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GENERAL STRENGTH AND MUSCULAR ENDURANCE: RELATIONSHIP TO V1- AND V2-SKATE SKIING ECONOMY IN COLLEGIATE CROSS-COUNTRY SKIERS

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GENERAL STRENGTH AND MUSCULAR ENDURANCE: RELATIONSHIP TO V1- AND V2-SKATE SKIING ECONOMY IN COLLEGIATE CROSS-COUNTRY SKIERS

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ABSTRACT

GENERAL STRENGTH AND MUSCULAR ENDURANCE: RELATIONSHIP TO V1- AND V2-SKATE SKIING ECONOMY IN COLLEGIATE CROSS-COUNTRY SKIERS

By

Ian Michael Torchia

Introduction Cross-country skiing is a power-endurance sport requiring upper and lower body activation for propulsion across the ground. While high aerobic markers such as VO_{2max} and lactate threshold are important performance indicators, recent research has demonstrated the importance of full-body general strength and muscular endurance in skiing success. The purpose of this study was to examine the relationship of strength indices via a full-body series of muscular endurance tests, as well as a general 1-RM strength test, to VO_2 skiing economy utilizing the V1- and V2-skate technique.

Methods Oxygen uptake was measured during baseline and economy testing on a specialized skiing treadmill. A paired samples t-test was utilized to determine differences between V1- and V2-skate skiing economy. Correlation analysis was used to identify relationships of strength and endurance indices to skiing economy values. Furthermore, a stepwise regression with resampling cross-validation (25 holdout groups) was performed to determine the best predictor of skiing economy.

Results The results of the study found no significant differences between V1- and V2-skate skiing economy VO_2 values ($p>0.05$), as well as other metabolic variables. Pearson partial correlation analysis controlling for sex revealed weight, V1 RER, V2 RER, and shoulder extension were positively correlated with V2 oxygen uptake ($p<0.05$). Shoulder extension and FIS distance points were positively correlated with V1 oxygen uptake ($p<0.05$). Stepwise regression resampling cross-validation found shoulder extension to be the best predictor of V1 & V2 skiing economy.

Conclusion The crossover point of no significant differences in oxygen uptake between V1- & V2-skate was found to be at a greater velocity and grade than previously reported literature. Less oxygen uptake during V1-skate was an indicator of distance racing performance, as a majority of competition time is spent racing uphill utilizing the aforementioned technique. Greater general strength and muscular endurance were not correlated to greater V1 and V2 skiing economy as hypothesized.

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CHAPTER I: JOURNAL MANUSCRIPT

INTRODUCTION

Cross-country skiing is a quadrupedal sport requiring whole-body activation for movement across the ground. Traditional aerobic markers such as VO_{2max} and lactate threshold were rigorously researched on skiers in the past and found to be significant performance predictors. However, recent research has demonstrated the importance of full-body general strength and muscular endurance in skiing success (1-3). Furthermore, skiing economy, or the amount of metabolic energy spent at a given velocity, has been highlighted as a key indicator separating elite skiers from the recreational level (4). The V2- and V1-skate techniques, used during freestyle races, utilize this full-body muscle activation to move economically across varying terrain. Skiers tend to use the V2-technique on flat and moderate inclines and increase their aerobic power and mechanical efficiency to match increases in grade (5). However, the V1-skate technique, which relies more heavily on the legs for propulsion, is more efficient to use at steeper inclines (6). Previous research examined the effect of grade on physiological markers and muscle coordination on flat or graded inclines, but no studies currently, have analyzed general strength or muscular endurance and their relationship to skiing economy during the V1- and V2-skate techniques.

Introduced to the Olympics in 1924, cross-country skiing consisted of the classic discipline only. In 1986, skate or "freestyle" skiing was added as a separate competition discipline, and it generated race speeds 9-20% faster than those of classical skiing (7). The skate discipline consists of the sub-techniques V1 for steep grades, V2 for flats and gradual inclines, and V2-alternate for high speeds (8). An upper-body muscle activation chain of the abdominals, latissimus dorsi, and triceps brachii are activated in succession at pole plant; in addition to the gluteal and quadriceps muscles, which are responsible for lower-body power (9). V1 (Figure 1) consists of asymmetric arm movements in which the skier places most of their weight on one “hang” pole and skates once with each leg for each push of the arms. A double pole motion and a simultaneous push onto the opposite ski, which is then repeated on the opposite side, highlights the V2-technique (Figure 2). The V2-alternate is equivalent to V2, but utilizes two skate-pushes for every one double-pole push.

Due to the varying terrain of a ski course, skiers must be efficient at all sub-techniques to move economically across the ground. All International Ski Federation (FIS) courses used at the highest level of competition are required to consist of one-third uphill, one-third downhill, one-third flat terrain (10). However, it is the ability to climb that delineates the best from the very good, as a ski racer will spend 50% of their time going up-hill due to the increased workload against gravity (11). As a skier encounters inclines, the ability to adapt different sub-techniques during a race places a premium on skiing economy (12). In addition, elite skiers were found to have better economy and higher efficiency than recreational skiers and their junior counterparts (4). Traversing undulating courses at a lower oxygen intake (VO_2) indicates a greater skiing economy; therefore, skiing economy during the V2- and V1-techniques on uphill terrain as a performance indicator are typically measured (4, 12-13).

On varying inclines, different skate techniques are interchangeably used to optimize skiing economy. At increasing grades with constant intensity, there is a tendency for increased upper body activation in the V2-technique (14). In addition, skiers utilizing the V2-skate increase their aerobic power and mechanical efficiency through decreasing the cycle time and increasing the relative poling phase in response to increased grade (5). At increased grades, the superior aerobic power of the legs contributes to a greater efficiency during V1 compared to V2 (6). Traversing the undulating terrain of ski trails with greater economy has been targeted as an area of improvement for cross-country skiers through greater power and muscle development, linking the muscular and cardiovascular systems.

Skiers rely heavily on power produced from the muscles of the upper and lower body during competition. In response to the high aerobic demands, skiers have high concentrations of approximately 60-75% Type I slow twitch fibers in the legs (11). Muscular endurance is also an important factor in cross-country skiing as a 1-kilometer upper-body power test has proven a better indicator of 10km time trial performance than VO_{2max} and lactate threshold tests (1). In addition, muscular endurance training was found to improve one repetition maximum (1-RM) in simulated double poling, muscular endurance, faster double poling, and greater skiing economy (3). Furthermore, power outputs of bench press and bench pull have been related to maximum velocity during double-poling and ski-striding (2) In the same study, testing of jump height and rate of force development during squat jumps found lower body power was an important determinant of maximum V2-skating speeds (2). Previous studies have supported a strong correlation between upper body strength and double pole performance (15-17). The recent implementation of mass start racing has provided more opportunities to benefit from upper-body power and high-speed techniques (12).

Past studies have highlighted the importance of skiing economy in the performance of cross-country skiing. Cross-country skiing has changed significantly in the past 25 years, and elite athletes must keep pace with these changes during both summer training and winter racing to perform optimally. Additionally, roller-skiing is a key element in all cross-country skiers' off-season training as the practice closely simulates skiing on snow during the winter months (18). World class skiers separate themselves from national level skiers with efficiency and technique-specific power (4,19). In addition, strength and power have been indicated as determinants of performance (1-2) and proposed as an area for future improvement (11). At this writing, no research has investigated muscular strength, endurance, and their relationship to skate skiing economy. Such research would help elucidate how a skier could switch between techniques at varying stages of a race to gain maximum efficiency. Thus, the purpose of this investigation will be to examine the relationship of strength indices via a series of full-body muscular endurance tests, as well as a general 1-RM strength test, to VO_2 skiing economy utilizing the V1- and V2-skate techniques.

METHODS

Experimental Design

A quasi-experimental repeated measures design was used to compare subjects' skiing economy metabolic responses utilizing V1- and V2-skate techniques at the same grade and velocity. Men and women performed VO_{2max} and skiing economy tests at respective grades and velocities due to women having lower levels of maximal strength and lower percentages of upper body lean mass than men (20). Furthermore, correlation and regression analysis were utilized to examine the relationship of metabolic responses during different skate skiing techniques to 1-RM strength and muscular endurance measures. The independent variables were cross-country skating techniques (V1, V2), general strength 1-RM test values, muscular endurance test scores, as well as FIS cross-country distance and sprint point rankings. The dependent variable was the skiing economy of each subject during the steady-state tests and was measured as VO_2 in $ml \cdot kg^{-1} \cdot min^{-1}$. However, it is worth noting that a *greater* skiing economy will result in a *lower* oxygen cost and vice versa. To avoid confusion, skiing economy will be reported as VO_2 unless otherwise specified.

Research Participants

A convenience sample of 15 NCAA cross-country skiers was utilized in the study. Seven males (n = 7, age = 20.7 ± 1.0 years, height = 180.0 ± 6.0 cm, mass = 73.3 ± 5.4 kg, VO_{2max} = 70.8 ± 3.9 ml·kg^{-1}·min^{-1}, FIS points = 81.4 ± 31.8) and eight females (n = 8, age = 20.5 ± 1.5 years, height = 167.8 ± 5.6 cm, mass = 62.6 ± 5.3 kg, VO_{2max} = 57.3 ± 2.7 ml·kg^{-1}·min^{-1}, FIS points = 169.8 ± 58.3) from the Northern Michigan University Cross-Country Skiing Team were accepted on a volunteer basis. Subjects were required to be current NCAA cross-country skiing athletes and physically able to complete regular training. Exclusion criteria included injuries limiting the ability to roller-ski, failure to complete general strength and muscular endurance testing, or failure to reach one of the three VO_{2max} criteria during baseline testing. Two subjects were excluded from the original 17 for failure to complete the strength testing.

Data collection occurred over one month during September. Muscular endurance testing commenced on the first weekend of Northern Michigan University's cross-country ski team fall training. VO_{2max} testing occurred two weeks later during the team's easy week to ensure accurate results not altered by fatigue. Skiing economy testing occurred one week later over a week-long period. Similarly, general strength 1-RM testing commenced the following week.

Procedures

Muscular Endurance Testing

The Northern Michigan University Cross-Country Skiing muscular endurance testing was performed during the first weekend of official fall training. Members of the team were informed that the normal procedures were in place and their strength test scores would be used for the study if they volunteered. Informed consent (Appendix A) and a Physical Activity Readiness Questionnaire (PAR-Q) (Appendix B) were given; as well as height and weight recorded. The study was approved by the Institutional Review Board at Northern Michigan University (NMU; HS18-968). The tests involved sit-ups, push-ups, pull-ups, dips, and a 3-minute diagonal arm effort performed on a ski ergometer. Athletes performed the exercises for one minute, rested for one minute, and repeated for another minute. Sit-ups were performed from a supine position with flexed knees and arms folded across the abdomen, utilizing full torso flexion until the crossed arms touched the thighs; and returned to the supine position with the back touching the ground (21). Push-ups were completed according to ACSM standards starting with the hands shoulder-width apart and elbows and body straight. The push-up low position was reached when the chest made contact with the recorder's fist held vertically against the ground. The subject then returned to full extension (21). Pull-ups were correctly performed starting with hands pronated and slightly wider than shoulder width apart and finished when the underside of the chin was level or above the top surface of the bar; followed by full extension of the arms back down (22). Dips were started in a suspended position between the parallel bars with the arms fully extended and completed when the body was lowered to the point of the elbows flexed to 90 degrees, followed by full extension back to the starting position (23). Repetitions not performed to the required standards listed above were not counted. The 3-minute diagonal arm test was performed on a Concept2 Ski Ergometer (Morrisville, VT, USA) at a damper setting of 8, with the subjects only pulling the ergometer one arm at a time, mimicking the classic technique. The muscular endurance test repetitions were individually tallied and combined for an overall muscular endurance score, as well as the ski ergometer average watts and relative watts to mass ratio.

VO_{2max} Testing

Two weeks following the muscular endurance test, subjects completed baseline testing in the form of a roller-ski VO_{2max} test, utilizing primarily V2-skate, with V1 in the latter stages, on a FitNex roller-ski treadmill (14). Subjects warmed up for 10 minutes at a self-selected pace and grade prior to testing. The VO_{2max} protocols for men and women can be found in Table 1. Subjects started at stage 1 or stage 2, depending on their current fitness level. The skier's last stage occurred when they could no longer voluntarily advance to the next stage. Each stage lasted one-minute, with the final stage lasting 1.5 minutes, or until the skier became maximally fatigued, whichever came first. Criteria for achieving VO_{2max} included attaining one of the following three requirements: a plateau in oxygen uptake with an increase in work rate, RER above 1.15, or attainment of age predicted maximum heart rate (24, 25). The plateau was determined to be reached when the subject had a minimal increase in VO_2 (<2.5 $ml \cdot kg^{-1} \cdot min^{-1}$) during an increased work rate (26). Oxygen uptake was calculated by the ParvoMedics system (Sandy, UT, USA) utilizing breath-by-breath mode. The maximum value observed during 30-second sampling intervals was recorded as the VO_{2max} (27). The slowest male and female subjects' velocity and grade at 85% of VO_{2max} was documented for utilization during the skiing economy test.

Skiing Economy Testing

One week after the VO_{2max} testing, subjects completed the skiing economy test. Subjects were randomly ordered alternating their starting technique between V2 and V1. Following a 10-minute skate roller-ski at a self-selected pace and grade, male subjects skated, utilizing V2 or V1, for five minutes at 3.58 $m \cdot s^{-1}$ and 8% grade, the velocity and grade of the slowest subject's 85% VO_{2max} found during baseline testing. This threshold was used to ensure subjects were between 80-90% of their VO_{2max} for testing of skiing economy, adhering to the guidelines suggesting one bout close to racing speed of each sub-technique to elucidate skiing economy (4). Women completed the same bout at 3.13 $m \cdot s^{-1}$ and 7% incline, their respective slowest subject's velocity and grade at 85% of VO_{2max}. Following the five minute bout, subjects skied easy at a self-selected pace and grade for five minutes as a recovery before embarking on a second five-minute segment at the same velocity and grade as the first five-minute bout utilizing either V2- or V1-skate technique. Average oxygen uptake in the last minute during both trials was recorded as VO_2 relative to body mass in $ml \cdot min^{-1} \cdot kg^{-1}$, as well as converted to a percentage of the subject's VO_{2max} ($\%VO_{2max}$). Heart rate (HR), respiratory exchange ratio (RER), and percentage of heart rate maximum ($\%HR_{max}$), based on heart rate maximum during baseline testing, were analyzed during the last minute as well.

General Strength Testing

Strength of the elbow extension, shoulder extension, trunk flexion, and hip flexion movements were assessed via 1-RM testing. The elbow and shoulder extension, as well as trunk flexion, are poling-specific movements in which the upper-body maximal strength of these can predict double pole power production and overall cross-country skiing performance (28). The fourth and final 1-RM test isolated hip extension, including the gluteals and quadriceps, which are responsible for lower-body power development (9).

All subjects performed the test protocols in order: (a) 10-minute running warmup at low intensity; (b) warm-up sets including 10 repetitions at approximately 40% of estimated 1-RM, 5 repetitions at 60% of estimated 1-RM, & 3 repetitions at 85% of subject's estimated 1-RM; (c) 1-RM testing first attempt was performed at 5% below the expected 1-RM, and the weight was increased by 1-5 kg until the participant failed to lift the load (29). Approximately 5-10 minute recovery times were utilized between tests to reduce the effect of muscular fatigue. All tests were performed on the same day within an hour and the participants were familiarized to the exercises by the researcher prior to testing. The four strength values were examined as absolute and relative to body weight values.

The elbow extension exercise was performed on a curl-bench next to a cable apparatus (F624 Genesis Dual-Cable Cross, Freemotion Fitness, Logan, Utah) with a small handlebar (50 cm) attached to its grip. The lift started with approximately a 90° angle between the humerus and ulna/radius and was completed when the forearm touched the bench and the elbow joint was fully extended (Figure 3A). The shoulder extension was performed sitting on an adjustable bench in an upright position at approximately a 110° angle with the seat. The same cable apparatus was utilized and participants were strapped to the bench over their hip and chest regions to restrict interfering movement from other body segments and to create stability during the lift. The shoulder extension started with straight arms above the head and was finished when the handlebar touched the chest (Figure 3B). The trunk flexion exercise was performed on an abdominal machine (Abdominal #DSL0714, Precor, Woodinville, WA) The trunk flexion exercise was performed with the handlebar placed at shoulder height and was completed when the top of the handlebar touched the participant's leg (Figure 3C). The hip flexion exercise was performed utilizing a Smith machine (Magnum #40180, Strength Industry, Redlands, CA) as well as a 61-cm box. The subject started in the bottom of a 1-legged squat position with the free leg at a 45° degree angle forward. The exercise was finished when the working leg was fully extended to return to standing (Figure 3D). The general strength test 1-RM values were taken as absolute values as well as converted to a percentage relative to body weight.

Data Analysis

Analysis of the data included paired samples t-tests to determine differences in oxygen uptake between the two skate techniques during the skiing economy test. Pearson correlation analysis was used to determine the relationships between strength/endurance testing scores (by total score and individual test measures) to V1 & V2 oxygen uptake values. Stepwise regression analysis was performed using V1 & V2 skiing economy values as the dependent variables. Independent variables were those used in the correlational analysis. Because of a low sample size (n = 15), resampling cross validation was performed according to the 1994 paper by Jensen and Kline (30). In total, 50 regression analyses were attempted by randomly selecting 11 of 15 subjects for inclusion. Minimum R^2 improvement advance to the next model was > 0.05. Cross-validation was performed by entering the most common independent variable predictor of the hold-out group (n = 4) into each equation. The predicted V1 & V2 skiing economy values were then compared to obtained values utilizing paired samples t-tests and correlation analysis. Results were then reported as a mean ± standard deviation of the 25 regression samples for the V1 & V2 skiing economy models.

RESULTS

Economy Testing

A paired samples t-test was utilized to determine differences between V1- and V2-skate oxygen uptake during the last minute of both tests. No significant differences were found as $t(14) = 1.03$, $p>0.05$ (Table 2). Furthermore, no significant differences were found between $\%VO_{2max}$, RER, $\%HR_{max}$, and HR during the last minute ($p>0.05$).

Partial Correlations

Controlling for sex, V2 VO_2 was positively correlated with V1 VO_2, $r = 0.712$, $p<0.05$ (Table 3). Weight, V1 RER, V2 RER were all positively correlated with V2 VO_2 ($p<0.05$). FIS distance points were positively correlated with V1 VO_2 ($p<0.05$). Finally, 1-RM shoulder extension was positively correlated with both V1 VO_2 ($p<0.05$) and V2 VO_2 ($p<0.01$). No other significant correlations to skiing economy VO_2 values were found.

Female Correlations

For females, V1 VO_2 was positively correlated with V2 VO_2, $r = 0.915$, $p<0.05$ (Table 4). Shoulder extension, body weight shoulder extension percentage, V1 RER, and V2 RER were positively correlated with V1 VO_2, $p<0.05$. Shoulder extension and V2 RER were positively correlated with V2 VO_2, $p<0.05$. No other significant correlations to skiing economy VO_2 values were found.

Male Correlations

For males, ergometer watts was positively correlated with V1 VO_2, $r = 0.805$, $p<0.05$ (Table 5). No other significant correlations between skiing economy VO_2 values and variables were found.

Stepwise Regression

Models were developed from 25 regression samples to predict V1 & V2 economy. The independent variable of shoulder extension was found to be the single predictor of all 25 V2 economy equations producing a significant average $R^2 = 0.955 \pm 0.010$ ($p<0.01$). The average standard error of the estimate (SEE) for 25 V2 predictor equations = 1.428 ± 0.130. V2 economy was predicted at the $p<0.01$ significance level with the following equation:

$$V2\ Economy = 26.967 + 0.358 * Shoulder\ Extension$$

For V1 economy prediction, shoulder extension was the independent variable for 23 of the 25 equations. Ergometer watts and trunk flexion were the independent variables for the other two equations, respectively. When ergometer watts and trunk flexion were excluded, shoulder extension predicted all 25 V1 economy equations producing a significant $R^2 = 0.937 \pm 0.014$ ($p<0.01$). The average SEE for 25 V1 predictor equations = 1.533 ± 0.118. Economy for V1 skate skiing was predicted at the $p<0.01$ significance level with the following equation:

$$V1\ Economy = 30.017 + 0.322 * Shoulder\ Extension$$

The 50 regression model equations with shoulder extension as predictor were cross-validated across each of the 50 hold-out groups. V1 and V2 economy prediction equations had a Pearson correlation of 0.930 and 0.906 ($p>0.05$), respectively. No differences were found between the paired T-tests for the predicted and observed values of the holdout group ($p>0.05$). The mean results of the equation development and validation are presented in Table 6.

DISCUSSION

The two 5-minute V1- & V2-skate skiing economy tests averaged to a workload of 87% VO_{2max} (V1) and 86% VO_{2max} for the final minute, above the 75-80% threshold recommended by Millet, Boissiere, & Candau in 2002 for skiing economy testing (31). However, it was within the 80-90% VO_{2max} zone proposed by Ainegren and colleagues in 2013, when they suggested one bout close to race speed of each sub-technique was enough to elucidate skiing economy (4). Subjects reached a steady-state VO_2 plateau within the first 2-2.5 minutes of the economy testing.

There were no significant differences found between V1- and V2-skate skiing economy values, or the other metabolic values, including: $\%HR_{max}$, $\%VO_{2max}$, RER, and HR. This was similar to findings of no difference in heart rate responses in all skating techniques at an incline of 5° (32). Additionally, no differences were found between V1 and V2 oxygen costs in 14 elite Norwegian male cross-country skiers when skiing at inclines of 4, 5, and 6° (33). Conversely, Kvamme and colleagues found V2 to be more costly at grades above 5°, in addition to having a higher oxygen cost at a range of speeds from 2.25 – 3.25 $m \cdot s^{-1}$ at a constant grade of 5° (6). The current study examined differences at a constant pace and grade described as the "crossover point" between V1 and V2, for both sexes (6). The crossover point was a higher speed (3.13 and 3.58 $m \cdot s^{-1}$) and higher incline (7 and 8%) for women and men, respectively, than the findings by Kvamme and colleagues (6). The differences in metabolic responses between the aforementioned study and the current study can be explained by Kvamme's subjects being well-trained Nordic combined and junior biathlon athletes with less ski-skating experience than elite cross country skiers. No significant differences at this crossover point were found between V1 & V2 in oxygen uptake as well as other aforementioned metabolic values, suggesting both techniques could be used interchangeably based on the skier's preference.

Partial correlations for skiing economy controlling for sex showed a positive relationship between FIS distance points and V1 oxygen uptake. It is worth noting that higher FIS points specifies a skier is further down the rankings, thus lower points are indicative of better distance results. Therefore, the faster distance skiers (greater than 10-kilometer race) had greater skiing economy when performing the primary uphill technique. This finding is supported by previous research in which 56% of racing time for 10 elite females was spent going uphill and the uphill time was a key indicator in overall skiing performance (34). Additionally, weight was positively correlated with V2 oxygen uptake, suggesting the lighter skiers have an advantage when performing the primary flat technique while going uphill. The greater effect of gravity at inclines could be a possible mechanism to explain this finding.

For women, V1 and V2 respiratory exchange ratios were both positively correlated with V2 oxygen uptake, a possible advantage for sparing of carbohydrate stores during the longer skiing competitions. Only two women went above a 1.0 RER, suggesting greater oxygen uptake than calculated due to anaerobic energy sources not being included in the estimate. Interestingly, absolute weight lifted during shoulder extension was positively correlated with both V1 and V2 VO_2 cost as well as relative body weight shoulder extension percentage with V1 economy. Thus, the stronger female skiers had lower skiing economy during submaximal roller-skiing. The stronger females in absolute values also likely had more muscle mass due to the tendancy in results revealing a greater overall weight. No changes in oxygen uptake have been seen in previous research between heavy strength trained and control groups (35); and higher oxygen costs from greater strength levels have not been reported. In the current study, women consistently lifted below their body weight during the 1-RM general strength tests. Thus, it may be that the lower level of relative strength for females as opposed to males incurs a higher actual oxygen cost as well as intensity to move their mass. Greater strength training has been proposed as an area of improvement in female skiers (35).

Male correlations revealed the power output (watts) produced during the 3-minute diagonal arm ergometer testing to be positively correlated with V1 VO_2, as the stronger muscular endurance skiers had lower skiing economy. While greater V1 skiing economy has been found to be a predictor of distance racing performance via FIS points, these findings contradict previous research in which a 1-kilometer double-poling ergometer test was the key predictor of 10-kilometer mass start classical race performance (1). However, classical mass start performance might rely on greater strength levels as opposed to V1- and V2-skate skiing due to tactics and double-pole sprint finishes.

The current study revealed similar oxygen costs between V1- and V2-skate skiing techniques at a higher incline and faster velocity than previously reported. No studies have yet reported on changes in technique and subsequent effect on speed and metabolic responses, but anecdotal speculation has suggested that a minor loss in speed and rhythm are connected. Thus, individual preference for V1 or V2 when going uphill must be taken into consideration. However, greater V1 skiing economy was correlated with faster distance skiing performance, suggesting more practice can be undertaken by athletes to improve this highly complex technique. Lastly, strength measures were not correlated with skiing economy, yet, more accurate force testing could be employed to further examine this relationship.

CHAPTER II: LITERATURE REVIEW

The purpose of this study is to examine the differences in skiing economy of elite collegiate cross-country skiers during the V1- and V2-skate technique and further examine the relationships of these results to the participants' general strength and muscular endurance indices. Previous research on skate techniques, muscular endurance, and general strength were examined in the following literature review and divided into the following sections: 1) explanation of skate skiing techniques & physiological differences; 2) muscular considerations in elite cross-country skiers; and 3) testing protocols for skiing economy, general strength, and muscular endurance.

SKATE SKIING TECHNIQUES

Introduced in 1985, skate skiing was quickly added as a separate discipline the next year to cross-country skiing competitions alongside the classical technique. Skate skiing is divided into three sub-techniques, which are used interchangeably as a skier traverses varied terrain. Traditionally, V1 has been used for steep hills, V2 for gradual uphill and flats, and V2-alternate for gradual downhills and high speeds (8). The V1-technique consists of asymmetric arm movements in which the skier places most of their weight on one "hang" pole and skates once with each leg for each push of the arms (Figure 1). A double-pole motion and a simultaneous push onto the opposite ski, then repeated on the opposite side, highlight the V2-technique (Figure 2). V2-alternate is equivalent to V2, but utilizes two skate-pushes for every one double-pole push. The upper body activation in skate skiing is similar to the classic discipline, but the addition of leg utilization produces speeds 9-20% faster than classical (7). An upper-body muscle activation chain of the abdominals, latissimus dorsi, and triceps brachii are activated in succession at pole plant, in addition to the gluteal and quadriceps muscles, which are responsible for lower-body power (9).

Differences Between V1- and V2-Skate Techniques

The main sub-techniques of skating, V1 and V2 are used variably throughout a race due to the changing terrain a skier encounters. This technical complexity places a premium on efficiency as skiers adapt to the different speeds and slopes with different sub-techniques (12). However, approximately 56% of racing time in a 10-kilometer time trial was found to be spent uphill, and overall uphill time was considered the main predictor of overall performance (34). Faster skiers have been found to be more economical and efficient than their recreational and junior counterparts (4). However, at steeper inclines, it becomes more efficient to utilize the leg-dominant V1 technique. V2 was found to be more costly at increased inclines from 3-8 degrees and increased speeds at 5 degrees as it demonstrated a higher heart rate, lactate, and VO_2 than V1 (6). There is also a tendency to increase upper-body activation at steeper grades during V2 (14). Regardless of the technique, skiers increase aerobic power and mechanical efficiency to match increasing grade during constant speed; and achieve better efficiency through a decreasing cycle time and increasing relative poling phase (5). Thus, to improve performance, economy of movement has been targeted with greater importance in cross-country skiing.

CROSS-COUNTRY SKIING MUSCULAR CONSIDERATIONS

In addition to a premium on economy, strength training has become increasingly trained and utilized at the elite level. In terms of muscular make-up, top cross-country skiers have been found to have a high percentage of slow twitch fibers (11). In addition, a 1-kilometer ergometer test, typically more associated with power development, has been indicative of 10-kilometer mass start performance (1). Lower body power has been correlated with maximum velocity utilizing the V2 technique (2). With its pack racing and tactics, mass start racing provides more opportunity to profit from upper-body power and high-speed techniques (12). Thus, both upper and lower body strength are important in the propulsion across ground quickly. While greater strength has been correlated with increased double-pole and classical mass-start performance, its effect on skiing economy in the skating technique is yet to be elucidated.

TESTING PROTOCOLS

VO_{2max}

Ski-specific laboratory testing using roller-skis on treadmills provides a model for cross-country skiing and allows measurements of metabolic response (36). Previous research on elite cross-country skiers has utilized the FitNex roller-ski treadmill for metabolic and muscle activation studies and found it to be an accurate comparable measure for cross-country skiing (14, 39). Gas exchange variables measured via the ParvoMedics TrueOne metabolic measurement system have been tested for reliability and accuracy in preceding studies (38). VO_{2max} protocols are designed to provide accurate and reliable results bringing subjects to several of the standardized VO_{2max} criteria, including: a plateau in oxygen uptake with an increase in work rate, RER above 1.15, or attainment of age predicted maximum heart rate (14, 25). The current guidelines for graded exercise tests recommend bringing the subject to their limit of tolerance in 8-12 minutes to avoid excess muscular fatigue (24).

Skiing Economy

Analysis of exercise economy through submaximal testing has been used to determine performance across several aerobic sports, including running, cross-country skiing, cycling, and swimming. Economy has been defined as the submaximal oxygen uptake per unit of body weight required to perform a given task (39).

Millet and colleagues studied twelve male skiers ranging from recreational to national standard over four skating techniques during 6-minute bouts at a constant speed (31). The subjects maintained a speed at 75-80% of VO_{2max}, an intensity that was slightly below lactate threshold. It was found that aerobic energy cost (VO_2/mean speed) and heart rate were higher in V2 compared to the V1 technique.

One workload close to racing speed (80-90% VO_{2max}) for each core sub-technique of the skate and classical disciplines was recommended to be enough to detect skiing economy (4). Ainegren and colleagues examined 88 subjects and found elite cross-country skiers to have better skiing economy compared to their recreational counterparts. Furthermore, the senior elite skiers had better economy than elite juniors, while no differences were found between genders.

The metabolic responses across different slopes and speeds were measured in 2005 by Kvamme and colleagues (6). Fifteen national ski team members partook in 12 trials of 5-minute steady skate skiing across various uphill conditions, as well as two trials on a constant slope of 5% with various speeds. It was revealed that as slope and speed increased, V2 was more costly than V1 in terms of elevated heart rate, lactate concentrations, and oxygen uptake. The authors suggested it may be disadvantageous for skiers to use V2 instead of V1 technique on moderate to steep uphill terrain.

General Strength

General strength has been targeted as an area of improvement in cross-country skiers for greater performance. The one repetition maximum test is considered the highest standard for assessing muscle strength in outside-laboratory situations, and has been proven as a reliable measurement technique regardless of muscle group location and gender (40).

Previous general strength testing by Østeras and partners in 2016 details an extensive study in which three maximal strength tests designed for poling-specific movements isolate elbow extension, shoulder extension, and trunk flexion (28). It was found that the maximal strength of these upper-body segments was significant in predicting double-pole power production and overall cross-country skiing performance.

In 2011, Støggl and colleagues studied sixteen elite male skiers and their maximal skiing speed in double-poling, diagonal stride, and V2-skate on a roller-ski treadmill (2). While power outputs of bench pull and bench press were related to maximal speed in the classical sub-techniques, 1-RM was related to the highest velocities in the V2-skate technique. However, it was also determined that while general strength and power played a role in maximal speed development, coordination and proper timing of force application (i.e. planting poles at the right moment to ensure the most forward velocity) was a more discriminating factor for overall top velocity.

In addition, maximal strength training in the upper-body has been found to improve double-poling performance in trained female skiers by improving work economy (15). A further study by Hoff and colleagues in 2002 studied 19 male skiers performing maximal strength work 3 times per week at 85% of their 1-RM (41). Strength training was found to improve time to peak force by 50% in submaximal workload, time to exhaustion, as well as greater work economy.

Many studies have focused on the development of upper-body strength and its increased use during competition, however, there is little research on the effectiveness of lower body strength training in relation to cross-country skiing performance. The gluteals and quadriceps, responsible for lower-body power development, are active during the skating push of both the V2 and V1 techniques (9). Isokinetic and vertical jump tests have been found to discriminate between subjects of differing performance levels, yet isometric rate of force development was an ineffective assessment modality (42). Further research can focus on lower body strength and power development and its performance response in elite cross-country skiers.

Muscular Endurance

Previous research has focused on heavy strength training to improve upper-body power and skiing performance. However, muscular endurance training that focuses on completing 20-100 repetitions per set, has been shown to increase aerobic power and time to exhaustion (43).

Double-pole ergometer training for 20, 30, and 180 second interval training has been shown to increase power output and time to exhaustion in well-trained skiers (44, 45). In addition, upper-body muscular endurance training has been shown to improve performance in double-poling, muscular endurance, double-pole ergometer 1-RM, as well as promote a lower O_2 cost (3).

Summary

An extensive review of the literature revealed functional differences between the two main skating techniques, as well as an increased prevalence of strength and muscular endurance training to complement the cardiovascular requirements of cross-country skiing. Testing protocols for VO_{2max} and skiing economy are various and many, but strength and muscular endurance testing is far less common.

CHAPTER III: SUMMARY

Prior research has focused on the physiological differences between skiing techniques, as well as the benefits of strength and power during performance, particularly in the double-pole technique. Cross-country skiing is continuously being investigated for elite performance, however, little research has examined the skiing economy of two corresponding skate techniques during uphill skiing or the possible relationship of general strength and muscular endurance to economy of motion. The purpose of the current study was to investigate the differences in V1 and V2 skiing economy and their connection to general strength and muscular endurance results.

No significant differences were found between V1- and V2-skate skiing economy, as well as other metabolic variables, at higher grades and velocities than previous studies. This higher crossover point underscores a trend being seen on the international stage of elite skiers performing V2 at steeper grades. The correlation between greater V1 skiing economy and distance FIS points is supported by previous research showing uphill speed to be a key determinant of performance. Additionally, lighter skiers appear to have greater V2 economy at high grades, perhaps due to the lower body mass propulsion and less effect of gravity. Furthermore, RER values of both techniques were correlated with greater oxygen uptake, suggesting a sparing effect on carbohydrates, which may be important during marathon ski racing.

Conversely, no significant correlations were found between greater strength values and lowered oxygen cost of V1- and V2-skate skiing. Interestingly, greater 1-RM values for females and greater ski ergometer values for males were correlated to an *increased* oxygen cost, of which two explanations are proposed. First, the females' weaker strength values are not enough to propel their body mass, leading to increased VO_2, and an increased need for general strength to gain greater skiing economy. Secondly, ski ergometer tests have mostly been shown to increase double-poling and classical race performance, while having no effect on skate skiing oxygen cost or performance. However, strength and skiing economy may not be correlated and further research is needed to elucidate the strength values and their relationship with all techniques in cross-country skiing.

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APPENDICES

Appendix A

NORTHERN MICHIGAN UNIVERSITY

DEPARTMENT OF HEALTH AND HUMAN PERFORMANCE

CONSENT TO ACT AS A HUMAN SUBJECT

Subject Name (print):________________________________ Date _________________

I hereby volunteer to participate as a subject in exercise testing. I understand that this testing is part of a study entitled: "General Strength and Muscular Endurance: Relationship to V1- and V2-Skate Skiing Economy in Collegiate Cross-Country Skiers." The purpose of the study is to examine the effect of strength indices via a full-body general cross-country skiing strength test on VO_2 gross efficiency at varying inclines utilizing the V1- & V2-skate technique.

I hereby authorize Ian Torchia, Randall L. Jensen, and/or assistants as may be selected by them to perform on me the following procedures:

(a) I understand that I will perform the NMU Cross-Country Ski Team Strength Test entailing: sit-ups, push-ups, pull-ups, and dips for 1 minute, rest for 1 minute, and repeat for another minute bout. Box jumps will be performed at the end of the test for 90 seconds on a 36-inch box.

(b) I understand that I will perform a general strength 1-Repitition Max Test entailing: elbow extension, shoulder extension, trunk flexion, and hip flexion.

(c) I understand that I will perform a max VO_2 skate-roller-ski test on a roller-ski treadmill.

(d) I understand that I will roller-ski on a treadmill at a set incline and velocity at approximately a race effort for two short bouts, once using the V1-skate technique, and the other using the V2-skate technique.

(e) I understand that I will wear a mask connected to a gas-analysis machine, which will be used to assess VO_2.

2. The procedures outlined in paragraph 1 [above] have been explained to me.

I understand that the procedures described in paragraph 1 (above) involve the following risks and discomforts: musculoskeletal injuries including but not limited to; muscle strains, ligament sprains, joint dislocations, concussions, and abrasions.
I understand that there is potential risk of falling while roller-skiing on a treadmill.
In order to prevent any of the above-mentioned risks, I understand that the examiners shall adopt the necessary measures to prevent them, including using a safety harness during roller-ski testing. However, I understand that I can terminate any testing at any time at my discretion. Furthermore, I should stop any test if I experience any abnormalities such as dizziness, light-headedness, or abnormal heart functioning, breathing, etc.

3. I have been advised that the following benefits will be derived from my participation in this study: there could be educational benefits for ski training and race strategy in the future, but there are no direct benefits to me at this time.

4. I understand that Ian Torchia, Randall L. Jensen and/or appropriate assistants, as may be selected by them, will answer any inquiries that I may have at any time concerning these procedures and/or investigations.

5. I understand that all data, concerning myself will be kept confidential and available only upon my written request. I further understand that in the event of publication, no association will be made between the reported data and myself.

6. I understand that there is no financial compensation for my participation in this study.

7. I understand that in the event of physical injury directly resulting from participation, compensation cannot be provided. However if injury occurs, emergency first aid will be provided and the EMS system activated.

8. I understand that I may terminate participation in this study at any time without prejudice to future care or any possible reimbursement of expenses, compensation, or employment status.

9. I understand that if I have any further questions regarding my rights as a participant in a research project I may contact Dr. Robert Winn (906-227-2300) rwinn@nmu.edu, IRB Administrator at Northern Michigan University. Any questions I have regarding the nature of this research project will be answered by Dr. Randall Jensen (906-227-1184) rajensen@nmu.edu or Ian Torchia (507-261-8772) itorchia@nmu.edu

Subject's Signature:____

Witness:____ Date:_________________

Appendix B

Physical Activity Readiness Questionnaire (PAR-Q)

PAR-Q is designed to help you help yourself. Many health benefits are associated with regular exercise, and the completion of PAR-Q is a sensible first step to take if you are planning to increase the amount of physical activity in your life. For most people, physical activity should not pose any problems or hazard. PAR-Q has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the type of activity most suitable for them. Common sense is your best guide in answering these few questions. Please read the carefully and check YES or NO opposite the question if it applies to you. If yes, please explain.

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
☐	☐	**1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	**2. Do you feel pain in your chest when you do physical activity?**
☐	☐	**3. In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	**4. Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	**5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	**6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	**7. Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ________________________________

SIGNATURE ________________________________ DATE ________________________________

SIGNATURE OF PARENT or GUARDIAN (for participants under the age of majority) ________________________________ WITNESS ________________________________

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

continued on other side...

Appendix C

IRB Approval

NORTHERN MICHIGAN UNIVERSITY

Memorandum

OFFICE OF GRADUATE EDUCATION AND RESEARCH
1401 Presque Isle Avenue
Marquette, MI 49855-5301
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TO:	Ian Torchia School of Health and Human Performance
CC:	Randall Jensen School of Health and Human Performance
DATE:	August 22, 2018
FROM:	Lisa Schade Eckert, Ph.D. Interim Dean of Graduate Education and Research
SUBJECT:	**IRB Proposal** HS18-968 **IRB Approval Dates: 8/22/18 – 8/21/19** Proposed Project Dates: 9/1/18 – 12/12/18 "General Strength and Muscular Endurance: Relationship to V1 and V2-Skate Skiing Economy in Collegiate Cross-Country Skiers"

The Institutional Review Board (IRB) has reviewed your proposal and has given it final approval. To maintain permission from the Federal government to use human subjects in research, certain reporting processes are required.

A. You must include the statement "Approved by IRB: Project # HS18-968" on all research materials you distribute, as well as on any correspondence concerning this project.

B. If a subject suffers an injury during research, or if there is an incident of non-compliance with IRB policies and procedures, you must take immediate action to assist the subject and notify the IRB chair (dereande@nmu.edu) and NMU's IRB administrator (rwinn@nmu.edu) within 48 hours. Additionally, you must complete an Unanticipated Problem or Adverse Event Form for Research Involving Human Subjects

C. Please remember that informed consent is a process beginning with a description of the project and insurance of participant understanding. Informed consent must continue throughout the project via a dialogue between the researcher and research participant.

D. If you find that modifications of methods or procedures are necessary, you must submit a Project Modification Form for Research Involving Human Subjects before collecting data.

E. If you complete your project within 12 months from the date of your approval notification, you must submit a Project Completion Form for Research Involving Human Subjects. If you do not complete your project within 12 months from the date of your approval notification, you must submit a Project Renewal Form for Research Involving Human Subjects. You may apply for a one-year project renewal up to four times.

NOTE: Failure to submit a Project Completion Form or Project Renewal Form within 12 months from the date of your approval notification will result in a suspension of Human Subjects Research privileges <u>for all investigators listed on the application</u> until the form is submitted and approved.

All forms can be found at the NMU Grants and Research website:
http://www.nmu.edu/grantsandresearch/node/102

Appendix D

TABLES

TABLE 1. VO_{2max} Testing Protocol.

Women										
Stage	1	2	3	4	5	6	7	8	9	10
Velocity ($m \cdot s^{-1}$)	2.91	2.91	3.13	3.13	3.35	3.35	3.58	3.58	3.58	3.58
Grade	6%	7%	7%	8%	8%	9%	9%	9.5%	10%	10.5%
Men										
Stage	1	2	3	4	5	6	7	8	9	10
Velocity ($m \cdot s^{-1}$)	3.13	3.35	3.58	3.8	4.02	4.02	4.02	4.02	4.02	4.02
Grade	7%	8%	9%	10%	10.5%	11%	11.5%	12%	12.5%	13.0%

TABLE 2. Paired Samples T-Test for V1 & V2 VO_2 & other Metabolic Variables

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	V1 VO_2 - V2 VO_2	0.4478	1.6817	0.4342	-0.4835	1.3791	1.031	14	0.320
Pair 2	V1 %VO2max - V2 %VO2max	0.00811	0.02601	0.00672	-0.00629	0.02252	1.208	14	0.247
Pair 3	V1 RER - V2 RER	0.00733	0.03745	0.00967	-0.01341	0.02807	0.758	14	0.461
Pair 4	V1 %HRmax - V2 %HRmax	-0.00333	0.03848	0.00994	-0.02464	0.01798	-0.335	14	0.742
Pair 5	V1 HR - V2 HR	-0.773	7.752	2.002	-5.066	3.520	-0.386	14	0.705

TABLE 3. Pearson Partial Correlations for V1 & V2 VO_2 Controlling for Sex

Variables	**V1 VO_2**	**V2 VO_2**
V1 Economy	1.00	
V2 Economy	**0.71****	1.00
Age	0.11	0.12
Height	0.30	0.36
Weight	0.46	**0.57***
VO2max	0.49	0.34
V1 %VO2max	0.29	0.24
V1 RER	0.55	0.66*
V1 %HRmax	0.34	0.26
V1 HR	0.43	0.40
V2 %VO2max	0.16	0.51
V2 RER	0.40	**0.70****
V2 %HRmax	0.02	0.34
V2 HR	0.24	0.51
Elbow Extension	-0.10	0.16
%BW Elbow Extension	-0.50	-0.31
Shoulder Extension	**0.71****	**0.80****
%BW Shoulder Extension	0.33	0.31
Trunk Flexion	0.38	0.42
%BW Trunk Flexion	0.08	0.08
Left One Leg Squat	0.00	0.38
%BW Left One Leg Squat	-0.18	0.16
Right One Leg Squat	0.09	0.42
%BW Right One Leg Squat	-0.09	0.24
FIS Distance Points	**0.58***	0.46
FIS Distance World Rank	0.22	0.22
FIS Sprint Points	-0.01	0.04
FIS Sprint World Rank	-0.12	-0.04
Pushup #1	-0.23	-0.11
Pushup #2	-0.24	-0.33
Dip #1	-0.41	-0.14
Dip #2	-0.40	-0.44
Pullup #1	0.16	0.13
Pullup #2	-0.14	-0.11
Situp #1	-0.43	-0.28
Situp #2	-0.21	-0.20
Single Arm Ergometer Watts	0.38	0.12
Single Arm Ergometer Watts/Pounds	0.21	-0.13
Total Muscular Endurance Score	-0.32	-0.22

TABLE 4. Pearson Correlations for Female V1 & V2 VO_2.

Variables	**V1 VO_2**	**V2 VO_2**
V1 Economy	1.00	
V2 Economy	**.915****	1.00
Age	0.345	0.330
Height	-0.002	0.200
Weight	0.307	0.458
VO2max	0.330	0.315
V1 %VO2max	0.463	0.404
V1 RER	**.717***	0.627
V1 %HRmax	0.630	0.465
V1 HR	0.643	0.512
V2 %VO2max	0.597	0.677
V2 RER	**.748***	**.790***
V2 %HRmax	0.545	0.626
V2 HR	0.623	0.653
Elbow Extension	-0.105	0.064
%BW Elbow Extension	-0.332	-0.257
Shoulder Extension	**.796***	**.789***
%BW Shoulder Extension	**.849****	0.678
Trunk Flexion	-0.062	0.247
%BW Trunk Flexion	-0.281	0.012
Left One Leg Squat	0.155	0.126
%BW Left One Leg Squat	0.025	-0.071
Right One Leg Squat	0.147	0.197
%BW Right One Leg Squat	0.031	0.027
FIS Distance Points	0.540	0.376
FIS Distance World Rank	0.538	0.379
FIS Sprint Points	0.636	0.504
FIS Sprint World Rank	0.634	0.510
Pushup #1	0.024	-0.042
Pushup #2	0.020	-0.159
Dip #1	-0.243	-0.339
Dip #2	-0.472	-0.557
Pullup #1	0.015	-0.047
Pullup #2	-0.254	-0.255
Situp #1	-0.359	-0.322
Situp #2	0.046	0.073
Single Arm Ergometer Watts	-0.341	-0.304
Single Arm Ergometer Watts/Pounds	-0.467	-0.496
Total Muscular Endurance Score	-0.161	-0.219

TABLE 5. Pearson Correlations for Male V1 & V2 VO_2.

Variables	**V1 VO_2**	**V2 VO_2**
V1 Economy	1.00	
V2 Economy	0.460	1.00
Age	-0.276	-0.411
Height	0.584	0.669
Weight	0.589	0.723
VO2max	0.579	0.452
V1 %VO2max	0.061	-0.229
V1 RER	0.070	0.223
V1 %HRmax	0.094	-0.029
V1 HR	0.216	0.177
V2 %VO2max	-0.409	0.042
V2 RER	-0.042	0.332
V2 %HRmax	-0.629	-0.368
V2 HR	-0.303	0.001
Elbow Extension	-0.095	0.382
%BW Elbow Extension	-0.709	-0.312
Shoulder Extension	0.571	0.592
%BW Shoulder Extension	-0.272	-0.474
Trunk Flexion	0.747	0.737
%BW Trunk Flexion	0.611	0.365
Left One Leg Squat	-0.110	0.711
%BW Left One Leg Squat	-0.361	0.513
Right One Leg Squat	0.044	0.724
%BW Right One Leg Squat	-0.212	0.568
FIS Distance Points	0.402	0.152
FIS Distance World Rank	-0.170	-0.249
FIS Sprint Points	-0.436	-0.479
FIS Sprint World Rank	-0.425	-0.425
Pushup #1	-0.369	-0.209
Pushup #2	-0.401	-0.498
Dip #1	-0.529	0.128
Dip #2	-0.304	-0.168
Pullup #1	0.330	0.523
Pullup #2	0.012	0.273
Situp #1	-0.523	-0.122
Situp #2	-0.452	-0.575
Single Arm Ergometer Watts	**.805***	0.548
Single Arm Ergometer Watts/Pounds	0.676	0.265
Total Muscular Endurance Score	-0.440	-0.179

TABLE 6. Mean ± SD Regression Development and Validation of 25 Sample Predictors of V1 & V2 Oxygen Uptake.

Regression Development	**V1 VO_2**	**V2 VO_2**
R^2	0.937 ± 0.014	0.955 ± 0.01
SEE	1.533 ± 0.118	1.428 ± 0.13
Constant	30.017 ± 1.281	26.967 ± 0.924
SE	2.290 ± 0.314	2.145 ± 0.292
Shoulder Extension	0.322 ± 0.016	0.358 ± 0.013
SE	0.029 ± 0.004	0.027 ± 0.003
Validation		
Pearson Correlation	0.930 ± 0.161	0.906 ± 0.198
T-Statistic	0.247 ± 1.315	-0.603 ± 1.883
P-value (<0.05) two-tail	0.529 ± 0.298	0.542 ± 0.276

SE = Standard Error, SEE = Standard Error of the Estimate

Appendix E

FIGURES

Figure 1. Phases of the V1-Skate technique. Retrieved from http://skixc.com/images-v1/v1-basic.jpg

Figure 2. Phases of the V2-skate technique. Anders Gløersen of Norway during the 2013 Tour de Ski. Retrieved from https://www.youtube.com/watch?v=Stdif0JL9to&feature=youtu.be

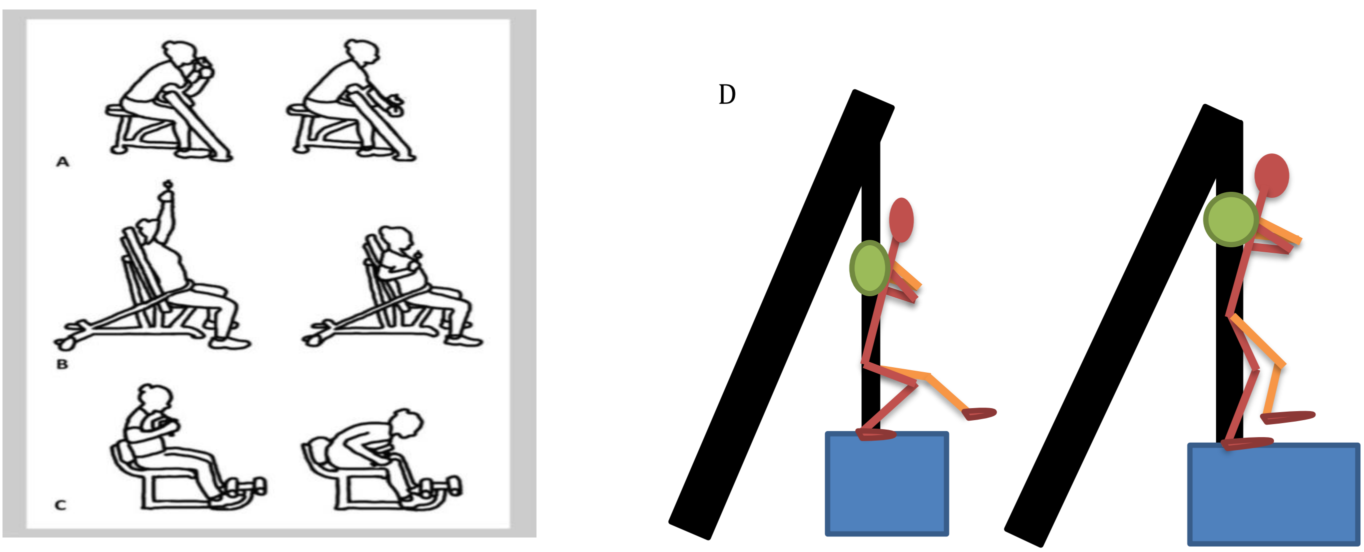

Figure 3. Illustrations of the (A) elbow extension, (B) shoulder extension, and (C) the trunk flexion exercises from start to end position (Østerås et al., 2016) as well as (D) hip flexion.