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Upper Body Characteristics Related To Double Pole Performance in Female Cross Country Skiers

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UPPER BODY CHARACTERISTICS RELATED TO DOUBLE POLE PERFORMANCE IN FEMALE CROSS COUNTRY SKIERS

By

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UPPER BODY CHARACTERISTICS RELATED TO DOUBLE POLE PERFORMANCE IN FEMALE CROSS COUNTRY SKIERS

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ABSTRACT

UPPER BODY CHARACTERISTICS RELATED TO DOUBLE POLE PERFORMANCE IN FEMALE CROSS COUNTRY SKIERS

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The purpose of the current study was to correlate upper body (UB) lean mass (UBLM), UB maximal strength (UBMS), and average power production during a 3-min ski ergometer (SERG) test to predict the dependent variable, a one-kilometer uphill double pole time trial (DPTT) on snow. We hypothesized UBLM would be most important to performance. All tests were conducted within four weeks of completing the championship phase of a Division I cross country (XC) ski season. Skiers (n=10; all females) performed the mass-start DPTT on snow (i.e., criterion measure), SERG, and UBMS separated by at least a few days recovery. Lastly, body composition was determined via dual-energy x-ray absorptiometry (DXA) with a focus on UB mass characteristics (i.e., trunk + arm lean mass). A significant ($p = 0.02$) correlation was observed between DPTT and UBLM. No significant ($p > 0.05$) correlations were observed for UBMS or SERG vs. DPTT. Thus, our hypothesis was supported and we suggest female, competitive cross country skiers work to build functional UB lean mass to best prepare for utilizing the ever popular and evolving double pole technique.

Keywords: Cross-country skiing, upper body, strength, correlation, body composition

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LIST OF SYMBOLS AND ABBREVIATIONS

Double pole……………………………………………………………......................DP

Dual-energy x-ray absorptiometry scan……………………………………………DXA

One kilometer uphill double pole time trial…………….........…………..……….....DPTT

Upper body…………………………………………………………………………UB

Upper body lean mass of the arms and trunk ………………………………….......UBLM

One repetition maximum…......……..………………………………………………..1RM

International Ski Federation…………………………………………………….….FIS

Heart rate……………………………………………………………………………HR

Heart rate maximum………………………………………………………..………HRmax

National Strength and Conditioning……………………………………………….NSCA

Rating of perceived exertion………………………………………………………RPE

Concept 2 SkiErgometer…………………………………………………………..SkiErg

Cross Country………………………………………………………………….......XC

3-min all out SkiErg test measuring average power (watts)…………………………SERG

CHAPTER 1: JOURNAL MANUSCRIPT

Introduction:

Cross-Country (XC) skiing is regarded as a demanding endurance sport, and, in fact, the highest maximal oxygen consumption values ever reported were observed in xc skiers (22). Specifically, men achieved values approaching 96.0 $ml \cdot kg^{-1} \cdot min^{-1}$ and women as high as 76.0 $ml \cdot kg^{-1} \cdot min^{-1}$. Moreover, XC skiing is a technically challenging sport and is unique because it utilizes the whole body in a weight-bearing position (i.e., use of leg, arm and core mass) (27). XC skiing places significant demands on many aspects of human locomotion, including aerobic and anaerobic power, strength, speed, endurance, ski technique, and tactical vitality (14). Interestingly, xc skiing has undergone a transformation since its introduction to the Olympic Games in 1924 to the most recent games in 2014. In this period overall time to complete races has decreased substantially in events ranging from 1.2 to 50 kilometers (km). Racing velocities have nearly doubled, requiring greater propulsive forces from competitors, alluding to the gains in strength and muscular endurance of the upper body (UB) (14).

With the introduction of sprint racing by the International Ski Federation (FIS) in 2001, researchers and athletes became progressively interested in the anaerobic power component of cross-country skiing, which led to a considerable emphasis on training the contributions from UB propulsion. UB, which is defined as all body mass superior of the grater trochanter, has been found to aid in overall forward propulsion (14). Concurrently, investigations on differences between male and female skiers in this regard, although in their infancy, have indicated that female skiers tend to train the UB to a lesser extent than male skiers (10, 23). Aside from biological differences between males and females, research indicates that females may have the potential to make gains in UB power to reach similar peak power output as seen by their male counterparts (12). Further investigation on upper body lean mass (UBLM) development in females may prove advantageous when considering training protocols for elite female skiers. Therefore, the aim of this study was to determine how select UB characteristics related to a criterion measure – 1 km double pole time trial (DPTT) on snow. The select UB characteristics were: dual-energy x-ray absorptiometry (DXA) test with a focus on trunk plus arm lean mass or UBLM, composite score of three upper body maximal (1 RM) strength tests (UBMS), and 3-min average power output during maximal isolated double poling on a ski ergometer (SERG).

Methods:

Subjects**:** Ten female skiers competing in the National Colligate Athletic Association (NCAA) from the Northern Michigan University Cross-Country Ski Team (mean ± SD; age = 29.5±13 years, height= 165.5±7.1 cm, body mass= 57.6±6.36 kg) volunteered to serve as subjects for this study. Each skier signed an informed consent and submitted a PAR-Q or exercise readiness questionnaire prior to testing approved by the Institutional Review Board (#HS15-694). Skiers began testing one-week after completing their competitive racing season. Therefore, they came into the investigation at similar points in their training schedules. Their basic characteristics are documented in Table 1.

Experimental Approach to the Problem: This section briefly and in a general fashion introduces chosen variables with more detailed descriptions to follow. Overall, skiers completed four different tests within a span of four weeks. Skiers first completed the DPTT on snow. The following week, UBMS was assessed via a one repetition max (1 RM) on three different strength exercises: (a) bench press, (b) trunk flexion, and (c) triceps extension. To get the UBMS score, the three 1 RM tests were summed and used in the statistical analysis. The subsequent week, subjects completed the SERG to assess mean power output (watts), heart rate (bpm), and rating of perceived exertion (RPE), which were monitored throughout the warm-up and 3-min race simulation. The last test in the fourth week post xc season was a DXA obtained at a local orthopedic office.

Procedures:

Double Pole Performance Test

The DPTT was completed on a groomed ski trail. All skiers used their personal race skis, boots, and poles normally worn throughout the competitive season. Each skier according to specific instructions the day before the DPTT, waxed skis uniformly. All skiers warmed up at the same time with a 15-min low-intensity ski at <75% maximal heart rate on the 1-km ski course. Thereafter, each skier, stood in a horizontal line in mass-start fashion and completed the course using only double-pole technique at maximal race speed or "as fast as possible". The course was groomed wide enough that there was no funnel effect. After the test all skiers completed a 15-min cool down. Total time to complete the course was recorded using a standard stopwatch program (Apple iPadmini 3, Apple Inc., Cupertino, CA, USA). The moment their first ski boot crossed the finish line, time was stopped and recorded.

DXA Scan

All subjects completed a dual-energy x-ray absorptiometry scan (GE Medical Systems Lunar, Madison, WI, USA). Subjects were instructed to come in for the scan (at Advanced Center for Orthopedics, Marquette, MI, USA) well hydrated, having abstained from eating three hours prior, and having refrained from hard exercise forty-eight hours prior to the scan. To prepare for DXA, all subjects were instructed to remove any metals and excess clothing from their person before lying in the supine position within a box outlined on the DXA table. Once positioned skiers were instructed to lay completely still until the scan was completed.

Maximal Strength Tests

The upper body strength tests consisted of: (1) bench press, (2) trunk flexion, and (3) triceps extension. Maximal strength or 1RM for the bench press was tested on an adjustable bench press machine (Magnum Fitness Systems Bench Press, Milwaukee, WI, USA). Maximal strength for the trunk flexion test was completed on a crunch machine (Magnum Fitness Systems Abdominal Crunch, Milwaukee, WI, USA). Maximal strength for the triceps extension was completed on a multiuse pulley machine (Magnum Fitness Systems Multiuse Machine, Milwaukee, WI, USA). All skiers were familiar with the tests as part of their strength programs. Before the start of the tests, skiers performed a standard warm-up of 10-min easy submaximal running. The 1RM protocol was performed by skiers for each exercise according to the National Strength and Conditioning Association (NSCA) standards as follows: (a) warm-up of 50% of the approximate 1RM for five repetitions, (b) 2 min rest, and (c) 1 repetition with a weight increased by 4.5 to 9kg from previous warm-up weight or greater depending on how easy the warm-up weight appeared (9). In general, a 2 min rest period and increase in weight by 4.5kg or slightly greater continued (steps b and c) until the subject could no longer lift the weight. At that point the subject rested for 3 minutes and attempted to repeat the last unsuccessful lift. The last successful list was then recorded as the 1 RM (4). A minimum of 5-minutes of rest between each different strength exercise test was implemented.

Isolated double pole power test

Isolated UB poling was performed on a ski ergometer (SkiErg 2, Concept 2, Morrisville, VT, USA), with the flywheel set to the highest possible drag allowed by the machine. The skiers stood a distance of approximately 1.1m from the base of the SkiErg flywheel. Each skier wore a heart rate monitor/transmitter strap around her chest corresponding to a watch that was located approximately 1 m away from the transmitter (Polar Electro Inc., NY, USA). Each skier completed a three x 4-min submaximal double poling staged protocol on the SkiErg at progressively increasing intensities. The 4-min protocol was used based on previous researchers, who observed elite skiers reaching an aerobic steady-state within 4-min (11). The skiers were instructed to perform the three submaximal stages at rating of perceived exertion (RPE) values of 2-3, 3-5, 5-7 (out of 10 max exertion), corresponding to intensity zones 1, zone 2, and zone 3, respectively. All skiers were familiar with this intensity system as part of their regular training (1,28). Immediately following the submaximal warm-up, a 15-min break was given followed by a 2 min warm-up at their own pace. Immediately after this, skiers were instructed to perform a 3-min self-paced maximal performance test (i.e., not all-out from the start, but rather a max pacing effort to achieve the highest average watts possible) until exhaustion and to strive for an RPE of 10 by the end of the 3-min "race" (1). The instantaneous wattage was used as the power measure and was recorded every minute along with the accumulative average power over the course of the test.

Statistical Analysis

Individual correlations and multiple linear regression analyses were performed using Pearson's correlation coefficients for the independent variables (i.e., strength, lean mass, and average watts or power). All analyses were performed using SPSS version 21.0 (SPSS, Inc., Chicago, IL, USA) and Microsoft Excel 2011version 14.0 (Microsoft Corporation, Redmond, WA, USA).

The bootstrap protocol was used in this study using a sample (n=10-2) of the total subject pool (n=10). Bootstrapping is a resampling technique utilizing variance and bias extensions when the sample population is small (31). The bootstrap protocol systematically eliminated two subjects from the dataset and calculated the remaining subjects to generate an average from these calculations. The bootstrap protocol for this study estimated n=10-2 from the total subject pool n=10, over 40 times in a row, running a regression analysis each time.

All data for the three 1RM strength tests were tested for correlations shown in table 3. (Microsoft Corporation, Redmond, WA, USA). A composite score of the three strength tests was computed in excel by adding together 1RM values from each strength test for each subject to get total kilograms lifted for all three tests.

Data from DPTT (minutes), DXA (lean mass or kg of mass from arm + trunk), SERG (watts), and UBMS (kg) for each subject were put into a multiple regression analysis. To confirm, a bootstrap protocol was used in SPSS by running 40 different trials with each trial eliminating two of the ten subjects. A separate analysis using all 10 subjects was also calculated and compared to the bootstrap data.

Standardized beta coefficient values produced each time the independent and dependent variables from the 40 trials (n=8) were calculated, and a mean overall value for each variable was obtained. The following, average observations occurred during the bootstrap method: β =-1.68, β =0.796, and β =0.518, respectively, for UBLM, SERG, and UBMS. The standardized beta coefficients (shown in Table 4) for all ten subjects (n=10) were: β =-1.776, β =0.64, and β =0.79, respectively.

For the correlation matrix, (shown in Table 4), Pearson Correlation values for each independent variable and the dependent variable from the 40 trials (n=8) was calculated in Excel and a mean value for each independent variable of the 40 trails was obtained.

For the regression analysis all independent variables (i.e., UBLM, UBMS, SERG) were measured against the criterion measure (i.e., DPTT) to obtain r and r^2, and significance level using Microsoft Excel.

Results: The participants' means and standard deviations for average power, absolute power, HR and, RPE for isolated double pole test are shown in Table 2. The correlations for the three strength tests are summarized in Table 3. A comparison between the raw data and the bootstrapped regression equations for Beta coefficient and Pearson's correlation is demonstrated in Table 4. The correlation for each independent variable and the criterion measure is shown in Table 5. UBLM and DPTT were significantly correlated: r= -0.72, (p=0.02). Neither power (SERG) or strength (UBMS) were significantly correlated to the criterion measure: r = -0.55, (p=0.10); and r =-0.06 (p=.87), respectively. The regression analysis for lean mass, strength, and power are depicted in figures 1, 2 and 3, respectively. A multiple regression analysis found UBLM, SERG, and UBMS combined to explain 77% of DPTT (R^2= 0.7779). UBLM and SERG together explained 53% of DPTT and is shown in table 6.

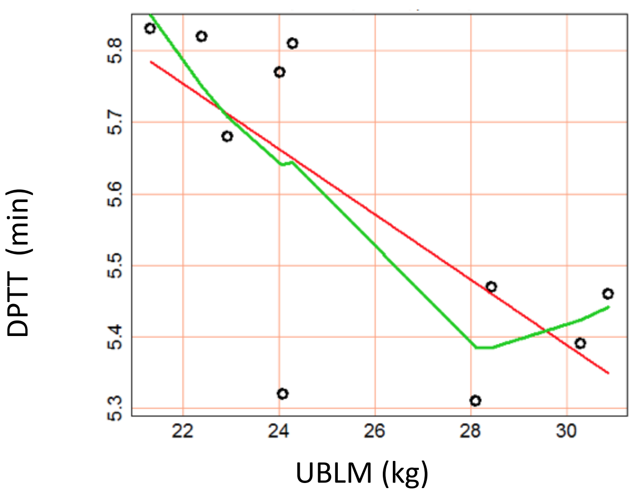

Fig. 1 Lean mass vs. double pole r= -0.72, r^2 = .52, p= 0.02, N=10

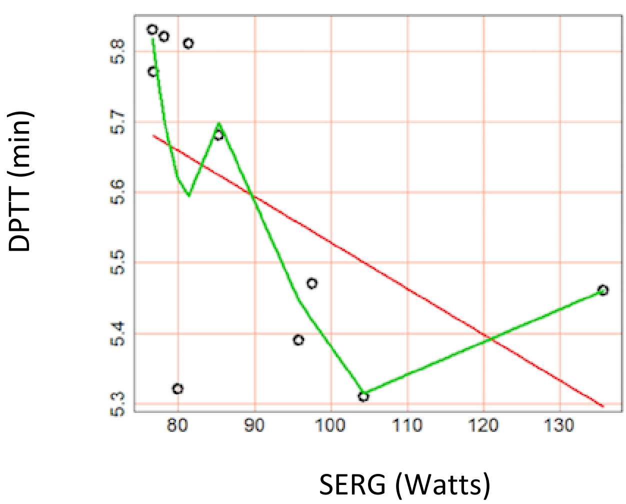

Fig. 2 Power vs. double pole r= -0.55, r^2 = .30, p =0.10, N=10

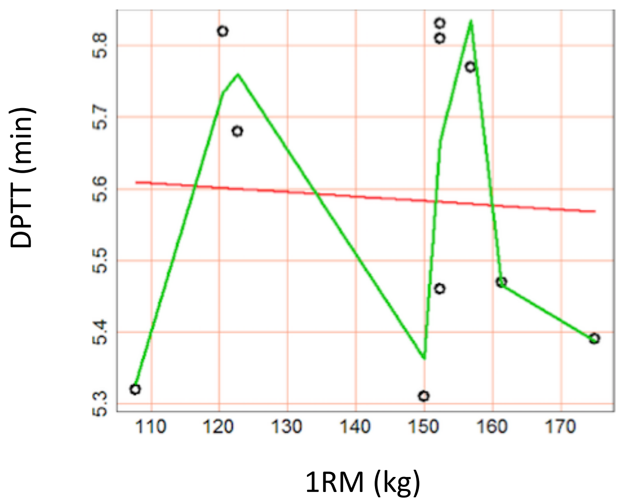

Fig. 3 Strength vs. double pole r= -0.06, r^2 = .0036, p= 0.87, N=10

Discussion

The purpose of the present study was to investigate female xc skier UB characteristics that may be associated with better double pole performance. A multiple regression/correlational method was implemented. Though the subject pool was limited relative to the number of independent variables employed and total number of skiers, the data seemingly upholds good accountability between the raw data and the bootstrapped data for the Beta coefficient and Pearson's correlation. Table 5 demonstrates the correlation between the independent variables (i.e., UBLM, SERG, and UBMS) and the dependent variable (DPTT). Strikingly, UBLM was the strongest predictor for double pole performance ($p = 0.02$) with no correlation for UBMS or SERG vs. DPTT ($p>0.05$).

Although previous researchers (14) examining elite female skiers found a correlation between on-snow performance (using FIS points) and power output in a 3-min all out Ski

Ergometer test, in the present study DPTT and SERG were not significantly correlated (r=-0.376). Despite this, previous researchers observed both power output produced on a SkiErg test and maximal strength to be strongly related to lean mass in the arms and trunk, which is similar to our study, although not significant (18, 19).

Though UBMS did not show significant correlation to DPTT in the present study, previous investigators found maximal strength to be important for double pole performance (18, 20, 30). Although the 1RM strength assessments were not highly correlated with each other in the present study, nonetheless a composite score of the three 1RM strength tests was used for this analysis, which may have contributed to the poor correlation observed. Future investigations should use one UB strength measure most important to double pole technique or a combination of scores if significantly correlated. Notably, previous investigators observed maximal strength to be important for double pole performance (5, 18, 20, 30). Future research groups may also provide more confidence in the current results if a larger number of subjects (n>10) performed all tests to incur less reliance on statistical manipulations posed by the bootstrapping technique used in this study.

Pervious researchers have compared men and women skiers stated men generally have more muscle mass located in the upper body, with the majority of muscle mass found in the arms (11). This appeared to explain their ability to generate more power compared to females (11). Though average power or SERG was not significantly correlated with time-trial performance or DPTT in the present study, another study demonstrated the advantageous association between greater lean mass in males (vs. females) and greater skiing performance (11). However, rather than looking at the difference between genders illustrated in previous literature, we were able to establish comparable differences within the female population to discover that lean mass was similarly associated with greater skiing performance (11, 12).

In summary, the correlations of the independent variables tested in the current study would indicate a greater need for lean muscle mass than for maximal strength and average power produced during the double pole technique. Recall, literature by Hegg et al. demonstrated the benefit of greater lean mass in the upper body on skiing performance (11,12). Other researchers have also found maximal strength and power to be beneficial for female skiers (20). We agree with this and believe significant correlations for maximal strength and power may be important but do not explain DPTT performance in the present study.

Conclusion

We found greater lean mass in the arms and trunk to best predict DPTT. Whereas UBMS and SERG seemed to hold less importance to DPTT. Therefore, this study indicated it may be advantageous for female skiers to develop and maintain greater lean mass in the UB, specifically for DPTT. Although the present study showed non-significant correlations between DPTT vs. UBMS and SERG, these variables should not be discounted when writing a structured training plan for female skiers. Specifically, female skiers should seek to develop greater lean mass in the upper body and thereby also increase UB strength and power to best predict on snow DPTT.

Table 1. Basic Characteristics of the subjects; mean ± SD; *n=10.*

Age (years) 20.462 ± 1.3
Height (cm) 165.481 ± 7.1
Mass (kg) 57.59 ± 6.36
Body Fat (%) 21.15 ± 3.4
*Current FIS point ranking (points) 630.1 ± 57.5
**Ski age (years) 6.5 ± 1.6
Collegiate skiing experience (years) 2.3 ± 1.4

*FIS points were obtained online https://data.fis-ski.com/alpine-skiing/fis-points-lists.html
**Ski age was determined by the participants' number of years training year round for competitive ski racing

Table 2. Means and standard deviations for the power test

	Mean	SD
Average Power (Watts)	93.9	18.4
Instantaneous Power (Watts)	168.65	27.5
HR (bpm)	170.9	12.6
RPE	9.2	0.04

	Beta Coefficient		Pearson's Correlation	
	All Subjects	Bootstrapping	All Subjects	Bootstrapping
Lean Mass	-1.776	0.796775	0.722	-0.6802
Maximal Strength	0.79	-1.68385	-0.127	-0.1098725-
Average Power	0.64	0.5186	-0.554	-0.596625

Table 3. Beta Coefficients and Pearson's Correlation comparison

Table 4. Correlation of independent and dependent variables

Variable	DPTT
DPTT	1
Strength	0.11
Lean Mass	-0.68
Avg.watts	-0.59

Table 5. Multiple Regression Statistics

Standard Multiple Predictor Linear Regression Model				
	Estimated Std.	Error	t-value	Pr (>|t|)
Intercept	6.8064	0.4446	15.3087	0
Lean Mass	-0.0551	0.0302	-1.8268	0.1105
Power	0.0021	0.0056	0.3783	0.7164
Residual Standard Error	0.1682 on 7 degrees of freedom			
Multiple R-squared	0.5306			
F-Statistic	3.956 on 2 and 7 degrees of freedom, the p-value is 0.07087			
	Estimated Std.	Error	t-value	Pr (>|t|)
Intercept	6.5382	0.3463	18.8816	0
Lean Mass	-0.0963	0.0275	-3.5012	0.0128
Power	0.0061	0.0044	1.3657	0.221
Strength	0.0067	0.0026	2.5844	0.0415
Residual Standard Error	0.125 on 6 degrees of freedom			
Multiple R-squared	0.7779			
F-Statistic	7.004 on 3 ad 6 degrees of freedom, the p-value is 0.02188			

CHAPTER II: LITERATURE REVIEW

INTRODUCTION

Cross country skiing is a technically and physiologically demanding sport that requires maximal aerobic and anaerobic endurance, utilizing the whole body in a weight-bearing position where energy and power are utilized from both the upper and lower limbs (27).

Over the past two decades' elite skiers have achieved greater race pacing as a result of enhanced equipment and race course preparation, thereby creating the demand for athletes to obtain higher, sustained speeds (14). The onset of sprint-style races and mass-start competitions during this period has also contributed to the importance for creating higher race speeds (13,18,29). Upper body power (UBP) has since been investigated as an attribute for obtaining the aforementioned higher race tempos. Researchers have adapted to the need for investigating physiological factors associated with UBP by using the double-pole technique as the representative mode for determining performance outcomes relating to manipulations in upper-body (UB) endurance training and muscular-strength training (8).

Characteristics of elite skiers: *Muscles:* Earlier research using histochemical analysis showed skiers to have a predominance for type I, slow twitch fibers in the shoulder and arms muscles. Muscle biopsies have shown fiber density profiles of sprint and endurance athletes with sprinters excluding less density than endurance athletes, though it is not known if this is caused by training and/or genetic factors. However, it is known that metabolic, contractile and Ca^{2+} handling properties of muscles can be altered by consistent training (23).

Skiers normally have larger cross sectional areas of muscle fibers vs. other endurance athletes, particularly in the arms and shoulders. Skiers today exhibit 15-25% larger fiber areas in the arms and shoulders when compared to skiers over the past four decades. This is likely due to the increasing emphasis on strength and power training that has occurred over the past forty years (14). *Capillaries:* Skiers have been found to have just as many capillaries in their leg muscles as cyclists and runners who use their lower limbs almost exclusively (~5-7 capillaries per fiber) (23). Kayakers and swimmers who are upper body dominant have been reported to have the same number of capillaries in their arm and shoulder muscles as skiers, cyclists and runners exhibit in their legs. However, this has not been found in the upper body of elite skiers (23), indicating the hidden potential for skiers to improve upper body development and possibly performance.. By increasing capillaries in this respect, skiers would enhance O_2 extraction in the arm and shoulder muscles (23). *Pulmonary:* Researchers have shown double poling to enhance pulmonary gas exchange and arterial saturation better vs. diagonal striding technique. It is speculated that this is because locomotor and respiratory movements are matched when exhalation is assisted by a forceful contraction of the abdominal muscles that flex the trunk while inhalation is enhanced with extension on the trunk (17).

Both the arms and legs of elite skiers extract O_2 to a significant level, specifically, 93-95% by the legs and only 10-12% less by the arms. The difference between upper and lower limb O_2 extraction is reasoned to be caused by lower mean transit time, lower diffusion area and longer diffusion distance in the arms (6). *Energy Production:* In a study by Van Hall (10), elite skiers who underwent a submaximal classic roller skiing protocol on an indoor treadmill produced more lactate in the arms than they took up, which is opposite of what occurs in the legs at a submaximal level. They found that the legs oxidize most of the lactate produced by the whole body because they are large muscles requiring increased energy (14.1 mmol lactate) (10). However, blood lactate concentration is not a valid measure of aerobic/anaerobic capacity during exercise because it largely depends on relative involvement of the arms and legs, therefore inter-limb difference in lactate production and utilization studies may provide better information on metabolic regulation in the muscles. This information may improve the training strategies for skiers, and needs to be further researched (10)(16). Calbet et al. summarized this in his findings to say arms have lower O_2 extraction and lower capillary muscle O_2 conductance values than the leg muscles (6). Upon further investigation on this concept, Calbet et al. were able to conclude skeletal muscle vascular conductance (blood flow) is kept under control during whole body exercise in the upright position to avoid abnormally low blood pressure (hypotension) (5). This is key information in the sport of cross country skiing in that it is one of the only sports that requires the whole body in a weight bearing stance, and may help further explain how the upper and lower body respond in unison and at the same time separate from each other during high intensity exercise.

Cross-country skiing technique: Cross country ski courses are typically designed to incorporate one-third uphill, one-third flat and one-third downhill. The topography of the course and wide range of velocities (anywhere from 5-70 km/h) requires the athlete to change between the nine main sub-techniques of classic and skate skiing (14). It has been found via global positioning systems that a skier will transition between sub-techniques nearly 30 times throughout a 1.5km sprint race, and several hundred times during longer distance races (3).

Classical style skiing sub-techniques include diagonal striding (DS), double-poling (DP) and double pole kick (DK) (11). For elite skiers DS is performed by exerting force through the skis and poles while the arms and legs are moved in a coordinated pattern that resembles that of walking or running (11). The push arm is performed along with the push leg of the contralateral side. The leg’s propulsive action involves a stop in the forward motion of the ski and a rapid down and backward movement of the leg that can be described as a backward kick. DP is performed with symmetrical and synchronized movements of both poles (11). The propulsive action is enhanced by a significant trunk flexion with minimal involvement from the legs. This technique would be considered the second gear and is typically used on flat terrain and mild inclines, although as skiers become more developed in the UB they are able to utilize DP on all but the steepest of uphill's. The DP cycle length is depicted by the topography of the course where the cycle rate becomes shorter as the incline increases, resulting in a higher tempo. Although the legs have a substantial role in repositioning the body during the DP, all propulsive forces are generated by the arms and trunk during the poling phase (11).

The DK is performed through a poling action similar to that of the DP, but in this sub-technique propulsion is obtained also by a left or right leg kick in a coordinated pattern by alternating the leg that kicks back during each poling phase. DK is used when velocity is too low for DS, but too high for DS, or when the skier is not strong enough to utilize the DP (21).

In skate skiing the athlete will choose between one of four different sub-techniques, V1, V2, V2-Alternate, No-Pole skating and the Hop-Skate. In the literature you may see these terms referred to in the European context where they refer to V1, V2, V2-alternate and No-pole skate as G2, G3, G4 and G5. "G" stands for "gear" in this sense, and with the American version "V" represents the "V" orientation of the skis while in the skating position (23,24). It is good to note this distinction because much of the literature on skiing hails from Scandinavia where the "G" system is used (23, 24, 25). In general, skating is performed in a zig-zag fashion where the ski is gliding perpendicular to the push-off movement with the skis angled toward the average direction of travel (23,24,25). V1/G2 skating is an uphill technique with asymmetrical poling action occurring on every second leg. V2/G3 skating is used on flat terrain up to moderate uphill inclines and is performed with on poling action for every leg stroke. The upper-body application nearly mimics that of the double-poling action in classical skiing. V2-Alternate/G4 skating is used on flat terrain with a symmetrical poling action on every second leg stroke.

No-Pole Skate/G5 is when the athlete uses the skating technique without administering any pole plant and is used on downhill slopes where skating is used without poling when velocities are very high. The Hop-Skate is a relatively new technique born out of necessity during skate sprint races. The hop skate mimics V1 skating, but with more of a jumping action from the lower limbs and is used on steep uphill climbs, sprint races or sprint sections and starts of a distance race (3,20).

Two techniques that are used in both classic and skate skiing are the downhill tuck and the step turn. The downhill tuck is used on downhill tracks when the athlete tucks all limbs together and crouches down to maximize aerodynamics, in both classic and skate techniques. The step-turn is when the skier makes small, repeated steps to maneuver around tight corners and embankments in both classic and skate.

Due to the multifaceted nature of skiing techniques researchers are consistently investigating the kinematic nature of elite performers as the sport evolves.
Because of technical complexity and the myriad of sub-techniques activating the upper and lower body to different extents, researchers continue to utilize VO_{2max} to represent total or localized maximal oxygen uptake. For skiers a true max is typically only found in diagonal stride classic skiing and sometimes in v1 or v2 skating (14). For all other sub-techniques and training methods, a VO_{2peak} is used, which represents the peak oxygen uptake for a particular exercise, but is not necessarily representative of the athlete’s total VO_{2max}. VO_{2peak} for elite skiers

employing all techniques is typically 5-15% lower than their VO_{2max} values found in uphill skating and diagonal striding (13,27). Unlike other sports, such as running or cycling, researchers are able to test the same athlete in skiing across many different sub-techniques, giving a unique insight into human performance in more than just a few aspects. A study comparing the oxygen uptake of skiers across different exercises found 4% lower values in running and 14% lower values in double poling compared to diagonal striding. The main assumption is that in DS the athlete is using both the upper and lower body, where in running it is primarily the lower body and in double poling the upper body (15). This insight has motivated athletes to enhance their VO_{2peak} to at least 95% of their VO2max during sub-techniques, especially in those techniques that utilize the smallest muscle groups, such as the double pole (14).

Gender Differences*:* Related to most endurance sports, men are ~12%% faster than females (7). Gender differences in endurance performance are caused by biological differences, specifically higher testosterone and hemoglobin levels, larger body sizes with relatively more muscle mass, and less fat mass in men (24). However, exercise efficiency does not differ between men and women, as the relationship between VO_2 and power output dose not appear to be different between sexes (7, 24). In a study that matched 10 male and female elite skiers based on international performance level, subjects completed three incremental tests (i.e., whole-body, upper body and arm poling) and a three-minute self-paced performance test on a Concept2 SkiErg. Subjects were tested for power output, cardiorespiratory and kinematic variables, and body composition. Men demonstrated higher power output while using more of their running VO_{2max} in all tests. Lower VO_{2max} values among women demonstrated female skiers were less able to utilize their aerobic capacity (11). Gender differences have also been found during diagonal striding, V2 skating, and double poling (24, 26). When looking at the upper body in more isolation by double poling with locked legs during submaximal tests, gender differences increase (11, 12). Gender differences appear to be higher in skiing than other endurance sports such as running, cycling and speed skating, where the main propulsion is generated by the legs. This may indicate that women demonstrate greater weaknesses in the upper body when compared to men, though the extent to which this differences is attributable to the trunk and arms remains to be examined (11).

Another insightful difference between genders is the work rate per cycle (indicated by double poling cycle length). Women tend to show higher cycle rates during poling while men have been shown to start the poling phase with larger elbow and shoulder angles, thereby allowing a longer poling phase and reaching a lower position at the end of the poling. The method employed by men demonstrates better utilization of potential energy to generate poling power, explaining the discrepancy in skiing velocities between genders (12, 14, 26). During a race, cycle rate is often referred to as tempo, indicating that women tend to complete the course with higher work rate but produce less power. The aforementioned key differences between genders may indicate that women would benefit from more strength training, particularly that which increases upper body hypertrophy or mass.

Several studies have determined UBP to be a strong predictor for racing performance. Research has indicated that upper-limb propulsion and an enhanced upper body strength and aerobic capacity are fundamental for predicting cross-country ski performance (6,7,14,18). This holds true whether power output is sustained for a few seconds to several minutes, indicating that an athlete who has greater UB strength will have an advantage in both short sprint-style racing and longer races that require more endurance (2). Similarly, a study by Staib et al. found a significant relationship between International Ski Federation point ranking (FIS) and DP time to exhaustion, DP VO_{2peak}, and UBP expressed in watts where DP time to exhaustion was correlated to UBP and DP VO_{2peak}. The study indicated that DP VO_{2peak} accounted for 75% of the variance in FIS points, with those ranked highest exhibiting the longest time to exhaustion (29). Therefore, the need to understand and utilize UB power is of utmost importance for competitive cross-country skiers today. UB power may be explained by simulated double pole performance on snow, average power, upper body lean mass and maximal strength capability (29).

Strength Training

Strength contribution to skiing performance has been investigated, particularly how overall strength relates to power output expressed during the propulsive phase of skiing techniques.

There is supporting evidence that increasing strength positively correlates to better DP performance. One group of researchers showed that DP performance improved after 12 weeks of heavy strength training, implying that greater UB strength were a positive attribute to DP performance (the effect of heavy…) Another study group of investigators demonstrated that maximal strength in UB segments is important to DP performance in that increased strength is associated with greater power output, which in turn improved skiing performance in elite female skiers tested (19). Relative to male skiers, maximal UB strength has been shown to be more of a limiting factor for female skiers concerning DP performance (13).

Power Output

Average power output has commonly been used in studies that investigate UB contributions to skiing performance (18). Increases in power output during the DP have been shown to cause greater cycle lengths in the double pole, which increases DP performance overall. In an intervention study investigators indicated that average power output in a 5-minute DP test increased in subjects who underwent

12 weeks of heavy strength training. This illustrated increased strength is an important attribute to increasing power during DP, which in effect may enhance DP performance.

Lean Mass

Lean muscle mass has proven to be a common variable used in studies investigating how power output and strength relate to skiing performance.

In a study investigating lean mass and its effect on DP performance in elite skiers researchers have found that the cross sectional area (CSA) of UB segments before and after a heavy strength training intervention increased for the triceps bracii. A strong correlation was found between the CSA of the triceps brachii and a seated pull down strength test. This seems to indicate greater lean mass in UB segments may be associated with higher maximal strength and thus overall DP performance (18). Researchers have shown that greater lean mass of the arms and trunk was related to higher power output during a SkiErg DP test as well as greater weight lifted during 1RM strength tests. (19). Pervious studies have shown that UB strength is an important determinant for DP performance, where maximal UB strength has shown to be particularly important for female skiers.

To our knowledge there have been few studies that correlate double pole performance, average power output, lean mass and maximal strength among elite female cross country skiers. Therefore, the purpose of the current study was to correlate three independent variables, upper body lean mass, maximal strength and average power production to predict the dependent variable, a one-kilometer uphill double pole time trial on snow.

CHAPTER III: CONCLUSIONS AND RECOMMENDATIONS

The present study indicated that lean mass of the arms and trunk was correlated with double pole performance on snow whereas maximal strength and average power produced during isolated double poling on a SkiErgometer were not significantly correlated with on snow performance. Based on our findings, elite female cross country skiers may improve their double pole performance by increasing the amount of lean mass in the upper body.

Prior to additional discussion, we first want to point out a few study limitations. We chose to employ a strength (i.e., 1 RM) composite score based on three maximal strength exercises; however, the three 1 RM tests were not strongly correlated with one another. Further investigation should use maximal strength tests highly correlated and relevant to musculature utilized during the double pole, which were included in the current study. Furthermore, skiers were tested after completing their competitive racing season and were therefore more conditioned for ski racing performance and ski-specific movement patterns rather than maximal strength procedures; although, it was assumed each participant was similarly trained. Despite this, further performance-oriented testing could be administered during a different training cycle of the year, such as after a specific UB strength training program. A better indication for the role maximal strength plays in relation to double pole performance may then be realized.

Also, future research should continue to look at inter-correlations for the independent variables in this study to explain how they are related and thereby better explain the correlation between upper body involvement in the double pole technique, so that practical training programs can be implemented. Another interesting extension to this study would be to test all subjects on the relevant variables before and after undergoing a maximal strength training program to determine if hypertrophy of the upper body musculature occurs, and what effect that has on lean mass and strength in relation to double pole performance.

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