Upper Limb Isokinetic Muscle Strength Predicts the Performance in Cross-Country Sit-Skiing

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Research Article

Keywords: Strength training, Resistance training of shoulder, Strength endurance, Upper body strength characteristics, Isokinetic muscle strength

Posted Date: November 24th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-1048935/v1

Version of Record: A version of this preprint was published at Scientific Reports on April 12th, 2022. See the published version at https://doi.org/10.1038/s41598-022-10103-4.

Abstract

Understanding the physical fitness attributes in a sport-specific technical skill is a key to improve the action economy, and thus aerobic endurance performance. The present study was designed to investigate how upper limb muscle strength predicts double poling (DP) power performance in cross-country sit-skiing. A total of 19 female able-bodied college students (age 23.2±0.8 years, BMI 20.4±2.2) were subjected to a 30-s and 3-min DP performance tests using a sit-skiing ergometer. Isokinetic muscle strength by the angular velocity of 30 °/second, 60 °/second, and 120 °/second of the shoulder and elbow extensor/flexor were measured with an ISOMED2000 isokinetic system. A medium correlation was found between DP output power and isokinetic upper limb muscle strength (shoulder strength at all speed, r = 0.39-0.74, p < 0.1). Multiple regressions, which were employed to predict power production in the 30-s and 3-min tests, showed that shoulder extension strength at 60 °/second accounted for 34% of the variation in the 30-s test, and 40% of the variance in the 3-min test.

Introduction

Paralympic cross-country sit-skiing is an aerobic endurance sport that requires athletes to sit on a sit-ski and generate propulsion with upper limbs. The pushing technique performed by sit-skiers is adopted from the double poling (DP) technique used by standing able-bodied skiers. The determinants of cross-country skiing, which are mostly studied for able-bodied skiers, usually include the analysis of athlete kinematics (both during the race[1] and in the lab[2]) to determine the most economical technical action, and the biomechanical analysis[3, 4] of the patterns of poling force, active flexion-extension of key joints and EMG activity of both upper and lower body. Accumulated evidence has shown that the upper body power (UBP) has an important role in cross-country ski racing[5, 6], which was further confirmed by statistics from both aerobic energy systems[7] and shorter sprint-type UBP tests[8]. However, the required physical fitness to perform DP is still not clear and needs to be urgently analyzed to guide the specialized training of cross-country sit-skiing.

The isokinetic muscle strength test is the widely recognized and most common measurement used to assess muscle strength in limbs[9, 10]. Also, the positive relationship between isokinetic muscle strength and athletic ability has been well established[11, 12]. To further elucidate the relationship between physical fitness and cross-country sit-skiing performance, it is necessary to measure and analyze the isokinetic muscle strength of upper limb muscle groups.

Previous studies have discussed the relationship between muscle strength and DP performance, where muscle strength was represented by one-repetition maximum (1-RM) strength[13] or lean mass[14]. However, isokinetic muscle strength was not included as the normative standard value of muscle strength [15]. This lack of data on isokinetic muscle strength of upper limbs at different speeds and modes limited the systematic analysis of the relationship between upper limb muscle strength and DP performance.

The aim of the current study was to examine the relationship between the specific muscle strength of upper limb muscle groups and the power output in cross-country sit-skiing. Isokinetic muscle strength of shoulder and elbow were measured, and DP of sit-skiing was performed on a cross-country sit-skiing ergometer. The results of this study may be used to guide special physical training for paralympic cross-country sit-skiing.

Results

Table 1 shows the data collected from all 19 female able-bodied college students majoring in physical training (mean age, 23.2±0.8 years, height, 162.9±4.3 cm, and BMI, 20.4±2.2). Isokinetic MaxTorqu (Ext)/MaxTorqu (Flex) of shoulder and elbow at 30 °/second, 60 °/second, and 120 °/second were measured to establish the muscle strength. Δs - the mean distance of a poling phase was measured by monitoring the markers sticking on the poling platform using the Qualisys system. Output power was calculated by (barbell movement distance * barbell gravity) / time, and the barbell movement distance was represented by the marker movement sticking on the poling platform.

Table 1
Study Participant Characteristics of demographics,strength and outpower measures (n=19)

	Mean	SD
Age (y)	23.2	0.8
Height (cm)	162.9	4.3
Weight (kg)	54.2	5.3
Shoulder muscle strength (N*m)		
Flex, 30 °/second	18.4	3.5
Extend, 30 °/second	31.0	8.3
Flex, 60 °/second	18.4	5.3
Extend, 60 °/second	30.1	7.9
Flex, 120 °/second	17.7	8.0
Extend, 120 °/second	22.8	7.5
Elbow muscle strength (N*m)		
Flex, 30 °/second	14.3	4.0
Extend, 30 °/second	21.8	5.9
Flex, 60 °/second	14.3	3.9
Extend, 60 °/second	19.5	4.9
Flex, 120 °/second	13.1	3.3
Extend, 120 °/second	16.0	3.6
Distance of a poling phase (m)		
30-s Δs	0.84	0.1
3-min Δs	0.81	0.1
Output power (J)		
30-s work	202.3	39.2
30-s work	1087.0	295.2

Correlations among technical performance, output power, and isokinetic muscle strength

Pearson's correlation coefficients between upper limb isokinetic muscle strength and output production are shown in Table 2. Sit-skiing DP output power of 30-s was significantly correlated with isokinetic muscle strength of shoulder at all three different angular velocities of 30 °/second (flex $r = 0.61$, $p < 0.01$; extend r = 0.39, $p < 0.1$), 60 °/second (flex $r = 0.74$, $p < 0.01$; extend $r = 0.61$, $p < 0.01$) and 120 °/second (flex $r = 0.54$, $p < 0.05$; extend $r = 0.58$, $p < 0.01$). Sit-skiing DP output power of 3-min was also significantly correlated with isokinetic muscle strength of shoulder at all three different angular velocities of 30 °/second (flex $r = 0.6$, $p < 0.01$; extend $r = 0.47$, $p < 0.05$), 60 °/second (flex $r = 0.74$, $p < 0.01$, extend $r = 0.66$, $p < 0.01$) and 120 °/second (flex $r = 0.71$, $p < 0.01$; extend $r = 0.63$, $p < 0.01$). There was a weak insignificant correlation between isokinetic muscle strength of elbow and sit-skiing output power, except for isokinetic muscle strength of elbow flex at 120 °/second, which was strongly correlated with the output power of both 30-s test (coefficient $r = 0.57$, $p < 0.01$) and 3-min test ($r = 0.74$, $p < 0.01$). Δs of 30-s and 3-min were not significantly correlated with muscle strength. As shown in Figure 1A-B, and 2E-F, **Δ**s was significantly and positively correlated with output power both in 30-s (right hand, $r = 0.73$, $p < 0.01$; left hand, $r = 0.77$, $p < 0.01$) and 3-min (right hand $r = 0.63$, $p < 0.01$; left hand $r = 0.68$, $p < 0.01$) test, and all data were calculated for left and right hand separately. Overall, **Δ**t was not significantly correlated with the output power especially in 30-s test, in 3-min test (Figure 1C-D and Figure 1G-H).

Table 2
Correlations between subject **Δ**s, output power of 30-s and 3-min, and muscle strength

Pearson correlation	30-s Δs (m)	3-min Δs (m)	30-s Work (J)	3-min Work (J)
Shoulder				
Flex, 30 °/second	0.119	-0.026	0.606**	0.601**
Extend, 30 °/second	0.243	0.115	0.387	0.465*
Flex, 60 °/second	0.366	0.176	0.736**	0.741**
Extend, 60 °/second	0.232	0.103	0.614**	0.656**
Flex, 120 °/second	0.278	0.308	0.541*	0.706**
Extend, 120 °/second	0.273	0.359	0.575**	0.626**
Elbow				
Flex, 30 °/second	-0.254	-0.354	0.06	0.218
Extend, 30 °/second	-0.22	-0.302	0.07	0.292
Flex, 60 °/second	0.042	0.057	0.358	0.555*
Extend, 60 °/second	-0.345	-0.398	-0.008	0.171
Flex, 120 °/second	0.189	0.296	0.566**	0.743**
Extend, 120 °/second	-0.096	-0.111	0.289	0.434

Relationships between output power and isokinetic muscle strength

Results of multiple stepwise regression analysis between isokinetic muscle extension strength of upper limb and the sit-skiing DP output power of 30-s and 3-min showed that muscle strength of shoulder extension at 60 °/second accounted for 34% of the variation in the 30-s test, while shoulder extension at 60 °/second accounted for about 40% of the variance in 3 min test. Upper limb muscle extension strength measures from other velocities did not enter the regression.

Discussion

The present study results revealed that the shoulder extension and elbow flexion strength were the performance determining factors in DP. In detail, the muscle strength of shoulder extension at 60 °/second accounted for 34% of the variance in the 30-s test, while the muscle strength of shoulder extension at 60 °/second accounted for about 40% of the variance in the 3-min test. These findings add to an emerging body of literature explaining how upper limb muscle strength significantly contributes to cross-country sit-ski output power variations.

The correlation analysis showed that output power was significantly and positively correlated with upper limb isokinetic muscle strength. Correlation analysis of shoulder muscle and output power showed that isokinetic shoulder muscle strength at all angular velocities and modes were positively correlated with 30-s and 3-min output power. This is consistent with previous reports suggesting that the largest muscles of the shoulder, i.e., trapezius, deltoids, pectoralis major, and serratus anterior, are responsible for the majority of the upper-extremity tasks[17]. The muscle strength of elbow extension was not significantly correlated with output power count. One explanation for this discrepancy was that the subjects in this work were all primary skiers who, during the DP mainly swing the upper arm, and elbow extending strength contributed less. And, our results supported this argument, i.e., our Δs in a 3-min test was about 0.8 m, which is much smaller than in the able-bodied elite skiers, whose Δs = 1.8-2.2 m[4]). Further, Figure 1A-B and Figure 1E-F showed that larger Δs corresponding to larger power output, these results showed the importance of elbow extension at the later stage of the poling. And this is consistent with the previous study reporting that arm swings contribute considerably to the overall force generation and propulsion[19], as the arm swings more backward, the pole force sustains more efficiently and a longer time.

The above correlation results confirmed the importance of maximal strength training in cross-country skiers training programs[17]. Moreover, the same trend of lasting-mode (3-min) and short-mode (30-s) output power with the muscle strength conformed to results in abled-body cross-country skiing UBP tests, both in the aerobic energy system[7] and shorter sprint-type[8], suggesting the upper body muscle strength was import determinants in the racing.

Stepwise multiple regression analysis of muscle strength showed that shoulder extension at 60 °/second accounted for 34% of the variances in 30-s output power, while shoulder extension at 60 °/second accounted for about 40% of the variance in 3-min output power (Table 3). The muscle strength of shoulder extension velocity at 60 °/second is consist with our kinematic analysis, that shoulder extend at about 55 °/second during poling phase (calculated from markers sticking on the upper limb, data not shown). In addition to a general increase in lean upper-body mass and maximal upper-body strength [13], our results pointed out the contribution of upper limbs isokinetic muscle strength to the DP technique in cross-country sit-skiing.

Table 3

Unstandardized coefficient, standard error, partial correlation, and adjusted R^2 of stepwise multiple regression analysis on the upper limb extend muscle strength and output power of 30-s and 3-min

Predictor variables	B	SE	P-value*	r	Adjusted R^2
30-s output power					
Step1					0.341
Constant	110.417	29.554	0.002		
Shoulder Extend at 60 °/second	3.053	0.951	0.005	0.614	
3-min output power					
Step1					0.397
Constant	348.706	212.651	0.119		
Shoulder Extend at 60 °/second	24.527	6.844	0.002	0.656	

Above results indicated that isokinetic muscle strength and muscle coordination were important for the power output generation in sit-skiing DP. In detail, at the initial stage of the poling phase, the isokinetic extension strength at 60 °/second of the shoulder muscle group dominated the poling action, and at the later stage of the poling phase, the elbow swing action was the key to enhance the performance. These results may provide guidance for designing strength-training programs of cross-country sit-skiing athletes.

This study has a few limitations. Influenced by COVID-19, the researchers did not recruit as many subjects as expected, let alone the professional athletes they could not contact. The researchers also did not consider longer testing of DP on the ergometer, which could make the testing closer to the real situation of a cross-country sit-skiing race.

Methods

Participants

Among a total of 26 able-bodied students who were recruited from Capital University of Physical Education and Sports, 19 (age 23.2±0.8 years, BMI 20.4±2.2) met the following inclusion criteria: women who majored in physical training. Exclusion criteria were: not finishing the physical tests and isokinetic muscle strength measurements in 2 weeks and suffering from injuries during the testing period.

This study was approved by the Ethics Committee of the Capital University of Physical Education and Sports (Beijing, Peoples' Republic of China), and all experiments were performed in accordance with relevant guidelines and regulations. All participants provided written informed consent prior to the enrolment.

Physical tests and experiment setups

Physical tests started at December 2020 and ended at January 2021. All subjects visited the lab twice to complete the doubling poling testing; tests were performed on intelligent training and experimenting equipment for cross-country sit-skiing[16] in the lab environment with a temperature of 23 °C and suitable humidity. During the first visit, subjects were introduced to the testing equipment and allowed to warm up at self-selected resistance and poling rhythm. Following a 5 to 10 minutes warm-up, subjects were asked to sit with lower leg strapped to the seat so as to simulate the conditions of athletes with the disabled lower limb and performed three successive 30-s maximal effort tests with 3 minutes intervals in each group. Then, the subjects were allowed to rest 10 minutes before a final 3-min maximal effort test. Each test began with a 5-s countdown, during which subjects were instructed to start poling with a slow but steady cadence. The poling resistance was set at 5% of body mass, which was chosen from several pilot testing and gave skiers the most natural feeling of double-poling. During the second visit that was no less than 24 h after the first visit, the subjects were asked to repeat all the tests performed during the first visit.

The intelligent training and experimenting equipment of cross-country sit-skiing used the gravity of barbell pieces as a substitute for normal skiing resistances. The device included an underframe and a vertical frame, where a training seat was installed on the underframe. Barbell pieces mounted on the light-weighted wheeled platforms moved on the guide rail of the vertical frame, thus forming a cable and pulley system. The cables were rerouted through the underframe and connected with the horizontal platforms. Cross-country ski poles, which were inserted into the top of the horizontal platforms, moved the platforms along the rails, such that a simulated upper body double-poling motion was possible. The horizontal rails were able to rotate around the proximal end by manually adjusting the fixing bolt. Elastic bands around the seat twining the thigh and ankle helped to fix the legs, simulating the common situation of Paralympic cross-country sit-skiing. As the skier pushed backward on both poles, the rope pulled the barbells sliding on the vertical rail against the gravity. Seven Oqus3+ cameras (Qualisys AB, Gothenburg, Sweden) were used to track the markers sticking on poling platform that was to measure the barbell movement distance against the gravity direction. Marker motion data were recorded at 200 Hz.

Athletes' output power of a complete poling cycle was defined as: Output Power = (barbell movement distance * barbell gravity) / time.

Following the typical definition of double poling[3], a poling cycle consists of 2 main phases: poling phase and the recovery phase. The poling phase accelerates the sled, and during the recovery phase, the athlete gets ready for a new cycle. The total distance of the pole tip moving during the poling phase is named as Δs, and the corresponding time is named Δt.

Isokinetic muscle strength of the shoulder and elbow muscles was measured with the ISOMED2000 isokinetic system (Basic System and Back System; D&R Ferstl GmbH, Hanau, Germany). All the steps were performed in strict accordance with the requirements of the technical manual of the isokinetic system. After 5 min warm-up and one or two submaximal pronation and flexion exercises, which helped participants to get familiar with the instruments, three to eight consecutive measurements of maximum peak torque were taken, and only the maximum value was recorded. Isokinetic concentric contractile strength was measured by the angular velocity of 30 °/second, 60 °/second, and 120 °/second for the shoulder and elbow extensor/flexor.

Statistical analysis

Normality was tested by the use of –plot, and revealed the normal distribution of the main variables (muscle strength and output power). Values were recorded as mean values ± standard deviations (SD). Associations among technical performance, output power, and muscle strength were explored by Pearson's correlations. Stepwise multiple regression on output power measurements was used to identify significant predictive variables from measures of muscle strength of different testing modes and muscle groups. P-values ≤ 0.05 (two-sided) were considered as statistically significant in all analyses. All data were analyzed by using SPSS version 26.0.

Declarations

Conflicts of interest

The authors declare no conflict of interest.

Acknowledgements

This work was funded by grants from the National Key Research and Development Program of China (Grant No. 2020YFC2006200).

Authors' contributions

C.L., Z.Z., L.Z., G.S., and J.Y. conceived and designed this research. Y.T, Z.T. conducted the experiments and collected the data. Y.T., C.L., and Z.Z. analyzed the data. C.L. and Y.T. drafted the manuscript. All authors read and approved the final version of the manuscript.

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Figures

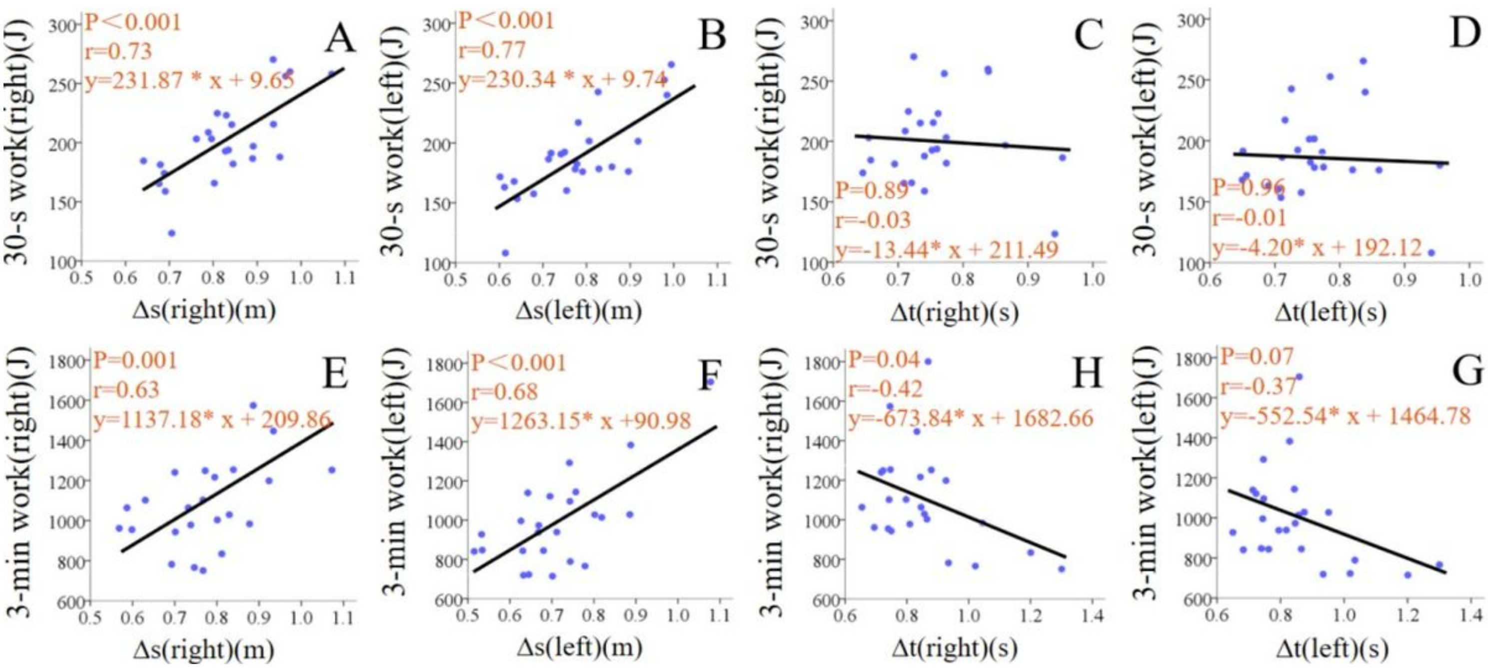

Figure 1

Correlations between Δs, Δt, and output power. Data from the left hand and right hand are calculated separately. (A-B) The relation between Δs and 30-s output power. (C-D) The relation between Δt and 30-s output power. (E-F) The relation between Δs and 3-min output power. (G-H) The relation between Δt and 3-min output power.