FLEXIBILITY AS A DETERMINANT OF ROLLERSKIING

ECONOMY IN CROSS-COUNTRY SKIERS

by

Karin Camenisch

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Health and Human Development

MONTANA STATE UNIVERSITY
Bozeman, Montana

May 2007

APPROVAL

of a thesis submitted by

Karin Camenisch

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the Division of Graduate Education.

Daniel P. Heil, PhD

Approved for the Department of Health and Human Development

Craig C. Stewart, EdD

Approved for the Division of Graduate Education

Carl Fox, PhD

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library.

Karin Camenisch

May 2007

TABLE OF CONTENTS

TABLE OF CONTENTS - CONTINUED

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The purpose of this study was to examine the correlational relationship between selected measures of flexibility and roller-ski economy (E). Twelve male competitive cross-country skiers (Mean±SD: 21±3 yrs, 183.2±6.5 cm, 76.7±6.8 kg and 60.4±3.4 ml/kg/min VO_{2max}) completed a VO_{2max} test on a motorized treadmill to volitional exhaustion utilizing the Australian XC Ski-Striding protocol. Heart rate (HR) and oxygen consumption (VO_2) were recorded with a metabolic cart using standard indirect calorimetry procedures. Immediately following the VO_{2max} test, seven flexibility tests were administered bilaterally twice each by the same administrator in a counterbalanced order. Flexibility measures included rotation of spine, lateral flexion of spine, shoulder rotation, standing and lying horizontal hip abduction, modified sit-and-reach test, and passive leg raise (Flex1-Flex7). During a second lab visit, subjects performed three 10-min trials at preset heart rates (65%, 75%, and 85% of HR_{max}) using roller-skis on an indoor track oval. Average HR and VO_2 values (ml/kg/min) obtained during the last four minutes of each 10-min trial were plotted against speed to produce line graphs. The slopes (VO_2 and HR slopes) of these graphs were used as indicators of roller-skiing E. Pearson product-moment correlations were used to examine associations between the measures of flexibility and VO_2 and HR slopes at the 0.05 alpha level. The correlational analysis revealed no significant relationships between any of the flexibility measures and either VO_2 or HR slopes. The findings of this study indicate that flexibility is not a good determinant of economy in a homogenous group of cross-country skiers. Although correlations between flexibility and E were non-significant, there were weak trends observable that might aid in designing protocols for future studies examining flexibility and E in cross-country skiers.

CHAPTER ONE

INTRODUCTION

During the twentieth century, there have been many changes to the sport of cross-country skiing. The technique called skate skiing has been introduced as well as the development of more advanced equipment. Though racers ski faster with the new equipment and technique, the physiological demands remain similar. It is widely accepted that maximal oxygen uptake (VO_{2max}) is the best indicator of endurance performance in a heterogeneous population (Costill, 1967). In highly trained athletes, however, VO_{2max} does not correlate well with performance (Conley & Krahenbuhl, 1980; Williams & Cavanagh, 1987). It is, however, a prerequisite to successful elite endurance performance (Brooks, Fahey, & Baldwin, 2005). Other factors such as economy, blood lactate threshold, or muscle fiber composition are also important for success in endurance events. In cross-country skiing, additional factors such as snow condition, terrain, ski wax, racing experience, equipment and technique affect athletic performance as well.

In addition to a high VO_{2max}, economy is one of the key physiological factors affecting the success of cross-country skiers. Economy is defined as the relative oxygen uptake during skiing at a given submaximal velocity ($VO_{2submax}$). According to this definition, decreased $VO_{2submax}$ corresponds to an increased endurance performance. Economy varies greatly between individuals and can therefore be used as a predictor of performance among homogenous groups of athletes such as elite runners (Daniels & Daniels, 1992). In skiing, however, individual differences in economy vary even more

than in running, because skiing depends more on technique and the skill of using proper terrain-specific techniques (Rusko, 2003).

A number of physiological and biomechanical factors appear to affect economy in highly trained athletes (Beaudoin & Blum, 2005; Cavanagh & Kram, 1985b; Conley & Krahenbuhl, 1980; Craib et al., 1996; Daniels & Daniels, 1992; Gleim, Stachenfeld, & Nicholas, 1990; Jones, 2002; Nelson, Kokkonen, Eldredge, Cornwell, & Glickman-Weiss, 2001). These include fractional utilization of VO_{2max} (Cavanagh & Kram, 1985b; Conley & Krahenbuhl, 1980; Daniels & Daniels, 1992), heart rate (Hoffman, Clifford, Foley, & Brice, 1989), kinematics (Williams & Cavanagh, 1987) and elastic energy storage in the muscles and connective tissues (Beaudoin & Blum, 2005; Cavanagh & Kram, 1985b; Conley & Krahenbuhl, 1980; Craib et al., 1996; Gleim et al., 1990; Jones, 2002; Nelson et al., 2001). The return of stored elastic energy can be enhanced with musculotendinous stiffness by improving force production capabilities of the contractile component and by increasing initial force transmission. Possible benefits from a rigid musculoskeletal system include decreased oxygen consumption and a reduced demand for the stabilization of muscle activities. More efficient mechanics of the muscles and technique should lead to less energy wasted on unnecessary motions.

Related to the stiffness of the musculoskeletal system is flexibility, which is defined as the ability to move a joint through its complete range of motion (ROM) (ACSM, 2006; Gleim & McHugh, 1997). According to Gleim and McHugh (1997), an increased stiffness in the musculoskeletal system was associated with decreased flexibility. While a certain amount of flexibility is important to carry out daily activities,

the influence of flexibility on sports performance is controversial. Among some competitive athletes such as gymnasts or swimmers, flexibility is a necessary attribute for performing well. However, some research has shown that too much flexibility could hurt sports performance (Bracko, 2002; Fowles, Sale, & MacDougall, 2000). In particular, increased flexibility could lead to a decrease in strength performance.

The effect of flexibility on economy or race performance in runners has been studied extensively (Beaudoin & Blum, 2005; Craib et al., 1996; Gleim & McHugh, 1997; Gleim et al., 1990; Jones, 2002; Nelson et al., 2001). The results of these studies, however, are contradictory. Some studies suggest that less flexible runners tend to have better economy than more flexible runners (Craib et al., 1996; Jones, 2002). Similar results were found by Gleim et al. (1990) who concluded that individuals with a tight musculoskeletal system were more economical during steady-state walking and running on the treadmill. Furthermore, subjects with a tight trunk region and lower extremity were especially economical. Other studies using trained, college-aged runners showed neither a negative nor a positive correlation between flexibility and economy (Beaudoin & Blum, 2005; Nelson et al., 2001). Limited information exists on the relationship between flexibility and performance in cross-country skiers. One study suggested dance training to have a positive effect on flexibility, speed, and agility in young cross-country skiers (Alricsson, Harms-Ringdahl, Eriksson, & Werner, 2003). As the aforementioned studies suggest, the relationship between flexibility and performance is probably sport-dependent (Gleim & McHugh, 1997).

The relationship between flexibility and economy in cross-country skiers has not been evaluated. Since previous research using mostly runners is contradictory, it is reasonable to examine the relationship in competitive cross-country skiers. Therefore, the purpose of this study was to examine the relationship between selected measures of flexibility and economy in cross-country skiers. The findings could provide useful information for coaches and athletes planning future training regimens.

Statement of the Problem

The purpose of this study was to determine the relationship between selected measures of flexibility and skate skiing economy. Indoor roller skiing was used to simulate on-snow skiing for the purpose of determining economy. The final analysis verified whether flexibility correlated significantly with skate skiing economy.

Research Hypothesis

All seven flexibility measures (total body rotation, lateral flexion of lumbar spine, shoulder rotation, standing and lying hip abduction, modified sit-and-reach, and straight leg raise) will significantly correlate with skate skiing economy:

$$H_0: \rho = 0$$

$$H_a: \rho \neq 0$$

where ρ is the population average correlation between skate skiing economy (independent variable) and one of several measures of flexibility (dependent variables).

Limitation

Individual roller-skis, even if same type/brand, may affect economy measures of the submaximal test.

Assumption

It is assumed that the results of the submaximal roller-ski test will be representative of a similar analysis during on-snow skiing.

Operational Definitions

Economy:	The submaximal steady-state aerobic demand at a given velocity. Economy may also be defined as the slope of the line of a heart rate (HR) versus velocity, or VO_2 versus velocity, graph. Economy is sometimes reported as $VO_{2submax}$.
Flexibility:	The ability to move a joint through its complete range of motion (ROM). Flexibility is joint specific.
Maximal Oxygen Uptake (VO_{2max}):	The maximum rate of oxygen uptake by the body measured during intense exercise. It can be expressed as either an absolute value (l/min) or relative to body mass (ml/kg/min).
Respiratory Exchange Ratio (RER):	The ratio of the amount of carbon dioxide produced by the body to the amount of oxygen consumed (VCO_2/VO_2).
Skate skiing:	A particular cross-country skiing technique that uses an inline skate type motion while pushing off with both poles.
Roller skiing:	A dryland training method used by cross-country skiers to imitate on-snow skiing techniques such as skate skiing.

Submaximal Oxygen Uptake ($VO_{2submax}$):

The rate of oxygen uptake by the body measured during steady-state exercise intensities below race pace. $VO_{2submax}$ is sometimes referred to as economy.

CHAPTER TWO

REVIEW OF THE LITERATURE

Introduction

In a group of athletes with similar physiological abilities, economy is considered a good determinant of endurance performance. Economy seems to be affected by various factors such as fractional utilization of VO_{2max}, heart rate, kinematics, as well as the storage of elastic energy or flexibility. The effect of flexibility on economy has been studied mostly in runners with contradictive findings. The findings vary greatly depending on the research protocol and subjects used. Limited information exists on the relationship between flexibility and race performance in cross-country skiers.

Factors Affecting Performance

Maximal oxygen consumption (VO_{2max}) is the maximal rate of oxygen uptake by the body measured during intense exercise (Wilmore & Costill, 2004). Through the 1970's, VO_{2max} was considered the most important physiological predictor of endurance performance (Costill, 1967). In a heterogeneous population, VO_{2max} correlates highly with endurance performances (Bergh, 1982). However, this phenomenon is not true among a homogenous group ($r = -0.12$) such as elite cross-country skiers (Conley & Krahenbuhl, 1980; Hoffman & Clifford, 1992). Even though a high VO_{2max} is necessary for elite skiers, it does not guarantee success.

Physiological factors other than a high VO_{2max} are important for skiing performance (Niinimaa, Dyon, & Shepard, 1978). Researchers tested a group of intercollegiate cross-country skiers and found that the skiers attained only 89% of their VO_{2max} (measured during uphill running on treadmill) at three-minute all-out skiing efforts. Researchers evaluated individual data and found a high correlation between skiing experience and VO_{2max}. Thus an experienced racer attained almost as high of a VO_{2max} while skiing as during running uphill. The researchers realized that VO_{2max} was not the only factor influencing performance or success. A multiple regression technique was used to determine variables affecting skiing success (race time) that were summarized in the following equation ($F_{3,6} = 16.92$; $R^2 = 89\%$) :

Performance success = 2.94(RE, years) **+** 0.52(VO_{2max}, ml/kg/min) – 0.98 (BF, %), where RE = racing experience and BF = body fat. According to the study, the higher the number from this equation, the greater the success in 5-15km cross-country ski races (decreased race time). On an elite level, skill and racing experience played a smaller role than physiological and anthropometric variables. Even though the "success equation" held true for the subjects tested, the finding that more than one factor influenced skiing performance was interesting.

In a study by the same authors, mechanical efficiency as total work over cost of skiing was calculated to be 21% (Niinimaa, Shepard, & Dyon, 1979). Researchers tested the same group of intercollegiate cross-country skiers and found a high correlation between skiing experience, VO_{2max} and percentage of body fat on performance (89%). Again subjects reached only 89% of their running VO_{2max} when they skied on snow.

Researchers hypothesized that performance could be improved by more than 20% if the running VO_{2max} could be developed on skis. Besides VO_{2max}, body fat could influence performance because there is a direct relationship between body mass and ski friction. In order to ski effectively, frictional work and drag work has to be minimized. In their multiple regression analysis, however, neither lean mass nor grip strength showed any advantage in competition, which could be explained by the counterforce of increased muscle force on friction. The mechanical efficiency for skiers was lower than for runners, which would be expected from a more complex sport. It is difficult to accurately measure mechanical efficiency especially in cross-country skiing where there are various environmental (snow condition) and equipment variables influencing work performed.

An older study tried to clarify the concept of efficiency of human movements (Cavanagh & Kram, 1985a). The researchers found that the amount of energy expended to perform submaximal work ($VO_{2submax}$), such as running at a particular speed, varied among individuals. These differences could be attributed to differences in efficiency. Since it has been difficult to measure actual work performed, especially in runners, the alternative term of economy was defined as the submaximal oxygen uptake per unit body weight. Therefore, energy cost (submaximal oxygen uptake) is highly related to successful endurance performance and is less dependent upon actual work accomplished.

<u>Economy in Runners</u>

Numerous studies have focused on economy as a determinant of endurance performance (Beaudoin & Blum, 2005; Cavanagh & Kram, 1985b; Conley &

Krahenbuhl, 1980; Craib et al., 1996; Daniels & Daniels, 1992; Gleim et al., 1990; Jones, 2002; Nelson et al., 2001; Williams & Cavanagh, 1987). To elucidate various factors affecting economy in runners, three studies have been chosen for further discussion (Conley & Krahenbuhl, 1980; Daniels & Daniels, 1992; Williams & Cavanagh, 1987).

The relationships between energy cost and several kinematic variables were examined by Williams & Cavanagh (1987). Sixteen actively training runners were studied at a given treadmill speed (216 m/min) below their lactate threshold for eight minutes and compared to 10-km running times. The large variability of the 10-km time (Mean ± SE: 35:09 ± 2:12 min) suggested a heterogeneous group. The researchers concluded that 54% of the variability in $VO_{2submax}$ (economy) could be explained by slow-twitch muscle fibers (r = - 0.88) and biomechanical variables such as shank angle during foot contact with ground and trunk angle. The main finding supported previous research concluding that economy could not be explained by one single variable but rather by multiple variables.

Other researchers have evaluated the relationship between running economy and performance among homogenous groups of runners (Conley & Krahenbuhl, 1980; Daniels & Daniels, 1992). Both studies examined elite runners at different submaximal running speeds. The most important finding from Conley & Krahenbuhl's (1980) study was the significant relationship between $VO_{2submax}$ at three running speeds (241, 268, and 295 m/min) and 10-km time (Mean ± SD: 32:10 ± 1:00 min) [r = 0.83, 0.82, and 0.79 (p<0.01), respectively]. All graphs depicting $VO_{2submax}$ and running speed showed a positive linear association. The researchers concluded that running economy accounted

for 65% of the variation in performance. The relationship between VO_{2max} and performance in the 10-km run, however, was not significantly correlated (r= -0.12) as was expected for a group of runners with similar VO_{2max} values.

Daniels & Daniels (1992) agreed with the findings of Conley and Krahenbuhl's (1980) study that there is a significant relationship between $VO_{2submax}$ and race performance. However, Daniels & Daniels (1992) emphasized the importance of the test velocity. The researchers suggested test velocities up to 95% of VO_{2max} to imitate typical race speeds. These researchers evaluated VO_2 values over a range of submaximal velocities. However, only three test velocities were chosen for further analysis. The three velocities were 268, 290, and 310 m/min respectively, which were on average higher than the velocities in Conley and Krahenbuhl's study (1980). In addition, velocity at VO_{2max} (vVO_{2max}) seemed to be a better predictor of running success than economy alone. This variable was a theoretical velocity associated with VO_{2max} resulting from an extrapolation of the $VO_{2submax}$ versus velocity relationship.

One main difference between the two studies was the inclusion of female runners in the latter study (Conley and Krahenbuhl, 1980; Daniels & Daniels, 1992). Males tended to be more economical (used less oxygen) than females if absolute values, at speeds of 268, 290, and 310 m/min, were compared (p<0.05). The 14% difference in vVO_{2max} between genders suggested an advantage in aerobic capabilities (VO_{2max} and economy combined) for men. However, at higher velocities such as race pace, the difference between male and female economy diminished (1-2%; p>0.05). These

findings underlined the importance of a good test protocol as well as considerations of gender differences when testing endurance athletes for economy.

<u>Economy in Cross-Country Skiers</u>

In comparison to runners, successful skiers rely more on proper technique, environmental conditions and equipment. Therefore, a good study protocol is vital when studying cross-country skiers to control for any possible confounders. A study by MacDougall and colleagues (1979) showed great variability in economy among cross-country skiers. The most important finding relevant to the present study was the linear regression line for $VO_{2submax}$ and skiing velocity (r = 0.868, p<0.001). The graph was comparable to those reported for runners by Conley and Krahenbuhl (1980) with $VO_{2submax}$ being higher in the skiing study. The authors proposed that a larger muscle mass utilized by skiers increased energy cost to travel the same speed relative to runners. Another reason for the increased $VO_{2submax}$ in comparison to runners could be attributed to equipment (including the metabolic system) and trail conditions (not hardpacked snow). Despite the great correlation between $VO_{2submax}$ and velocity, the study failed to identify gender differences. This could be attributed to the chosen test velocities of 50%, 75% and 100% of skier's "race pace" (124-292 m/min for elite and 112-201 m/min for novice skiers). Too many extraneous variables (gender, environmental condition, and equipment) could have potentially influenced the test results. Therefore, the reported variation in cross-country skiing economy should be viewed with caution.

To control for different snow conditions, ski wax and equipment on skiing economy, two studies examined cross-country skiers during their summer training regimen on roller-skis (Hoffman, Clifford, Foley, & Brice, 1989; Millet, Perrey, Candau, & Rouillon, 2002). Hoffman et al. (1989) concluded that the same factors affecting running economy would determine economy in skiers on roller-skis. They speculated that skill level might even be more important than in runners. Physiological responses such as heart rate (HR) and $VO_{2submax}$ were measured on flat terrain at two different velocities (233 m/min, 300 m/min) with three techniques (kick double pole, V1 skate, double pole). The slower velocity averaged 70-80% of each subject's predicted maximal HR. While there were no significant differences between techniques for any of the variables, researchers recognized the importance of skill level. The researchers noted that among four subjects with similar body weight and the same equipment, it was the individual who qualified for the United States Olympic Trials who showed an improved economy during skiing (decreased $VO_{2submax}$). One limitation to this study was the flat terrain. Cross-country skiers rarely ski only on flat terrain; therefore, the findings were not generalizable. In addition, the researchers suggested pole length (92% of body height) to affect economy. Skiers chose their own pole length, which suited their most economical skiing style.

The second study that examined cross-country skiers during their summer training, studied the relationship between $VO_{2submax}$ and performance as well as the inter-individual difference in $VO_{2submax}$ (Millet et al., 2002). Each subject performed four minutes at 317 m/min, which corresponded to 63-68% of VO_{2max}. $VO_{2submax}$ was

significantly correlated to French Ski Federation (FSF) points which were used as a comparison to performance ($r = 0.61$; $p < 0.05$). The authors proposed that the difference in $VO_{2submax}$ was determined by mechanical factors such as knee angular displacement ($r = 0.75$; $p < 0.01$) and vastus lateralis average EMG during the concentric phase ($r = 0.72$; $p < 0.01$). Also they suggested that skiers with a higher economy tended to use their upper limbs more and stored elastic energy more efficiently. Overall, economy in a homogenous group of cross-country skiers could be explained by mechanical efficiency and/or upper and lower body muscle utilization.

To summarize, an athlete who was more economical, spent less energy to cover a distance at a given speed. A higher economy, or decreased $VO_{2submax}$, was associated with an improved endurance performance because inefficient movements caused additional work for the cardiorespiratory system (Gleim et al., 1990). Researchers concluded that multiple factors contributed to economy. In a complex sport such as cross-country skiing, it is difficult to properly define economy with all its influencing factors. As was the case with cross-country skiing, factors such as skill level, technique, and environmental conditions played an even more important role than in a sport such as running. Another factor that had not been mentioned but could potentially affect economy was flexibility.

<u>Flexibility</u>

The word "flexibility" comes from the latin term flexibilis ("to bend") (Ingraham, 2003) and is defined as an ability to move a joint through its full range of motion

(ACSM, 2006). Flexibility can be measured via the stiffness of a structure or its

resistance to deformation (Gleim & McHugh, 1997). An increase in flexibility could be

regarded as decreased stiffness as well as a decreased ability to store and utilize elastic

energy. The use of stored elastic energy (a form of potential energy) can be described in

a process called the stretch-shortening cycle (SSC). This process describes the use of an

eccentric muscle contraction to enhance a subsequent explosive concentric contraction.

Through storage of elastic energy in the muscle, the stretch on the muscle increases its

tension. As a result, a high-force output occurs (Shorten, 1987).

Since flexibility is thought to be a component of fitness (Corbin & Noble, 1980),

the relationship of age and sex with range of motion has been studied (Bell & Hoshizaki,

1981). Females tended to be more flexible in the 17 joint actions measured than their

male counterparts. There were a few exceptions, however, where there was no gender

difference (cervical lateral flexion, shoulder abduction, forearm supination-pronation and

shoulder rotation). A general decline in flexibility with age was recorded except for

upper extremity joints. These general findings still left the question open if improved

flexibility had a positive effect on performance.

The effect of flexibility on strength performance has been studied (Fowles et al.,

2000). Fowles et al. (2000) examined strength performance after stretching the plantar

flexors for 33 minutes. Maximal voluntary contraction was decreased for up to an hour

after stretching exercises compared to a control group (28 % at 0 minute; 9 % at 60

minutes; $p < 0.05$). Motor unit activation and EMG activity were significantly depressed

immediately after stretching but recovered 15 minutes later. Complete recovery of the

force generating capacity was prolonged which was similar to the recovery of muscle stiffness.

Another study on strength performance and flexibility found similar results (Kokkonen, Nelson, & Cornwell, 1998). The experimental group engaged in 20 minutes of passive static stretching of the hip, thigh and calf muscles whereas the control group performed no stretching. The main finding was a significant decrease in one repetition maximum (1RM) performance for both knee-flexion (7.3% decline) and knee-extension (8.1% decline) following an acute stretching treatment. The authors concluded the stretching treatment to have influenced maximum strength through a reduction in either the passive or active stiffness of the musculotendinous unit. Both studies (Fowles et al., 2000; Kokkonen et al., 1998) concentrated their research on the performance of strength athletes. So the question still remains about the impact of flexibility on performance in endurance athletes.

<u>Flexibility and Economy in Endurance Athletes</u>

The relationship between flexibility and running performance or running economy has been studied extensively (Beaudoin & Blum, 2005; Craib et al., 1996; Gleim et al., 1990; Jones, 2002; Nelson et al., 2001). The results of these studies, however, are contradictory which is due, in part, to differences in study design and methodology (Table 2.1). Three out of the five studies concluded that less flexible runners were more economical. The first study used a homogenous group of males to assess running economy and flexibility (Jones, 2002). Running economy, lactate

threshold, and VO_{2max} were measured using an incremental treadmill test to exhaustion.

The sit-and-reach test (using toes as zero point) was used to measure lower limb and

trunk flexibility. The best score from 5-6 attempts was used to analyze the relationship

between running economy at speeds below lactate threshold (233, 250, and 267 m/min)

and flexibility. The researcher found a significant relationship between $VO_{2submax}$ at 267

m/min and the sit-and-reach test performance ($r = 0.68$; $p < 0.0001$). The author

concluded that the least flexible runners tended to be the most economical when running

at submaximal running speeds. The result could be explained by the tighter

musculotendinous structures for inflexible runners leading to the storage of elastic

energy. A limitation to the study was the use of only one flexibility test (sit-and-reach

test) to measure flexibility.

Table 2.1. Summary of research studies on flexibility and economy in endurance athletes.

Authors	Year	Participants	Flexibility measures	Findings
Beaudoin et al.	2005	17 F collegiate track athletes	6 trunk and lower limb flexibility tests	No relationship betw. FL and E
Craib et al.	1996	19 sub-elite M distance runners	9 trunk and lower limb flexibility tests	↓ FL → ↑ E
Gleim et al.	1990	38 F; 62 M	11 trunk and lower limb flexibility tests	↓ FL → ↑ E
Jones, A. M.	2002	34 M elite distance runners	Sit-and-reach test	↓ FL → ↑ E
Nelson et al.	2001	32 (16 F, 16 M) college students	Sit-and-reach test	No relationship betw. FL and E

F = Female; M = Male; FL=Flexibility; E=Economy

The second study used both men and women to assess eleven lower body and

trunk flexibility tests and economy at six different speeds (between 53.6 and 187.7

m/min) (Gleim et al., 1990). Flexibility measures were recorded as "loose", "normal" or

"tight" (no goniometric measurements) with respect to normal subjects. Again the least

flexible runners were the most economical (r = -0.433, p < 0.00005). Trunk rotation and

lower limb turnout were the best predictors of economy (8-12% difference in economy).

One explanation for these findings could be that "stiffer" runners required less energy to

stabilize the pelvic area. Another explanation is the theory of SSC where a tight muscle

should be able to generate more tension and therefore produce more force. The

researchers examined running economy at various speeds and looked at several flexibility

tests but included subjects with a wide age range and both genders.

The researchers of the third study only included sub-elite male distance runners

(Craib et al., 1996). Nine trunk and lower limb flexibility measures were compared to a

10-min run at 67% of VO_{2max} (248 m/min). All flexibility measures and the 10-min run

were performed twice and averaged. Flexibility measures for external hip rotation (r =

0.53, p < 0.05) and dorsiflexion (r = 0.65, p < 0.05) correlated positively with $VO_{2submax}$.

The researchers speculated that inflexibility in certain areas of the musculoskeletal

system may enhance running economy via the SSC. In addition, the need for muscle

stabilization of certain body areas during foot contact may be minimal in less flexible

runners. Craib et al. (1996) did not find a significant relationship between the sit-and-

reach test and running economy, which could be explained by the well-trained sub-elite

runners involved in the study. Jones (2002) used international-standard male distance

runners who had a slightly higher VO_{2max} than the sub-elite male runners in Craib's

study. There was no significant relationship recorded between flexibility and VO_{2max} in

either study by Jones (2002) and Gleim et al. (1996). Generally, all three correlational

studies found similar results even though different subject groups were examined at varying treadmill speeds.

Two other studies showed neither negative nor positive correlations between flexibility and economy (Beaudoin & Blum, 2005; Nelson et al., 2001). Beaudoin & Blum (2005) studied six trunk and lower limb flexibility measures and a 10-min run at 60% of VO_{2max} (161 m/min) using female collegiate track athletes. Even though similar flexibility tests, as in the study by Craib et al. (1996), were used, the results showed no relationship between flexibility and economy. This difference might be attributed to the inclusion of only female athletes who were not sub-elite or international-standard runners. Another difference might be due to the economy run that was chosen at a slightly lower speed (161 m/min). Jones's (2002) and Craib et al. (1996), for example used both speeds at 70% of VO_{2max} (267 m/min and 248 m/min respectively).

Another study used college-aged students who participated in 30 minutes of vigorous exercise 3-5 days per week to assess the effect of a 10-week stretching program on running economy (Nelson et al., 2001). Each subject's VO_{2max}, sit-and-reach, and running economy were tested at the beginning and at the end of the study for comparison. During the 10-week period, subjects maintained their activity habits while the experimental group engaged in an additional stretching program three times a week. The experimental group experienced a significant ($p < 0.05$) increase in ROM (3.1 ± 2.2 cm) after the stretching program but did not show a change in running economy in comparison to the control group (0.0 ± 0.4 cm). One reason for the results could be attributed to the subjects who were not elite athletes because differences in economy are

less apparent in these subject groups. In addition, 10 weeks might have been too short to show any significant changes in economy due to flexibility. The aforementioned studies on flexibility in runners were all correlational studies and thus the results do not prove cause-and-effect.

Limited information exists on the relationship between flexibility and performance in cross-country skiers. One study examined 12-15 year old cross-country skiers to evaluate the effect of dance training on joint mobility and muscle flexibility, speed and agility (Alricsson et al., 2003). The control group (five males and five females) carried out their typical cross-country skiing training consisting of skiing, roller-skiing and running during the study period of eight months. In addition to the usual cross-country skiing training, the experimental group (five males and five females) received six hours of dance training per week for eight months. Slalom and hurdle (six hurdles, 60 cm high, placed over a distance of 12 m for both tests) tests were used to test speed and agility, respectively, after three and eight months. At the beginning of the study, there was no significant difference between the groups regarding the two tests. After receiving dance training, the experimental group increased their speed by 0.3 s in the slalom test (running in a slalom pattern between hurdles) after three ($p = 0.05$) and eight months ($p = 0.02$) whereas the speed of the control group remained unchanged. The experimental group also improved speed and agility according to the hurdle test (jumping over first hurdle, crawling under the second, jumping over the third and so on) after three months with 0.8 s ($p = 0.000$) and eight months with 0.6 s ($p = 0.01$), while the control group showed an impairment of speed and agility by 0.4 s ($p = 0.05$) after eight

months. The improved speed and agility of the experimental group could be attributed to the dance training, which may have improved balance, coordination and rhythm in these subjects.

Eight flexibility tests were used to test flexibility of the spine, hip and ankle. At the beginning of the study, there was no significant difference in flexibility tests between the groups. After three months, the experimental group increased flexion-extension of the thoracic spine by 7.5° ($p = 0.05$) and after eight months by 9° ($p = 0.03$). Lateral flexion of the spine was increased by 0.04 m ($p = 0.005$) and 0.03 m ($p = 0.02$) after three and eight months, respectively. Hip flexion was also significantly increased after three months by 4.1° ($p = 0.03$). The results from the flexibility tests remained unchanged or decreased for the control group after both three and eight months.

Overall, dance training improved speed, agility, hip flexion and flexibility of the spine. The researchers suggested that the improved speed and agility (determined by the slalom and hurdle test) of the experimental group might be a result of improved balance, coordination and rhythm. Besides improving speed and agility, dance training also improved posture and flexibility in the experimental group. Researchers concluded that cross-country skiing was a very monotonous sport leading to muscle tightness as could be observed by the decreased flexibility in the control group. The results, however, should be examined with caution. Even though the subjects were at the same level of skiing, most of their physiological parameters ($VO_{2submax}$ or VO_{2max}) had not yet been fully developed and therefore, could be greatly influenced by training. Since the experimental group received a greater training volume (normal ski training plus dance training), it was

not clear whether the results were due to the dance training or to the increased training load.

Summary

Previous studies do not agree on the relationship between flexibility and economy in runners. The only clear conclusion that can be made is that economy plays an important role in improving race performance in highly trained athletes with similar VO_{2max}. Due to the lack of studies using cross-country skiers, the purpose of this study was to examine the relationship between selected measures of flexibility and economy in cross-country skiers.

CHAPTER THREE

METHODOLOGY

Subjects

This study was conducted through the Movement Science/Human Performance Lab (MSL) at Montana State University in Bozeman. Twelve male cross-country skiers of similar age were recruited from a Division I College Ski Team (Montana State University) and a local Elite Nordic Team (Bridger Ski Foundation). Each subject signed an Informed Consent Document, which included a description of the testing procedures. These procedures were approved by the Institution Review Board of Montana State University.

Procedure

Each subject participated in two testing sessions within a period of two weeks. The first testing session took place at the MSL whereas the second session was conducted in the Worthington Arena on the Rob Stark oval at Montana State University. The purpose of the first session was to collect anthropometric (age, weight, and height) data, maximum oxygen consumption (VO_{2max}), as well as selected flexibility measures. The second session consisted of a submaximal roller-ski test at three submaximal velocities. Subjects were instructed to maintain the same physical activity level throughout the study

period except forty-eight hours prior to each test session where subjects were instructed

to refrain from high intensity exercise.

<u>Session 1:</u>

VO_{2max} Test. Subjects completed an incremental treadmill test to exhaustion to

determine maximal heart rate for use during session #2. After measuring body weight

and height, subjects completed a warm-up on a treadmill at a self-selected speed and

grade for 10 minutes. The ski walking/running protocol (Australian XC Ski-Striding

Protocol) started with a speed of 99.24 m/min and a grade of 6%. For the remainder of

the test, grade and speed increased gradually every four minutes until subjects reached

volitional exhaustion. As the speed of the treadmill increased, subjects changed from

long walking strides to hill-bounding. To determine if the test was maximal, subjects test

data had to satisfy two out of the following three criteria for achieving VO_{2max}: 1)

respiratory exchange ratio (RER) of 1.1 or greater, 2) an increase in workload without an

increase in oxygen consumption (VO_2 plateau), and 3) a heart rate (HR) within 10 beats

of age predicted maximal heart rate (APMHR). During the VO_{2max} test, subjects used

poles with rubber tips to simulate diagonal stride skiing by poling with the upper body

while walking/running. Heart rate data was measured via telemetry and was further used

for the submaximal roller-ski test during session #2. Each test lasted between 15 and 20

minutes.

Flexibility Testing. Immediately following the VO_{2max} test, seven measures of

shoulder, trunk and lower limb flexibility were performed over a period of 30 minutes

(Figure 3.1). The seven flexibility tests were chosen according to previous studies that found a correlation between selected flexibility tests and economy, as well as having a relevance to cross-country skiing (Craib et al., 1996; Gleim, Stachenfeld, & Nicholas, 1990; Jones, 2002). Stretching prior to flexibility assessments was prohibited. The subjects were instructed to wear comfortable clothing. Two complete trials of all flexibility measures were consecutively recorded on each subject without shoes on. The order of flexibility measures were counterbalanced across subjects. To improve reliability, all flexibility measurements were taken by the same investigator.

Total Body Rotation Test: The total body rotation test measures flexibility of multiple joints such as ankles, knees, trunk, shoulder and neck (Figure 3.1E). The measurement bar was adjusted to the subjects shoulder height. Subjects stood sideways, one arm length away from the wall and with toes on a marked line on the floor. The shoulder opposite to the wall was abducted to a 90º position relative to the torso. Next, the subject rotated the torso externally in the transverse plane with the shoulder still in abducted position. The goal was to slide the panel on the measurement bar as much forward as possible using a closed hand. A fist had to be maintained throughout the motion with the little finger touching the panel. Subject's feet had to stay in place and point straight forward. The test was conducted on both sides (left and right) and an average of two trials was used for the final score. A higher final score indicated a greater range of motion (ROM).

Lateral flexion of Lumbar Spine: Lateral flexion of the spine was measured with this test (Figure 3.1B). Maximum active lateral flexion of the lumbar spine was measured on the right and left side. Subjects were asked to stand with the back against a wall and the arms by the sides with the wrist in a neutral position. The third finger was kept along the lateral side of the leg and marked with a pen on the thigh bilaterally before and after the measurements. The distance between the two marks was measured with a ruler. A greater distance measured between the two marks showed a greater ROM of the spine.

Shoulder Rotation Test: This test measured the degree of shoulder rotation. A stick with a measuring tape was used for this test. Biacromial width, from the lateral edges on each acromion process, of the shoulder was measured. The subject held the stick firmly with the right hand at the zero point while the left hand was placed on the other end. Both hands were positioned on the stick so that the thumbs pointed to the lateral side of the body. Subject stood and rotated the stick with straight arms through the sagittal plane. For each successful rotation over their head, the left hand was positioned 1inch closer to the right hand until the subject was no longer able to fulfill a complete rotation without bending an arm. Subjects had to complete this test with no more than five trials. The last complete motion was recorded and the biacromial width subtracted to determine the final score. A lower final score resulted in a greater ROM of the shoulder.

A) Modified sit-and-reach

B) Lateral flexion of lumbar spine

C) Shoulder rotation

D) Standing horizontal hip abduction
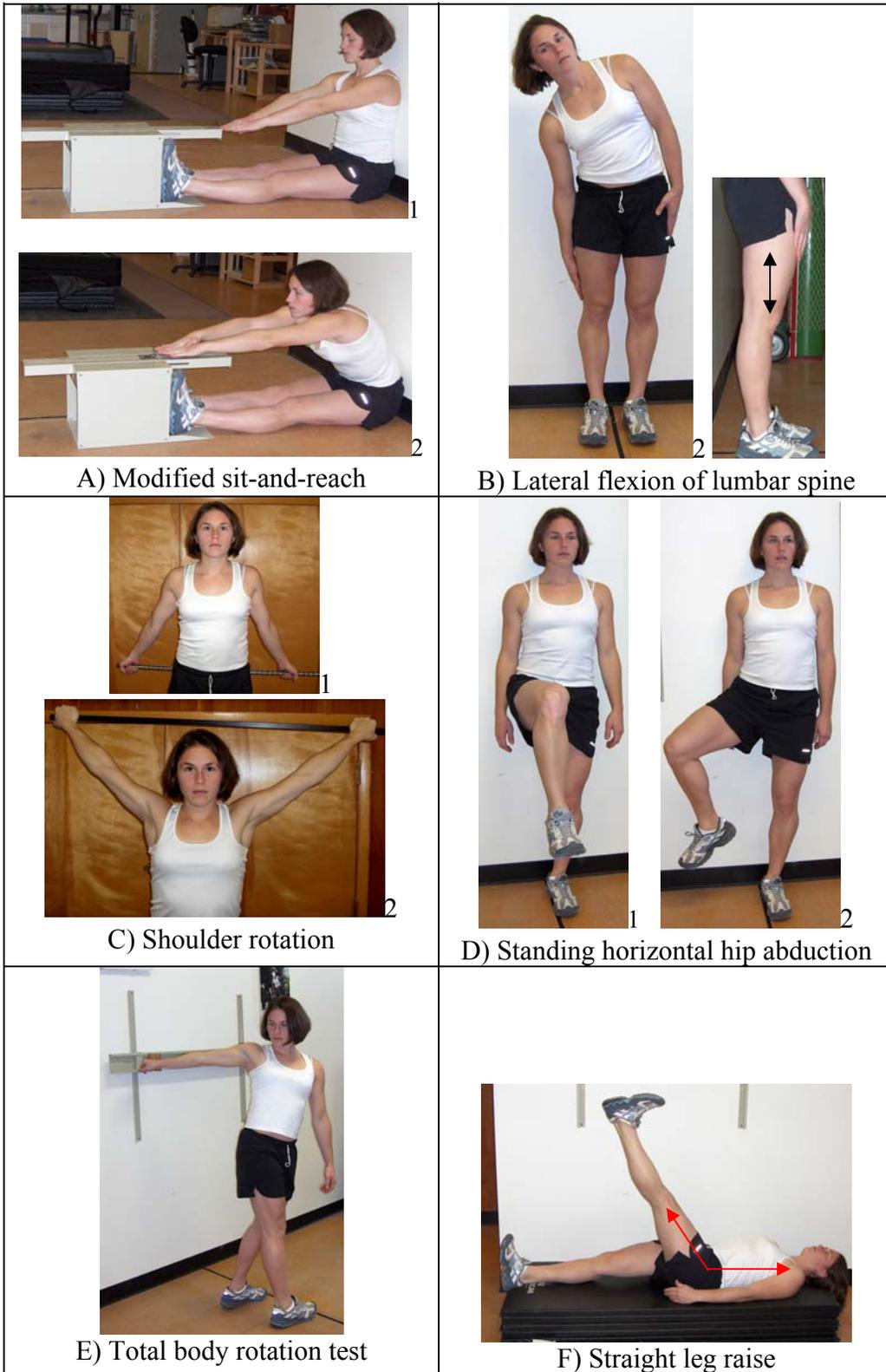
E) Total body rotation test

F) Straight leg raise

Figure 3.1. Seven flexibility tests (lying horizontal hip abduction not shown) for shoulder, trunk and lower limb (A-F): (1) starting position, (2) ending position

Standing and Lying Horizontal Hip Abduction: The degree of horizontal hip abduction was measured during this test (Figure 3.1D). For the standing test, subjects stood against a wall with their knee held in a 90º position. From this position, the subject abducted the hip horizontally as far toward the wall as possible. During the test, subjects were allowed to grasp the wall for stability. Horizontal hip abduction angle was measured with a goniometer. A greater goniometer measure (degree) indicated a greater ROM of the hip. The same test was performed on the subjects in a supine position (lying horizontal hip abduction).

Modified Sit-and-Reach Test: The modified sit-and-reach test is a multi-joint measure of flexibility (Figure 3.1A). Subjects were seated on the floor against modified sit-and-reach box with their hands together. After pronating the wrists, subjects performed shoulder flexion and the "L" shaped indicator was adjusted to the zero point. Without bending knees, subjects reached as far as possible by pushing the "L" shaped indicator. The furthest point reached and held for at least two seconds was used. The best score of two attempts was recorded. A higher score in the modified sit-and-reach test indicated a greater ROM.

Straight Leg Raise: The straight leg raise tested the flexibility of the hamstring muscles across the hip joint (Figure 3.1E). Subjects lay supine on a pad. One leg was held on the pad while the other leg was flexed by an assistant. With a goniometer, the researcher measured the hip flexion angle between the chest and the raised leg (without

flexing the knee). Greater flexibility of the hamstring muscles resulted in a higher

goniometer measure.

Session 2:

Submaximal Roller-Ski Test: The purpose of the second session was to perform a

submaximal roller-ski test at three submaximal speeds to measure economy. After

completion of a 15-min warm-up at self-selected speed, subjects performed three 10-min

trials at preset target heart rates (65%, 75%, 85% of HR_{max}) using roller-skis on an indoor

track oval (216.1 m). There was a 3-minute break between each trial where the

investigator had to reset the heart rate monitor. For each trial, target zones on the heart

rate monitor were set to the target heart rate plus/minus three beats with an audible alarm.

During each trial, subjects wore a metabolic system on their backs that collected VO_2

data. At the same time, subjects wore a heart rate monitor strap around their chest that

measured heart rate via telemetry. Average heart rate for each trial was recorded.

Subjects roller-skied two trials in one direction and one trial in the opposite direction on

the oval. The direction of each trial, as well as the order of the trials, were

counterbalanced across subjects. Subjects used the same pair of roller-skis for all three

trials. Each subject used their own ski poles for this test. The average lap time were

recorded by the investigator and used for calculating average speed. Oxygen

consumption (VO_2) data, HR data and speed were used for further analysis of economy.

Figure 3.2. Side view of one subject during submaximal roller-ski test.

To test the submaximal roller-ski protocol, a pilot study was conducted with one female subject. The purpose of this pilot study was to test the feasibility of roller-skiing according to preset heart rates. The subject was an elite skier (23 years of age) with a HR_{max} of 200 beats/min and target heart rates of 130, 150 and 170 beats/min (corresponding to 65%, 75% and 85% of HR_{max}). The direction of each trial was randomly assigned. Over the last few minutes of each trial, the average time per lap was recorded and used to calculate average speed. A summary of the test results can be found in Table 3.1.

Table 3.1. Data summary of pilot study (n=1).

	Trial #1	Trial #2	Trial #3
Target HR	65% of HRmax	75% of HRmax	85% of HRmax
Average HR	130	150	173
Direction	Counterclockwise	Counterclockwise	Clockwise
Length of one lap (m)	216.1	216.1	216.1
Average time/lap (s)	64.3	52.3	44.3
Average speed (m/s)	3.4	4.1	4.9

<u>Instrumentation</u>

The VO_{2max} tests were performed on a Trackmaster Research Treadmill (2.4 m x 1.2 m belt surface) located in the MSL. Oxygen uptake during the treadmill test was measured with a TrueMax 2400 Metabolic Measurement System (Parvo Medics, Sandy, UT, USA). Subjects wore a nose-clip and inspired room air through a mouthpiece with one-way valves. Prior to each test the oxygen and carbon dioxide gas analyzers were calibrated with gases of known composition. Gas values were obtained in 20-second intervals with the values collected from the last one minute of each stage being averaged to determine the oxygen uptake for the specific stage. A telemetry-based heart rate monitor (Polar Electro, Inc., Lake Success, NY, USA) was used to record an average heart rate every five seconds. During the submaximal roller-ski test, HR and VO_2 were recorded at 60 seconds sample intervals. The same Marwe roller-skis were used (Hyvinkään Kumi Oy, Finland) either with a pilot (Salomon, France) or a Rotefella NNN (Garmont USA, Inc.) binding. A Rolatape® Professional Series (Spokane, WA, USA) measuring wheel was used to measure the length of the indoor oval. The instrumentation used to measure flexibility included a stainless Baseline® goniometer (Country Technology Inc., Gays Mills, WI, USA), a gravity-type goniometer (Leighton Flexometer

Inc., Spokane, WA, USA) and the Acuflex® I, II and III (Novel Products, Inc., Rockton, IL, USA).

Statistical Analysis

Oxygen consumption (VO_2) and HR were averaged over the last four minutes of each 10-min roller-ski trial and used for further analysis. Measured VO_2 and heart rate values were plotted against speed during each stage to produce a line graph for each subject (VO_2 and HR slopes). The slope of the line of these graphs was used as an indicator of roller-ski economy. The Pearson product moment correlation was used to examine associations between flexibility measures and roller-ski economy. The alpha level was set at 0.05. The Statistical Package for the Social Sciences software, version 12.0 (SPSS Inc., Chicago, IL, USA) was used for all statistical analysis.

CHAPTER FOUR

RESULTS

The purpose of this study was to evaluate the relationship between flexibility and roller skiing economy in cross-country skiers. A ski-striding test to exhaustion yielded maximal heart rate (HR_{max}) data that were used for the submaximal roller-ski tests. The flexibility tests consisted of seven measures (Flex1-Flex7) for shoulder, trunk and lower limb and were completed over a 30-minute period. All flexibility tests were repeated twice on each side (where appropriate) of the body (e.g., Flex1r, Flex1l). Repeat measures were averaged for subsequent analyses. For the purpose of determining economy, three 10-min roller-ski trials at 65%, 75% and 85% of HR_{max} were tested.

Twelve male cross-country skiers participated in both testing sessions and completed all tests. All subjects met the inclusion criteria of having raced competitively for at least three years. The subjects' descriptive statistics including age, body height, body mass, training volume and years of competitive racing, are shown in Table 4.1. Information about subject's training and racing regimen was obtained from the subject's questionnaire (Appendix B). On average, subjects exercise 506.9 ± 95.3 hours per year and have been ski racing since they were 12 years old.

Table 4.1. Descriptive statistics for subjects (Mean±SD).

n	Age (yrs)	Body Height (cm)	Body Mass (kg)	Training volume (hours/yr)	Competitive XC-ski racing (yrs)
12	21±3	183.2±6.5	76.7±6.8	506.9±95.3	9.4±4.8

XC = cross-country

During the ski-striding treadmill test, each subject met the criteria for achieving maximal oxygen consumption (VO_{2max}). The results from this test are summarized in Table 4.2 with the VO_{2max} data presented as absolute and relative to body mass.

Table 4.2. Results from the ski-striding test to exhaustion (Mean±SD) (n=12).

Subjects	VO_{2max} (l/min)	VO_{2max} (ml/kg/min)	HR_{max} (bpm)
Male cross-country skiers	4.64±0.5	60.4±3.4	193.3±5.9

$VO2_{max}$ = maximal oxygen consumption; HR_{max} = maximal heart rate

All seven flexibility measures are described and their respective mean values are summarized in Table 4.3. Measurements taken on right and left sides are reported separately. For detailed results (e.g., flexibility measures for each subject) refer to Appendix C.

Table 4.3. Descriptive statistics of flexibility measures (n=12).

Variable	Description	Range	Mean ± SD
Flex1	Total body rotation test (right side) (in)	1.5 – 19.8	11.1 ± 5.3
	Total body rotation test (left side) (in)	4.4 – 20.8	12.7 ± 5.1
Flex2	Right lateral flexion of spine (cm)	19.3 – 29.8	24.6 ± 3.6
	Left lateral flexion of spine (cm)	19.5 – 30.0	25.1 ± 3.4
Flex3	Shoulder rotation test (in)	21.5 – 38.0	31.6 ± 5.1
Flex4	Right standing horizontal hip abduction (degrees)	53.5 – 86.5	67.2 ± 9.5
	Left standing horizontal hip abduction (degrees)	43.5 – 85.0	66.4 ± 13.8
Flex5	Right lying horizontal hip abduction (degrees)	57.5 – 80.0	70.6 ± 7.1
	Left lying horizontal hip abduction (degrees)	49.5 – 79.0	66.3 ± 8.5
Flex6	Modified sit-and-reach test (in)	10.9 – 20.3	15.7 ± 2.9
Flex7	Right passive leg raise (degrees)	72.5 – 122.5	98.8 ± 14.6
	Left passive leg raise (degrees)	75.0 – 120.0	98.1 ± 13.5

The results from the submaximal roller-ski tests are summarized in Table 4.4. All measurements were averaged over the last four minutes of each 10-min trial. The average time per lap and the length of the indoor track (216.1 meters) were used to calculate average speed. Submaximal oxygen consumption (VO_2) was expressed relative to the sum of body mass and equipment mass (Mean ± SD; 4.9 ± 0.1 kg). The equipment consisted of ski poles (0.34 ± 0.01 kg), ski boots (1.34 ± 0.10 kg), roller skis (2.1 kg), the metabolic system (1.04 kg), and the HR monitor and strap (0.12 kg).

Table 4.4. Summary statistics from the submaximal roller-ski tests (Mean±SD) (n=12).

Target % of HR_{max}	Time/lap (s)	Speed (m/min)	VO_2 (ml/kg/min)	HR (bpm)	Actual % of HR_{max}
65	65.8±12.0	202.7±33.3	25.7±4.3	127±4	65.7
75	49.5±5.1	264.5±25.6	28.8±4.6	145±5	75.0
85	41.3±2.7	315.3±20.9	37.0±4.4	165±5	85.4

HR_{max} = maximal heart rate; HR = heart rate; VO_2 - relative to body mass and equipment mass

For each subject, submaximal VO_2 and heart rate (HR) at each of the three rollerski intensities were plotted against rollerski speed. Figure 4.1 shows VO_2 versus speed for three selected subjects. Coincidently, subject 1 and 5 (dashed and broken lines on graph, respectively) exhibited similar VO_2 values at each intensity. Their corresponding speeds, however, were different. At each intensity, subject 5 was able to go faster compared to subject 1 while their mean VO_2 values were similar. Figure 4.2 represents HR versus speed for three selected subjects. Using simple linear regression, the slope of each graph was determined and used for further analysis (Appendix C). Slopes for VO_2 versus speed graphs (hereafter referred to as VO_2 slopes) represented economy (E) in ml/kg/m, while HR slopes (i.e., HR/speed graphs) represented E in beats/m.
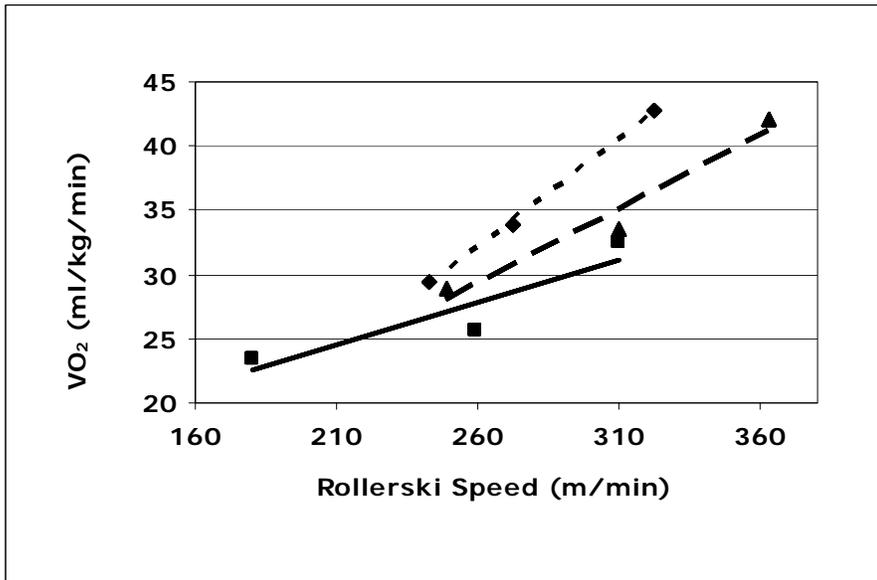
Figure 4.1. Relationship of VO_2 to speed for three selected subjects. VO_2 = oxygen consumption; diamonds correspond to data from subject 1 (VO_2=0.17xspeed-11.68; R^2=0.997), squares to data from subject 4 (VO_2=0.07xspeed+10.78; R^2=0.834), and triangles to data from subject 5 (VO_2=0.12xspeed-0.62; R^2=0.959). Best fit line (VO_2 slope) for subject 1, subject 4, and subject 5 are represented by dashed, solid, and broken lines, respectively.

Figure 4.2. Relationship of HR to speed for three selected subjects. HR = heart rate; diamonds correspond to data from subject 1 (HR=0.50xspeed+11.71; R^2=0.967), triangles to data from subject 2 (VO_2=0.20xspeed+99.85; R^2=0.997), and squares to data from subject 5 (VO_2=0.36xspeed+44.08; R^2=0.999). Best fit line (HR slope) for subject 1, subject 2, and subject 3 are represented by dashed, broken, and solid lines, respectively.

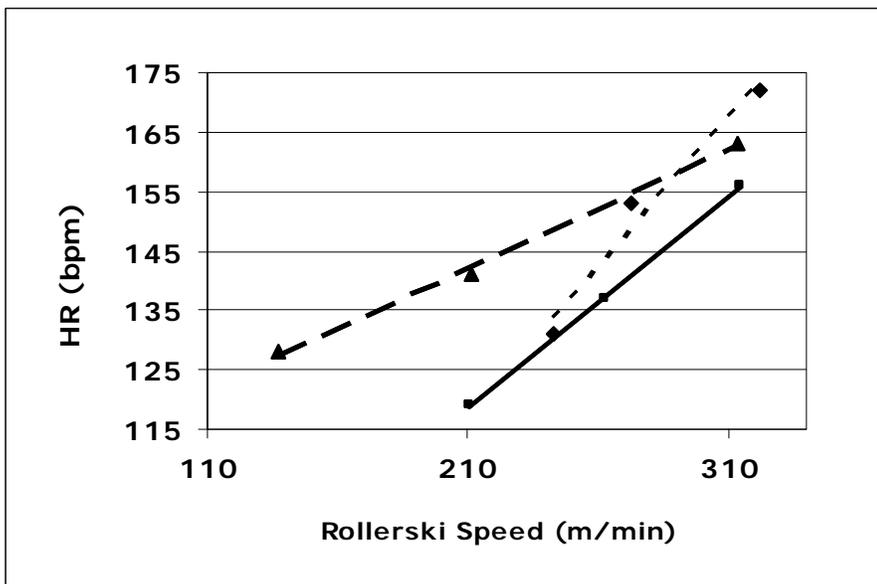The correlational analysis revealed no significant relationships between any of the flexibility measures and either VO_2 or HR slopes at the 0.05 alpha level (Table 4.5). However, there appeared to be weak negative trends between VO_2 slope and right total body rotation (Flex1r: r = -0.03), right and left lateral flexion of spine (Flex2r: r = -0.14, Flex2l: r = -0.38), right and left standing horizontal hip abduction (Flex4r: r = -0.27, Flex4l: r = -0.14), and left lying horizontal hip abduction (Flex5l: r = -0.34). All the other flexibility measures indicated possible weak positive trends (Flex1l: r = 0.05, Flex3: r = 0.49, Flex5r: r = 0.03, Flex6: r = 0.12, Flex7r: r = 0.14, Flex7l: r = 0.15). Similarly, a weak negative relationship was observed between HR slope and right and left total body rotation (Flex1r: r = -0.13, Flex1l: r = -0.10), right lateral flexion of spine (Flex2r: r = -0.08), right and left lying horizontal hip abduction (Flex5r: r = -0.05, Flex5l: r = -0.42), the modified sit-and-reach test (Flex6: r =-0.32), right and left passive leg raise (Flex7r: r = -0.27, Flex7l: r = -0.12). Left lateral flexion of spine (Flex2l: r = 0.09), shoulder rotation (Flex3: r = 0.31), right and left standing horizontal hip abduction (Flex4r: r = 0.06, Flex4l: r = 0.04) indicated possible weak positive trends with HR slope. As an example, Figure 4.3 and 4.4 represent the relationship between shoulder rotation (Flex3) and VO_2 and HR slopes, respectively. In both figures, there is a weak positive relationship visible between shoulder rotation (Flex3) and economies (r = 0.49 and r = 0.31 for VO_2 and HR slope, respectively).

Table 4.5. Correlation coefficients, with 95% confidence interval in parentheses, between flexibility measures and roller-skiing economy.

Flexibility Measures	Roller skiing economy variables	
	VO$_2$ slope (ml/kg/m)	HR slope (beats/m)
Flex1r	-0.03 (-0.59-0.55)	-0.13 (-0.66-0.48)
Flex1l	0.05 (-0.54-0.61)	-0.10 (-0.64-0.50)
Flex2r	-0.14 (-0.66-0.47)	-0.08 (-0.63-0.52)
Flex2l	-0.38 (-0.78-0.25)	0.09 (-0.51-0.63)
Flex3	0.49 (-0.12-0.83)	0.31 (-0.32-0.75)
Flex4r	-0.27 (-0.73-0.36)	0.06 (-0.53-0.61)
Flex4l	-0.14 (-0.66-0.47)	0.04 (-0.55-0.60)
Flex5r	0.03 (-0.55-0.59)	-0.05 (-0.61-0.54)
Flex5l	-0.34 (-0.76-0.29)	-0.42 (-0.80-0.20)
Flex6	0.12 (-0.49-0.65)	-0.32 (-0.76-0.31)
Flex7r	0.14 (-0.62-0.76)	-0.27 (-0.73-0.36)
Flex7l	0.15 (-0.46-0.67)	-0.12 (-0.65-0.49)

Flexibility measures - Flex1r, Flex1l: right and left total body rotation; Flex2r, Flex2l: right and left lateral flexion of spine; Flex3: shoulder rotation; Flex4r, Flex4l: right and left standing horizontal hip abduction; Flex5r, Flex5l: right and left lying horizontal hip abduction; Flex6: modified sit-and-reach test; Flex7r, Flex7l: right and left passive leg raise; *Roller skiing economy*-VO$_2$ slope: from VO$_2$ versus speed graph, HR slope: from HR versus speed graph, VO$_2$=submaximal oxygen consumption, HR=heart rate
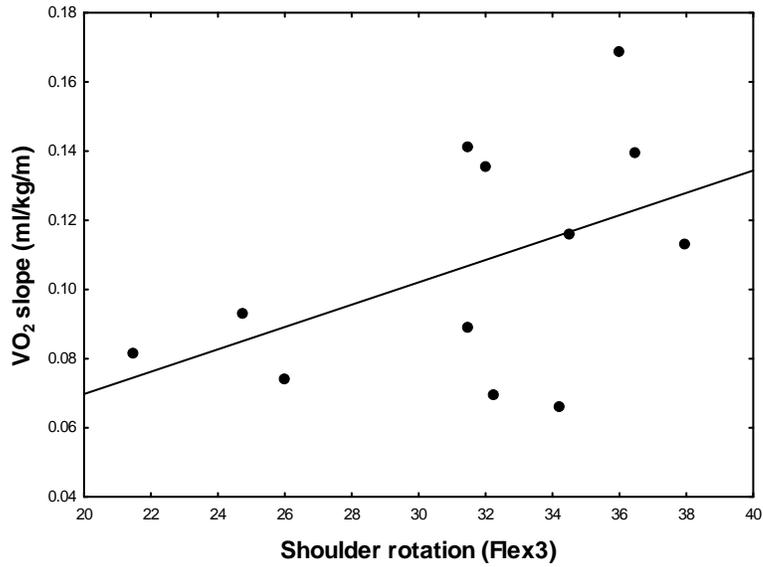
Figure 4.3. Relationship of economy (VO_2 slope) to shoulder rotation. VO_2 = oxygen consumption; Solid line represents best fit line (E=0.005+0.003xFlex3; R^2=0.239; n=12).
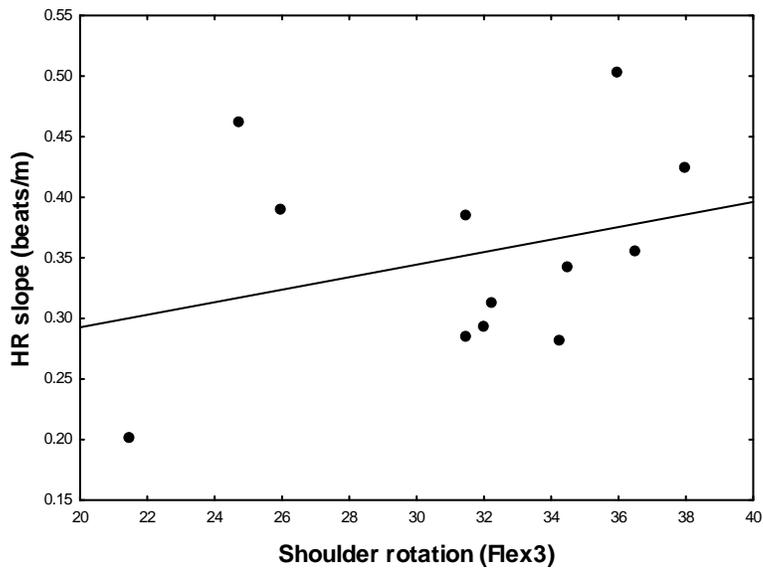

Figure 4.4. Relationship of economy (HR slope) to shoulder rotation. HR = heart rate; Solid line represents best fit line (E=0.189+0.005xFlex3; R^2=0.094; n=12).

CHAPTER FIVE

DISCUSSION

The primary finding of this study was that none of the seven flexibility measures correlated significantly with economy. In this relatively homogenous group of subjects, maximal oxygen consumption (VO_{2max}) was also not significantly correlated with either economy (E) expressed as VO_2 slope (r=0.09, p>0.05) or HR slope (r=0.25, p>0.05). Results of this study do not support previous research with runners suggesting that increased flexibility may be desirable for optimal running performance (Beaudoin & Blum, 2005; Nelson et al., 2001). The present results are also inconsistent with research proposing that inflexibility of the trunk and lower limbs are associated with enhanced running economy (Craib et al., 1996; Gleim, Stachenfeld, & Nicholas, 1990; Jones, 2002).

Analysis of Upper Body Flexibility Tests

The results of the total body rotation test indicated low flexibility (Table 4.3) because the subjects were ranked in the lowest 10th percentile for this flexibility test (Hoeger & Hopkins, 1988). One reason for this result could be attributed to the test that measured multi-joint flexibility in the transverse plane including flexibility of the glenohumeral joint, the thoracic and lumbar spine, the pelvic joint, the knee and ankle joint. Poor flexibility in the glenohumeral joint may have had the greatest impact on the overall score. This speculation was supported by the subjects who reported a slight pain

in this joint during the test. For that reason, the glenohumeral joint could be regarded as the limiting factor of the total body rotation test. However, additional upper body tests would need to be performed to confirm this statement.

To compare measurements for the lateral flexion of the spine to previous research, the results were converted to percentages of body height (BH). The scores for the right and left side were combined and revealed 13.6±1.9 % (Mean±SD) of BH (range: 11.1 – 17.2). Similar results were reported by Craib et al. (1996) who examined 19 sub-elite distance runners (Mean±SE: 10.2±0.3 % of BH; range: 7.8 – 12.4). Subjects in the present study (cross-country skiers) showed greater flexibility when compared with these distance runners. Even though different athletes were examined, neither the present study nor Craib's study found a significant correlational relationship between the flexibility measure and economy. The nonsignificant relationship could be attributed to the multi-joint flexibility test that included the glenohumeral joint, shoulder girdle, the spine and the pelvis.

According to the shoulder rotation test measurements (Table 4.3), subjects are ranked in the 20th percentile compared to other males of their respective age group (Hoeger & Hopkins, 1988). An explanation for this observation could be that low flexibility in the shoulder area is beneficial or even necessary for successful skate skiing performance. During skate skiing on flat terrain, the arm and pole movement occur mostly in the saggital plane. The poling phase of skate skiing is influenced by elbow and shoulder joint flexion/extension that affect the vertical and propulsive force (Rusko, 2003). Most skiers choose to plant the poles with relatively flexed elbows, which allows

for a greater elbow range of motion throughout poling. The initial elbow flexion is

associated with eccentric stretching of the triceps muscle (Rusko, 2003). This may help

preload the triceps to store elastic energy that can later be used to enhance the force

development during elbow extension. This pattern of muscle activity (eccentric followed

by concentric stretching) is called the stretch-shortening cycle (SSC). Other researchers

have indicated the importance of the arm acceleration during each poling motion

(Kvamme, Jacobsen, Hetland & Smith, 2005). These researchers suggested that the rapid

sequencing of the arm swing and pole plant could have been facilitated by the force

generation through SSC. Even though the relationship between shoulder rotation

flexibility and rollerski economy was not significant, a tight shoulder area may aid in the

transfer of force to the poles utilizing stored elastic energy. This could potentially result

in a decreased energy cost (VO_2) during skate skiing.

<div align="center">Analysis of Lower Body Flexibility Tests</div>

There was a small difference between standing and lying horizontal hip abduction

(Table 4.3). Combined scores for both tests revealed a mean value that was much higher

(Mean±SD: 66.8±11.7 degrees) compared with reported values (Mean±SE: 43.9±2.1

degrees) in runners (Craib et al., 1996). Craib et al. (1996) found a positive correlation (r

= 0.53) between standing external hip rotation (term used for horizontal hip abduction

test) and submaximal VO_2 in sub-elite male distance runners, which meant that the less

flexible runners had the best economy (lowest VO_2 value for given speed). The

researchers concluded that inflexibility in the transverse and frontal planes of the trunk

and hip regions might stabilize the pelvis during foot contact with the ground. In contrast, there was no significant correlation found between the two variables (right side: $r = -0.27$ and 0.06 for VO_2 and HR slope, respectively; left side: $r = -0.14$ and 0.04) in the present study. Disagreement between these studies may be due to differences between running and cross-country skiing technique. During roller-skiing, maximal force during the poling phase is generated by trunk flexion (Rusko, 2003). Trunk flexion allows the shoulder and elbow to remain in mid-range positions where greater joint torques can be generated. During running, however, the trunk remains relatively stable.

In comparison to the weak negative trend ($r = -0.32$) in the present study, Jones (2002) found a significant positive relationship ($r = 0.68$; $p < 0.0001$) between the sit-and-reach test and $VO_{2submax}$. The researcher suggested that greater stability in the pelvic area reduces the requirement of additional muscular activity as the foot strikes the ground. In addition, a tighter musculotendinous system allows for greater elastic energy storage with a subsequent increased release of the stored energy during the concentric phase (SSC). While this theory might hold true for lower back and hamstring muscles in runners, skiers need to be somewhat flexible in these muscle groups to properly carry out any skate ski motions. Rusko (2003) mentioned the importance of back extensors for effective force generation during skate skiing. The slight trunk flexion and vertical center of mass (COM) motion facilitate the proper pole position where a great amount of propulsive force can be generated. Runners, however, maintain a relatively stable body position during each foot strike. The quadriceps muscles in skiers might have the same effect as the hamstrings in runners in that they are in charge of storing elastic energy. In

skiers, the quadriceps muscles support the flexed knee position during skate skiing. These muscles could potentially store elastic energy that could be transferred to the ski during each push-off phase. Unfortunately, there was no test administered in this research study that specifically measured quadriceps flexibility.

Both the modified sit-and-reach test and the straight leg raise measured flexibility of the pelvis, hamstring, gastrocnemius, and soleus muscles. The results indicate a weak positive trend between the sit-and-reach test ($r = 0.12$), the straight leg raise ($r = 0.14$ and 0.15 for right and left side, respectively) and the VO_2 slope. A weak negative trend was observable between the sit-and-reach test ($r = -0.32$), the straight leg raise ($r = -0.27$ and -0.12 for right and left side, respectively) and the HR slope. A decrease in hamstring, gastrocnemius, and soleus flexibility might hinder a skier to properly complete a skating cycle. Ankle extensor and hamstring muscles that are "stiff" might disable a subject to balance on one ski and therefore might hinder a skier to position themselves properly above the skis. An inflexible skier might have difficulties holding an appropriate position for a long period of time. As a consequence, subjects might experience discomfort while trying to balance and maintain the proper body position.

Analysis of Economy

In the present study, the differences in economy values were not as great as expected between subjects. In cross-country skiing, the differences in economy are supposed to be greater than in running due to the greater demand on technique (Rusko, 2003). One reason for that phenomenon could be attributed to the small indoor track that

was available for roller-ski testing. In addition to the length, the terrain of the track was not optimal for an economy analysis of cross-country skiers. While the indoor facility provided a stable environment throughout all the testing sessions, the flat track did not perfectly simulate on-snow skiing. Compared to a common cross-country ski course profile, the less demanding terrain of the indoor track failed to discriminate between high and low skilled skiers. During the submaximal roller-ski trials, subjects utilized two skating techniques. On the straightaway, subjects used the V2 technique that involves one double poling action with each skating stroke (two poling actions per cycle) (Kvamme et al., 2005). Around the corners, subjects utilized the V2 alternate technique that involves one double poling action per two skating strokes. The smooth surface of the indoor track assisted the subjects with their skiing motion by increasing their gliding phases, which could have potentially increased cycle length. Researchers have shown that cycle length is highly correlated with velocity during V2 (r=0.91) and V2 alternate (r=0.97) (Bilodeau, Boulay, & Benoit, 1992). Smith (1992) proposed that cycle length could either be increased by improved glide or improved propulsive force. Thus, a more challenging course profile could have elicited greater inter-individual variations in economy.

The economy values of the present study did not agree with previous research. In a study investigating energy cost of competitive cross-country skiers, the researchers found oxygen cost of skiing to be 10-12 ml/kg/min higher than that for trained runners at the same running speed (MacDougall, Hughson, Sutton, & Moroz, 1979). The present VO_2 results (Table 4.4) indicate that the value at 75% of HR_{max} (Mean±SD; 28.8±4.6

ml/kg/min at 265 m/min) seems low compared to running values (Mean±SE; 45.5±0.06 ml/kg/min at 248 m/min) at similar speed (Craib et al., 1996). Jones (2002) also reported much higher VO_2 values (Mean±SD; 50.6±3.7 ml/kg/min) during running at a similar speed (267 m/min). One reason for the low VO_2 values during the submaximal roller-ski trials could be attributed to the smooth surface of the indoor track. Roller-skiing on a smooth surface could have facilitated the gliding phase during skating and could have potentially lowered the energy cost required to maintain a stable velocity. Oxygen consumption (VO_2) measured in this study is, therefore, not an accurate measure of on-snow energy expenditures and is not useful for comparison to running studies that used similar speeds. If future studies choose an indoor track for data collection, an adjustment in skiing speeds should be made. Speeds of 315 m/min (corresponded to 85% of HR_{max}) or higher should be chosen in order to elicit accurate oxygen consumption measures. Other researchers suggested using running speeds up to 95% of VO_{2max} to imitate race speeds (Daniels & Daniels, 1992). Examining roller-ski economy at speeds similar to those used when competing might be of great importance as economy influences performance.

There are some limitations to the present study. Even though subjects were homogenous with respect to age and training status, they were not elite skiers. Male collegiate cross-country skiers were selected because of their availability in the local area. The precision of the goniometric measurements was another limitation. The use of radiographic visualization of landmarks would certainly increase the accuracy of each measurement. Also, most flexibility measurements involved movement of multiple

joints. For example, passive straight leg raise might have involved pelvic rotation, which could have influenced the end result.

Future studies should focus on flexibility tests that are more specific to ski motions (for example a test for quadriceps flexibility). To eliminate erroneous flexibility results, a different measurement method such as an electric goniometer based to a computer should be considered. An emphasis should also be put on different roller skiing speeds/intensities. It would also be interesting to examine skiers during sprint (high speed/short distance) skiing. As the speed increases during skiing, technique gains a greater importance. Comparing sprint specialists to distance skiers would be another idea for a future study. This approach would be comparable to a similar analysis between sprinters and marathon runners.

The results of this study have limited generalizability due to the age, training status and racing experience of the subjects and the submaximal rollerski speeds selected. Therefore, future studies should include skiers differing in age and examine submaximal skiing trials with various speeds and course profiles. Also, female skiers should be considered in future analyses of flexibility and skiing economy.

CHAPTER SIX

CONCLUSION

The findings of this study indicate that flexibility is not a good determinant of economy in a homogenous group of cross-country skiers. Seven measures of shoulder, trunk and lower limbs were used to assess flexibility. Economy was evaluated by measuring oxygen uptake (VO_2) during three 10-min trials at 65%, 75% and 85% of VO_{2max} on roller-skis. Further, the slope of a VO_2 versus speed and HR versus speed graph were used as indicators of roller-skiing economy. Although correlations between flexibility and economy were non-significant, there were weak trends observable that might aid in designing protocols for future studies examining flexibility and economy in cross-country skiers.

The findings of the present study could have some practical implications. The results indicate that flexibility measures are location specific. Depending on the body regions assessed, there were either weak positive or weak negative trends observable. It is difficult, however, to predict if overall flexibility of the whole body is advantageous in cross-country skiing. According to Svensson (1994), a good range of motion (ROM) is an important factor for proper skate skiing technique. From this statement alone, however, the definition of a "good" ROM is not apparent. Therefore, athletes are advised to maintain their current flexibility status, until further research is conducted on flexibility measures specific to skiers. This recommendation seems logical, as cross-country skiing is a monotonous sport that often leads to muscle tightness (Mahlamaki,

Soimakallio, Michelsson, 1988). As a consequence, some individuals might need to include a regular stretching program in addition to their daily training routine while others might need no further practices to maintain their flexibility.

Future research needs to further evaluate the relationship between flexibility and economy in skiers. New findings might aid in planning training regimens for athletes trying to improve skiing technique and thus, skiing economy. Consequently, athletes would be able to improve skiing performance.

REFERENCES CITED

ACSM. (2006). *ACSM's guidelines for exercise testing and prescription* (7th ed.). Philadelphia: Lippincott Williams & Wilkins.

Alricsson, M., Harms-Ringdahl, K., Eriksson, K., & Werner, S. (2003). The effect of dance training on joint mobility, muscle flexibility, speed and agility in young cross-country skiers - a prospective controlled intervention study. *Scandinavian Journal of Medicine & Science in Sports, 13*, 237-243.

Beaudoin, C. M., & Blum, J. W. (2005). Flexibility and running economy in female collegiate track athletes. *Journal of Sports Medicine and Physical Fitness, 45*(3), 295-300.

Bell, R., D., & Hoshizaki, T. B. (1981). Relationships of age and sex with range of motion of seventeen joint actions in humans. *Canadian Journal of Applied Sport Sciences, 6*(4), 202-206.

Bilodeau, B, Boulay, M. R., & Benoit, R. (1992). Propulsive and gliding phases in four cross-country skiing techniques. *Medicine and Science in Sports and Exercise, 24*(8), 917-925.

Bergh, U. (1982). *Physiology of cross-country ski racing*. Champaign, IL: Human Kinetics.

Bracko, M. R. (2002). Can stretching prior to exercise and sports improve performance and prevent injury? *ACSM's Health & Fitness Journal, 6*(5).

Cavanagh, P. R., & Kram, R. (1985a). The efficiency of human movement - a statment of the problem. *Medicine and Science in Sports and Exercise, 17*(3), 304-308.

Cavanagh, P. R., & Kram, R. (1985b). Mechanical and muscular factors affecting the efficiency of human movement. *Medicine and Science in Sports and Exercise, 17*(3), 326-331.

Conley, D. L., & Krahenbuhl, G. S. (1980). Running economy and distance running performance of highly trained athletes. *Medicine and Science in Sports and Exercise, 12*(5), 357-360.

Corbin, C. B., & Noble, L. (1980). Flexibility: a major component of physical fitness. *Journal of Physical Education, 6*, 23-60.

Costill, D. (1967). The relationship between selected physiological variables and distance running performance. *Journal of Sports Medicine and Physical Fitness, 7*, 61-66.

Craib, M. W., Mitchell, V. A., Fields, K. B., R., C. T., Hopewell, R., & Morgan, D. W. (1996). The association between flexibility and running economy in sub-elite male distance runners. *Medicine and Science in Sports and Exercise, 28*(6), 737-743.

Daniels, J., & Daniels, N. (1992). Running economy of elite male and elite female runners. *Medicine and Science in Sports and Exercise, 24*(4), 483-489.

Fowles, J. R., Sale, D. G., & MacDougall, J. D. (2000). Reduced strength after passive strength of the human plantarflexors. *Journal of Applied Physiology, 89*(3), 1179-1188.

Gleim, G. W., & McHugh, M. P. (1997). Flexibility and its effects on sports injury and performance. *Sports Medicine, 24*(5), 289-299.

Gleim, G. W., Stachenfeld, N. S., & Nicholas, J. A. (1990). The influence of flexibility on the economy of walking and jogging. *Journal of Orthopaedic Research, 8*, 814-823.

Godges, J.J., MacRae, H., Longdon, C., Tinberg, C. & MacRae, P. (1989). The effects of two stretching procedures on hip range of motion and gait economy. *The Journal of Orthopaedic and Sports Physical Therapy, 7*, 350-357.

Hoeger, W. W. K. & Hopkins, D. R. (1988). *The assessment of muscular flexibility – Test protocols and national flexibility norms for the: modified sit-and-reach test, total body rotation test, and shoulder rotation test.* Gays Mills, WI: Country Technology, Inc.

Hoffman, M. D., & Clifford, P. S. (1992). Physiological aspects of competitive cross-country skiing. *Journal of Sports Sciences, 10*, 3-27.

Hoffman, M. D., Clifford, P. S., Foley, P. J., & Brice, A. G. (1989). Physiological responses to different roller skiing techniques. *Medicine and Science in Sports and Exercise, 22*(3), 391-396.

Ingraham, S. J. (2003). The role of flexibility in injury prevention and athletic performance - Have we stretched the truth? *Minnesota Medical Association, 86*(5), 58-61.

Jones, A. M. (2002). Running economy is negatively related to sit-and-reach test performance in international-standard distance runners. *International Journal of Sports Medicine, 23*, 40-43.

Kokkonen, J., Nelson, A. G., & Cornwell, A. (1998). Acute muscle stretching inhibits maximal strength performance. *Research Quarterly for Exercise and Sport, 69*(4), 411-416.

Kvamme, B., Jacobsen, V., Hetland, S. & Smith, G. (2005). Ski skating technique and physiological responses across slopes and speeds. *European Journal of Applied Physiology, 95*, 205-212.

MacDougall, J. D., Hughson, R., Sutton, J. R., & Moroz, J. R. (1979). The energy cost of cross-country skiing among elite competitors. *Medicine and Science in Sports and Exercise, 11*(3), 270-273.

Mahlamaki, S., Soimakallio, S., & Michelsson, J. E. (1988). Radiological findings in the lumbar spine of 39 young cross-country skiers with low back pain. *International Journal of Sports Medicine, 9*, 196-7.

Millet, G. Y., Perrey, S., Candau, R., & Rouillon, J. D. (2002). Relationships between aerobic energy cost, performance and kinematic parameters in roller ski skating. *International Journal of Sports Medicine, 23*, 191-195.

Nelson, A. G., Kokkonen, J., Eldredge, C., Cornwell, A., & Glickman-Weiss, E. (2001). Chronic stretching and running economy. *Scandinavian Journal of Medicine & Science in Sports, 11*, 260-265.

Niinimaa, V., Dyon, M., & Shepard, R. J. (1978). Performance and efficiency of intercollegiate cross-country skiers. *Medicine and Science in Sports and Exercise, 10*(2), 91-93.

Niinimaa, V., Shepard, R. J., & Dyon, M. (1979). Determinations of performance and mechanical efficiency in nordic skiing. *British Journal of Sports Medicine, 13*, 62-65.

Rusko, H. (2003). *Handbook of sports medicine and science - cross country skiing*: Blackwell Publishing Company.

Shorten, M. R. (1987). Muscle elasticity and human performance. *Medicine and Sports Science , 25*, 1-18.

Smith, G. A. (1992). Biomechanical analysis of cross-country skiing techniques. *Medicine and Science in Sports and Exercise, 24*(9), 1015-1022.

Svensson, E. (1994). *Ski skating with champions.* 18405 Aurora Ave. N., Suite H-83, Seattle, WA 98133, USA.

Williams, K. R., & Cavanagh, P. R. (1987). Relationship between distance running mechanics, running economy, and performance. *Journal of Applied Physiology, 63*(3), 1236-1245.

Wilmore, J. H., & Costill, D. L. (2004). *Physiology of sport and exercise* (3rd ed.). Champaign, IL: Human Kinetics.

APPENDICES

APPENDIX A:

SUBJECT CONSENT FORM

SUBJECT CONSENT FORM
FOR PARTICIPATION IN HUMAN RESEARCH
MONTANA STATE UNIVERSITY

PROJECT TITLE: *Flexibility as a Determinant of Economy in Cross-country Skiing*

PROJECT   Karin Camenisch, Graduate Student
DIRECTOR: Dept. of Health and Human Development,
                         Movement Science Laboratory
                         Montana State University, Bozeman, MT 59717-3540
                         Phone: (720) 934-6017; FAX: (406) 994-6314;
                         E-mail: kcamenisch@montana.edu

FUNDING: This project is not funded

PURPOSE OF THE STUDY:
The purpose of this project is to examine the relationship between selected measures of flexibility and economy in cross-country skiers. Economy is defined as the relative oxygen uptake during skiing at a given submaximal velocity. Indoor roller skiing will be used to simulate on-snow skiing for the purpose of determining economy. The findings could provide useful information for coaches and you, as an athlete, for planning future training regimens.

Each participant is presented with this *Informed Consent Document* which explains the purpose of the testing, as well as expected risks and benefits associated with participation. It is the participant's responsibility to acquire medical clearance from his/her physician prior to lab testing. Each participant will also be screened by the project director using responses provided by participants in the **Physical Activity Readiness Questionnaire (PAR-Q)** (the PAR-Q is attached to the end of this document). This procedure is in compliance with policies formulated by the American College of Sports Medicine[1].

Please talk with the Project Director, Karin Camenisch, about any pre-existing health conditions that may limit your participation in this project *BEFORE* testing.

STUDY PROCEDURES:
You (the participant) will be required to make one visit (session #1) to the Movement Science / Human Performance Lab (basement of Romney Building) and one visit (session #2) to the Worthington Arena at Montana State University (Bozeman) within a two-week period. Each visit will last approximately one hour and will be scheduled 24-48 hours AFTER your last hard workout - It is important that you prepare for each lab visit as you would for a race. Before arriving at the lab, you should refrain from ingesting any medications, including caffeine or aspirin, for at least 2 hours. If any medications were taken (such as cold or allergy medicine) please inform the lab personnel PRIOR to any testing - we will gladly reschedule your visit. *If you use an inhaler to treat asthma, make certain to bring the inhaler with you to the lab.* You should arrive at the lab ready to engage in moderate to high intensity exercise. Therefore, participants should dress (ie. running shoes, shorts, short sleeve shirt or tank top, etc), eat, and drink fluids appropriately for the occasion.

---

[1]American College of Sports Medicine (2006). *ACSM's Guidelines for Exercise Testing and Prescription* (7th edition). Lea & Fibiger; Philedelphia, PA.

☐ **Session #1- VO$_{2max}$ test and flexibility test.**
The purpose of the first session is to measure anthropometric (age, weight, and height) data, maximal oxygen consumption (VO$_{2max}$) via the ski walking/running protocol, as well as selected flexibility measures.

VO$_{2max}$ Test: The main purpose of the ski walking/running protocol is to measure your maximal heart rate that will be used for the submaximal test during session #2. After measuring body weight and height, you will be allowed to warmup on the treadmill at a self-selected speed and grade for 5-10 minutes (or until you feel comfortable with the testing environment). Using ski poles with rubber tips, you will simulate diagonal stride skiing by poling with the upper body while walking with long strides. Use of the poles on the treadmill allows the upper body to assist the lower body in propelling yourself forward. As the speed of the treadmill increases, it will be easier to change from long walking strides to hill-bounding. The test itself will start out easy (low treadmill grades and speeds) and gradually increase in difficulty every 1-2 minutes. The test will end when you literally cannot maintain the pace of the treadmill any longer (15 to 20 minutes). During the exercise test you will be breathing through a mouthpiece (like a snorkel mouthpiece) so that the amount of oxygen you are using can be measured. At the same time, you will be wearing a *heart rate monitor* strap around your chest to measure heart rate via telemetry. You may also be asked to provide a rating of your perceived exertion (*RPE*) on a scale of 0 to 10 (resting to maximal intensity exercise) during the test.

Flexibility Test:
The main purpose of the flexibility test is to take six measures of shoulder, trunk and lower limb flexibility (described in detail below) over a period of 30 minutes. Stretching prior to flexibility assessments is prohibited. You should wear comfortable clothing and remove any jewelry. Two complete trials of all flexibility measures will be consecutively recorded without shoes on. The order of flexibility testing will be counterbalanced across participants. To improve reliability, all flexibility measurements will be taken by the same investigator.

　　1. Rotation of thoracic spine (Trunk rotation): A measurement bar (mounted to the wall) will be adjusted to your shoulder height. You will stand sideways, one arm length away from the wall and with toes on a marked line on the floor. The shoulder opposite to the wall will be stretched out horizontally. Your goal is to rotate the trunk with the extended arm going backwards and to slide the panel on the measurement bar as much forward as possible using a fist. Your feet have to stay in place and point straight forward during the rotation. The test will be conducted on both sides (left and right) and an average of two trials will be used for the final score.

　　2. Lateral Flexion of lumbar spine (Side bend): You will be asked to stand with the back against a wall, the arms by the sides and hands touching your thighs. The third finger will be marked with a pen on your thigh before and after bending your trunk sidewise. The distance between the two marks will be measured with a ruler.

　　3. Shoulder Rotation Test: First, the width separating your shoulders will be measured. Next, you will hold a stick firmly with your right hand at the zero point while the left hand will be placed on the other end. Both hands will be positioned on the stick so that the thumbs point outward. You will stand and rotate the stick with straight arms over your head. For each successful rotation over your head, the left hand will be positioned closer to the right hand until you are no longer able to fulfill a complete rotation without bending an arm. The last complete motion will be recorded (distance between your hands) and the shoulder width will be subtracted to determine the final score.

4. Standing external hip rotation: You will stand against a wall and perform an outward hip rotation with your knee flexed at a 90⁰ angle. The hip rotation angle will be measured with a goniometer.

5. Modified sit-and-reach: You will sit on the floor against a modified sit-and-reach box with your arms stretched out. The "L" shaped indicator will be adjusted to the zero point. Without bending knees, you will reach as far as possible by pushing the "L" shaped indicator. The furthest point reached and held for at least two seconds will be recorded.

6. Straight leg raise: You will lay with your back on a table. One leg will be held on the table while the other leg will be raised by an assistant (without bending the knee). You will tell the assistant when discomfort occurs. With a goniometer, the researcher will measure the hip angle between the chest and the raised leg.

☐ **Session #2- Submaximal roller-ski test.**
The purpose of the second session is to perform a submaximal roller-ski test at three submaximal velocities to measure economy. After completion of a 15-min warm-up at self-selected speed on roller skis, you will perform three 6-10-min trials at preset heart rate limits (65%, 75%, 85% of maximal heart rate). There will be a 1-3 minute break between each trial. During the exercise test you will wear a metabolic system on your back that collects VO_2 data. The VO_2 data will be collected as you breathe through a face mask. At the same time, you will be wearing a *heart rate monitor* strap around your chest to measure heart rate via telemetry (same heart rate monitor as during the VO_{2max} test). You will roller-ski two trials in one direction and one trial in the opposite direction on the indoor track in Worthington Arena. The directions of each trial as well as the order of the trials will be counterbalanced across participants. You will use the same pair of roller-skis (provided by project director) for all three trials. You only need to bring your own ski poles and helmet for this test.

POTENTIAL RISKS:
You should be aware that both testing sessions may cause extreme fatigue immediately after the tests and possibly during the next day. VO_{2MAX} testing (ie. treadmill protocol) also involves a chance of precipitating a cardiac event (such as abnormal heart rhythms) or even death. However, the possibility of such an occurrence is very slight (less than 1 in 10,000) since 1) you are in good physical condition with no known symptoms of heart disease and 2) the test will be administered by trained personnel. *These risks are certainly no greater than those experienced by trained athletes in actual race competition.* The measuring devices (heart rate monitor and face mask) may feel somewhat restricting and/or uncomfortable during testing, but all possible adjustments will be used to achieve the greatest comfort for you. All possible precautions will be taken to ensure your safety and make you feel comfortable before any testing takes place.

BENEFITS:
Each participant will receive personalized feedback on the flexibility tests witnessed during their assessment. Additionally, study participants may request a summary of the study findings by contacting the Project Director, Karin Camenisch, by phone (720-934-6017) or by e-mail (kcamenisch@montana.edu).

CONFIDENTIALITY:
The data and personal information obtained from this study will be regarded as privileged and confidential. Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. Your right to privacy will be maintained in any ensuing analysis and/or presentation of the data by using coded identifications of each person's data. The code list will be kept separate and secure from the actual data files.

<u>FREEDOM OF CONSENT</u>:
Participation in this project is completely voluntary.
You may withdraw consent for participation in writing, by telephone, or in person without prejudice or loss of benefits (as described above). Please contact the Project Director, Karin Camenisch, by phone (720-934-6017) or by e-mail (kcamenisch@montana.edu) to discontinue participation.

In the UNLIKELY event that your participation in the project results in physical injury to you, the Project Director will advise and assist you in receiving medical treatment. No compensation is available from Montana State University for injury, accidents, or expenses that may occur as a result of your participation in this project. Additionally, no compensation is available from Montana State University for injury, accidents, or expenses that may occur as a result of traveling to and from your appointments at the Movement Science / Human Performance Laboratory. *Further information regarding medical treatment may be obtained by calling the Project Director, Karin Camenisch, at 720-934-6017.* You are encouraged to express any questions, doubts or concerns regarding this project. The Project Director will attempt to answer all questions to the best of their ability prior to any testing. The Project Director fully intends to conduct the study with your best interest, safety and comfort in mind. *Additional questions about the rights of human subjects can be answered by the Chairman of the Human Subjects Committee, Mark Quinn, at 406-994-5721*.

PROJECT TITLE: *Flexibility as a Determinant of Economy in Cross-country Skiing*

STATEMENT OF AUTHORIZATION

I, *the participant*, have read the Informed Consent Document and understand the discomforts, inconvenience, risks, and benefits of this project. I,

_____ *(print your name)*, agree to participate in the

project described in the preceding pages. I understand that I may later refuse to participate, and

that I may withdraw from the study at any time. I have received a copy of this consent form for

my own records.

Signed:_____ **Age** _____ **Date**_____
                Subject's Signature

Witness: _____ Date _____
                Print Name   *Sign Name*

APPENDIX B

SUBJECT QUESTIONNAIRE

Subject ID #: _____

Subject Questionnaire

1. How long are your skate ski poles? _____
2. What is your preferred skate skiing technique?

   _____

3. How many years have you been skiing? _____
4. How many years have you been xc-ski racing? _____
5. How many hours do you train in a year? _____
6. How many hours on average do you train in a week? _____
7. How many hours per week do you train on roller-skis in summer? _____
8. Do you frequently include a stretching program in your training? _____
   a. If yes, how long is your stretching program (per week)? _____
   b. If yes, what kind of stretching exercises do you usually include?

      _____

9. Do you attend yoga classes on a regular basis?_____
   a. If yes, how many classes do you attend in a month? _____
10. Do you include balance/coordination exercises in your training? _____
    a. If yes, what kind of exercises?

       _____

APPENDIX C

FLEXIBILITY AND SLOPES MEASURES FOR EACH SUBJECT

Table 1. Flexibility and slopes (VO$_2$ and HR) measures for each subject (n=12).

ID #	Flex1r	Flex1l	Flex2r	Flex2l	Flex3	Flex4r	Flex4l	Flex5r	Flex5l	Flex6	Flex7r	Flex7l	VO$_2$ slope	HR slope
1	6.25	8.38	22.50	22.25	36.00	60.00	72.50	71.50	60.00	13.88	93.50	100.00	0.169	0.503
2	9.63	10.88	28.25	28.50	21.50	62.00	75.00	73.00	79.00	20.25	122.50	112.50	0.081	0.200
3	10.13	12.13	26.50	24.75	36.50	60.00	43.50	57.50	49.50	19.25	104.00	105.00	0.139	0.356
4	1.50	4.38	19.25	19.50	34.25	53.50	53.50	66.50	67.50	12.75	72.50	79.00	0.066	0.282
5	9.25	4.50	21.50	25.75	34.50	65.00	83.00	71.50	65.00	13.63	87.50	75.00	0.116	0.342
6	11.13	10.75	21.50	25.75	24.75	67.00	63.50	70.00	70.00	10.88	79.00	81.00	0.093	0.461
8	13.25	16.25	29.75	30.00	26.00	65.00	50.00	57.50	52.50	16.50	102.50	101.00	0.074	0.390
9	19.75	17.25	23.50	24.50	31.50	84.00	85.00	80.00	72.50	18.00	116.50	120.00	0.089	0.384
10	17.88	20.75	26.50	22.75	31.50	69.00	59.00	72.00	70.50	15.38	104.00	102.50	0.141	0.285
11	16.00	16.75	26.70	27.35	32.25	86.50	82.50	75.00	72.50	12.88	91.00	95.00	0.069	0.312
12	13.50	16.00	20.00	20.50	32.00	64.50	59.00	75.50	67.50	16.75	105.00	103.50	0.136	0.293
13	5.25	13.75	29.00	29.00	38.00	70.00	70.00	77.50	69.00	18.25	107.50	102.50	0.113	0.424
Average	11.13	12.65	24.58	25.05	31.56	67.21	66.38	70.63	66.29	15.70	98.79	98.08	0.107	0.352
SD	5.32	5.13	3.64	3.35	5.05	9.54	13.76	7.07	8.49	2.93	14.64	13.53	0.033	0.085