lead to arm extensions no further than their hips. Consequently, they were probably not recruiting as many of the upper back and shoulder muscles and hence not applying as much muscular force on their poles as the top skiers.

Chapter 6

Summary & Recommendations

The summary section was divided into three sections: kinematic and temporal analysis, physiological and biomechanical profile of the Canadian skiers, and comparison between the top skiers and the Canadian skiers.

Kinematic and Temporal Analysis

The kinematic and temporal analysis revealed several significant relationships with race velocity:

1. The kinematic variables cycle length and cycle velocity were positively correlated with race velocity.
2. The kinematic variable uphill pole angle relative to vertical at pole plant was weakly negatively correlated with race velocity.
3. The temporal variable percentage of the full cycle spent skating on the downhill leg was weakly positively correlated with race velocity.

Other significant relationships included,

1. Cycle length had a weak negative correlation with uphill pole angle relative to vertical at the moment of pole plant.
2. Cycle time had a weak negative correlation with percentage of full cycle time spent skating on the uphill skate leg.
3. Percentage of the full cycle time spent skating on the uphill skate leg and percentage of the full cycle time spent skating on the downhill skate leg were weakly negatively correlated.

The multiple regression equation developed to predict race velocity from selected kinematics and temporal variables revealed that cycle length while offset skating on a steep slope was the most important predictor variable.

Physiological and Biomechanical Profile of the Canadian Skiers

The timing study indicated that the race velocity of the Canadian subjects varied within the group. These differences in race velocity were attributed to their individual physiological and biomechanical profiles.

Several physiological relationships were revealed including,

1. The anaerobic threshold values (expressed as a percentage of maximum heart rate) of the Canadian subjects were a good indicator of racing performance.
2. The faster subjects raced at approximately 90 percent of their maximum heart rate.
3. The mean pre-race whole blood lactate values for the Canadians was 1.9 mMoles/l.
4. The mean peak whole blood post-race lactate value was 8.66 mMoles/l.
5. The peak whole blood post-race lactate values varied considerably within the group and did not show any trend in relation to final race rankings.
6. The mean peak whole blood lactate clearance rate was 0.59 mMoles/l/min.
7. The faster subjects had the highest lactate clearance rates.

A comparison of the Canadian subjects on the basis of their mean kinematic and temporal values did not show any trends in relation to their final race rankings.

The Canadian subjects differed in their choice of skating techniques on slopes of varying degree. The fastest subject preferred to use the 2-skate on 1-5 degree slopes, but the other subjects used a combination of the 1-skate, 2-skate, or offset skate techniques. All of the Canadian subjects used the offset skate on slopes greater than 5 degrees.

Comparison Between the Top Skiers and the Canadian Skiers

A comparison was made between the top skiers and the Canadian skiers. The top skiers mean race velocity was faster than Canadian skiers throughout the race course. This difference was attributed to several physiological and biomechanical factors including,

1. The literature suggests that the Canadian subjects probably had lower peak VO_2 values than the top skiers.
2. The lower peak VO_2 values of the Canadians would set the upper limit to their anaerobic threshold values.
3. The top skiers had a mean cycle length 0.71 m longer than the Canadian skiers. Thus, the top skiers skied further during each complete cycle.
4. The top skiers offset skated more evenly off either

ski as compared to the Canadian skiers. A more balanced skate by the top skiers implies that they were able to direct more force along their resultant force vector down the trail.

5. The top skiers had a higher cycle velocity than the Canadian skiers.

6. The mean cycle times were similar for the top skiers and the Canadian subjects (approximately 1.2 s.).

7. The mean percentage of the full cycle time spent poling differed between the groups of skiers by only 4.12 percent.

8. The top skiers had a mean uphill pole angle relative to vertical at pole plant smaller than that of the Canadian skiers. This means that the top skiers planted their poles closer to vertical than the Canadian skiers.

9. The mean horizontal distance between the uphill pole tip and adjacent ankle at pole plant was smaller for the top skiers as compared to the Canadian skiers, but the individual values for all the skiers varied considerably. This may be related to the skiers' technical efficiency.

10. The top skiers preferred to use the 2-skate on 1-5 degree slopes as compared to the Canadian skiers who

used either the 1-skate, 2-skate, or offset skate techniques.

11. Both groups of skiers used the offset skate technique on the slopes greater than 5 degrees.

12. The top skiers extended their wrists well past their hips during the poling action as compared to the Canadians who tended to stop at the hip.

The intent of this study was to develop a physiological and biomechanical profile of World Cup level cross-country ski skaters. The scope of the study was limited by several factors including,

1. The absence of heart rate and whole blood lactate data on the non Canadian competitors in the relay race.
2. The lack of research on the physiological demands of the skating techniques relative to one another.
3. The 2D analysis limited the amount of information that could be analyzed for body limb segment angles.

Despite these limitations this study has revealed some interesting physiological and biomechanical differences between the top skiers and the Canadian skiers.

Further studies need to be conducted on the physiological demands of all the skating techniques on different terrain and these studies should involve the competitors from all countries in an elite level competition. Furthermore, future studies should attempt to develop an equation to predict racing success on the basis of both physiological and biomechanical data collected from skiers while performing all skating techniques.

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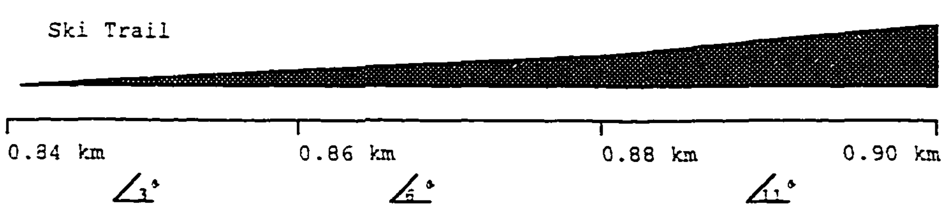
Appendices

Appendix 1

__Appendix 1__
Ski-Skating Techniques Used by the Top Skiers and the Canadian Skiers on a 3-11 Degree Slope During the Third Leg of the Relay Race.

Skating Technique	Lap 1	Lap 2	Lap 1	Lap 2	Lap 1	Lap 2
1-Skate	JM SB	JM SB HF				
2-Skate	JI C1 BD C3 HF C5	JI C1 BD C3 C5				
Offset			JI C1 BD C3 JM C5 SB HF	ALL	ALL	ALL



Top Skiers
JI J. Isometsa
BD B. Daehli
JM J. Muehlegg
SB S. Broers
HF H. Forsberg

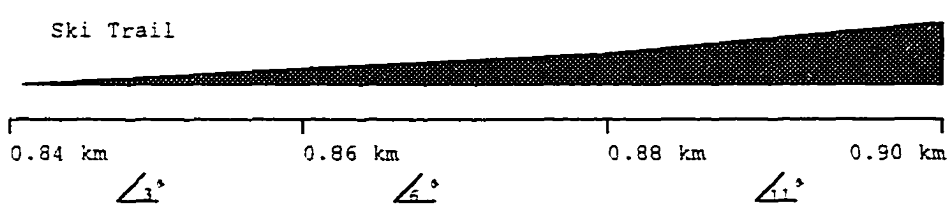
Canadian Skiers
C1 Subject 1
C3 Subject 3
C5 Subject 4

Appendix 2

Appendix 2

Ski-Skating Techniques Used by the Top Skiers and the Canadian Skiers on a 3-11 Degree Slope During the Fourth Leg of the Relay Race.

Skating Technique	Lap 1	Lap 2	Lap 1	Lap 2	Lap 1	Lap 2
1-Skate	AE C2 C4 C6	TM C4 JH C6 AE				
2-Skate	TA C2 TM JH PS	TA PS				
Offset			TA C2 TM C4 JH C6 AE PS	ALL	ALL	ALL



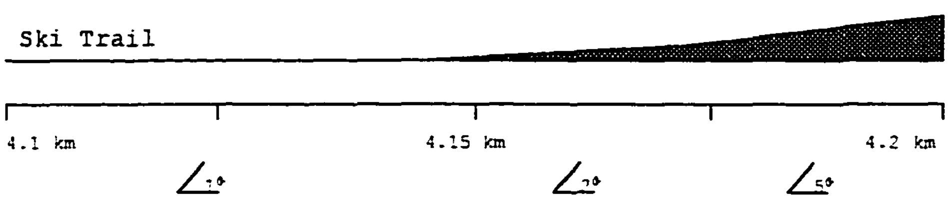
Top Skier
TA T. Alsgaard
TM T. Mogren
JH J. Hartonen
AE A. Eide
PS P. Schlickenreider

Canadian Skiers
C2 Subject 2
C4 Subject 4
C6 Subject 6

Appendix 3

Appendix 3
Ski-Skating Techniques Used by the Top Skiers and the Canadian Skiers on a 1-5 Degree Slope During the third Leg of the Relay Race.

Skating Technique	Lap 1	Lap 2	Lap 1	Lap 2	Lap 1	Lap 2	Lap 1	Lap 2
1-Skate	SB HF C3 C5	SB C3	JI C3 JM C5 SB HF	JI SB C3	JI SB HF C3	JI JM SB HF	JI JM	JI JM
2-Skate	JI C1 BD JM	JI C1 JM C5 SB HF	BD C1	BD C3 JM C5 HF	BD JM C1	BD C1	C1	C1
Offset					C5	C3 C5	BD SB HF C3 C5	BD SB HF C3 C5



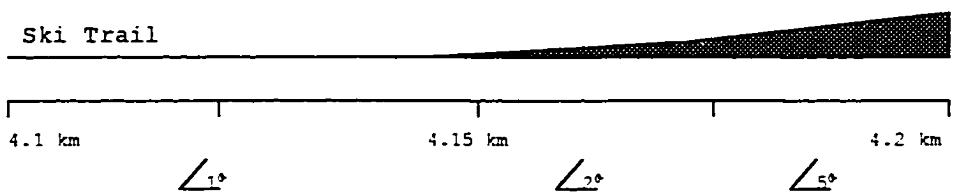
Top Skiers
JI J. Isometsa
BD B. Daehli
JM J. Moehlegg
SB S. Broers
HF H. Forsberg

Canadian Skiers
C1 Subject 1
C3 Subject 3
C5 Subject 5

Appendix 4

Appendix 4
Ski-Skating Techniques Used by the Top Skiers and the Canadian Skiers on a 1-5 Degree Slope During the Fourth Leg of the Relay Race.

Skating Technique	Lap 1	Lap 2	Lap 1	Lap 2	Lap 1	Lap 2	Lap 1	Lap 2
1-Skate	AE C6	AE C6	TM C6 AE C4	TM AE C6	TM C2 JH C4 AE C6	TM C2 JH C6 AE	TM JH PS	TM JH PS C4
2-Skate	TA TM JH PS	TA C4 TM C2 JH PS	TA JH PS	TA C2 JH C4 PS	TA PS	TA PS C4	TA	TA AE
Offset							C6 C2 C4	C2 C6

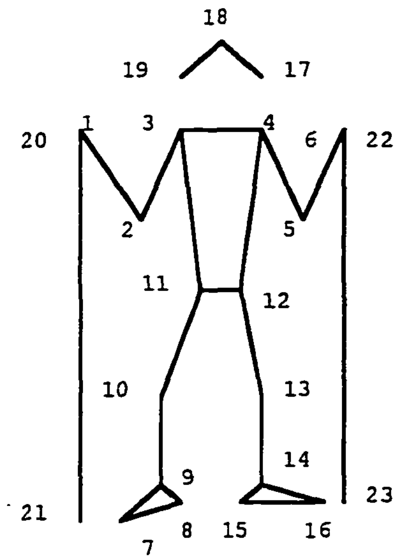


Top Skier
TA T. Alsgaard
TM T. Mogren
JH J. Hartonen
AE A. Eide
PS P. Schlickenreider

Canadian Skiers
C2 Subject 2
C4 Subject 4
C6 Subject 6

Appendix 5

<u>Appendix 5</u>
Spatial Model of a Cross Country Skier: Limb Joint Centres; Trunk, Head, and Pole Positions.



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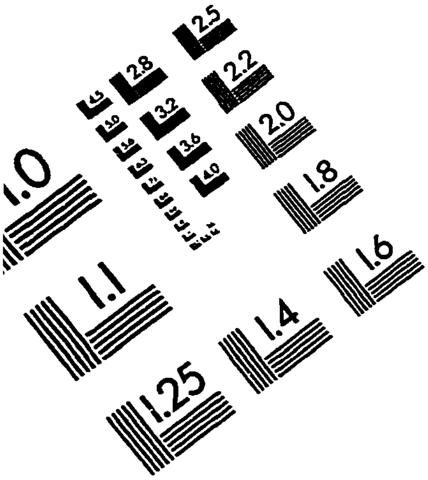

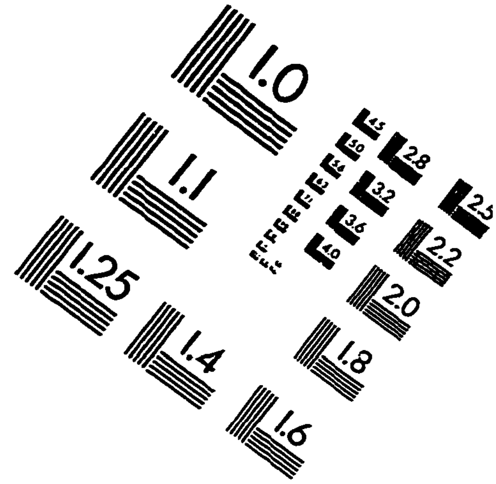

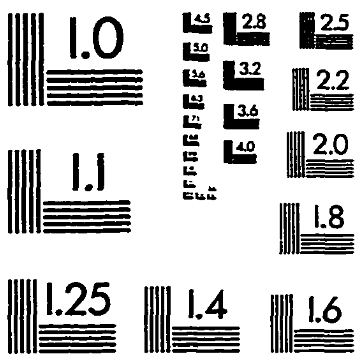

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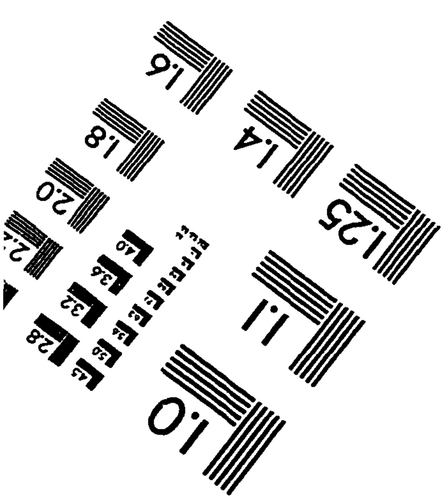

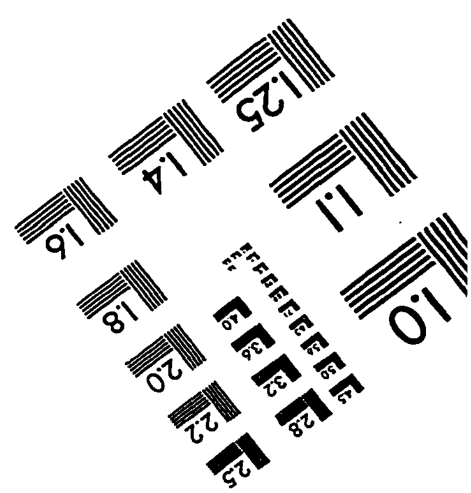

APPLIED IMAGE . Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989