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Effect of Roller-ski Aerobic High-intensity Interval Training on Leg Muscle Strength in Cross-country Skiers

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ABSTRACT The purpose of this study was to examine the effect of roller-ski aerobic high-intensity interval training on leg muscle strength and time-trial performance after 8-week of roller-ski uphill training. The sample comprised of 10 males (age, 18.8±2.1 years) and 8 females (age, 16.1±0.3 years) junior cross-country skiers, who performed 8-week intervention training periods three times a week in addition to their normal seasonal training. All skiers performed all-out uphill interval training, 2 sets as long duration (10-15 minutes), at 85-92 percent of HR_{max} with total duration of 40-45 minutes (height difference is 144 MT and 2-km distance). Before and after the intervention period all athletes were tested for hamstring and quadriceps isokinetic strength at 60^0/sec and 2-km time-trial performance. Both group improved leg muscle strength and time-trial performance between pre- and post-test (all $p<0.05$). In conclusion, 8-week of supplemental aerobic high-intensity interval training promotes increases in isokinetic strength and time-trial performance.

INTRODUCTION

The cross-country skiing involving sprint and classic race, is one of the most demanding endurance event (Saltin and Astrand 1967; Holmberg et al. 2007), where, the primary determinants of success is the ability to complete a specific distance in the shortest time possible (Carlsson et al. 2016). Because both the legs and arms contribute to generate propulsive power at varying degrees during skiing (Österas et al. 2002; Holmberg et al. 2005), the relationship between propelling and counteracting force is important for skiers' performance (Carlsson et al. 2016).

In cross-country skiing, especially in sprint skiing a lot of factors, such as physiological, biomechanical, anthropometric, and neuromuscular, have an impact on performance (Sandbakk 2014; Hebert-Losier 2016). Following the new sprint skate skiing racing events, involving four separate heats and lasts, each lasting 2-4 min, with different demands from traditional races associated with longer durations (Andersson 2016), and preparation of the snow the importance of both endurance and muscle strength in the arms and torso has emerged (Stögll 2011; Holmberg 2015). It has been known that the upper-body plays a crucial role in performance in cross-country skiing (Zory 2006; Stögll 2015). Numerous studies stated that upper-body power and technique are considered as primary components, especially in double poling (Nesser et al. 2004; Nilsson et al. 2004; Stöggl et al. 2008; Mikkola 2010; Hegge 2015; Skattebo 2015; Hegge 2016; Österas 2016; Zappirolli 2016). On the other hand, the activity of legs is non-negligible, which is the key factor for the main energy consumer in cross-country skiers (Van Hall et al. 2003; Stöggl and Lindinger 2006; Stögll 2011; Andersson 2014; Brown 2016). Getting optimal force might not only be attained by the arm, shoulder, and the trunk muscles, but also by the active movement of the legs (Holmberg 2005). In skate techniques (V1-skate, V2-skate), especially in V2-skate, the activity of leg for propulsion is important in different grades (Herzog 2015; Brown 2016). Legs have higher capillary density, lower lactate onset and higher aerobic capacity than the arms (Holmberg 2015; Monahan 2016). The potential association be-

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tween strength capacities and performance has been investigated in the past studies (Mikkola et al. 2007; Sandbakk 2010). Stöggl et al. (2011) determined the relationships between general strength, maximal skiing speeds, pole and leg kinetic and kinematics of a group of elite male skiers. Losnegard et al. (2011) have studied heavy strength training with normal endurance training in elite cross-country skiers. In addition to these studies, Larsson et al. (2002) stated in their study that quadriceps strength is correlated to performance in cross-country skiing.

Nowadays, the effects of high-intensity training on performance have become important topic again in endurance sports and it has been performed in a large variety of sporting events. Numerous studies have reported that high-intensity training has important effects on performance in endurance athletes (Pugliese 2015; Inoue 2016; Kilian 2016; Farley 2016; Paquette 2016). Several studies have also reported that high-intensity training has superior central adaptations compared to continuous exercises at lower intensity (Daussin et al. 2007; Helgerud et al. 2007; Sandbakk et al. 2013; Ní Chéilleachair 2016). As stated by Billat (2001) "the eighties were years of exceptional runners such as Sebastian Coe (800 to 1500m), performed aerobic and anaerobic interval training as well as circuit training for strength and power improvement."

Although data regarding high-intensity interval training are excessive, data between high-intensity interval training and strength studies are scarce in cross-country skiers. Besides, the researchers' knowledge, a limited number of studies have investigated the effects of sport-specific interval training on performance in cross-country skiers (Nilsson and Holmberg 2004). Therefore the purpose of the present study was to determine the effects of roller-ski aerobic high-intensity interval training on isokinetic strength of the quadriceps and hamstring and a time-trial performance task, 2-km roller-ski test, after 8-week of intervention period in cross-country skiers.

METHODOLOGY

Subjects

The total of 18 cross-country skiers who participated in the study included 10 males (age, 18.3±2.1 years; height, 171.3±4.12 cm; weight, 61.4±6.28 kg) and 8 females (age, 16.1±0.3 years; height, 158.3±6.47 cm; weight, 49.3±0.7 kg) junior cross-country skiers.

Experimental Design

The intervention period was performed after the winter season from April to May during the roller-ski competition and also preparation of the new winter season. During an 8-week intervention period, all athletes added all-out aerobic high-intensity intervals (2-km distance; 144 m height differences) 3 times a week in addition to their regular training. The subjects were instructed to perform the interval sessions with their maximal sustainable intensity. The participants were tested for hamstring and quadriceps isokinetic strength at 60^0/sec and 2-km all-out time trial performance with the roller-ski. The methods and experimental protocol for the study were approved by the ethics committee of the University of Gazi Medical Faculty, and all participants were fully acquainted with the nature of the study before they gave their written, informed consent to participate. The intervention training was carried out as follows;

- Roller-ski aerobic high-intensity training performed 2 sets as long duration uphill intervals (10-15 minutes), at 85-92 percent of HR_{max} with total work period durations of 40-45 minutes.

The skiers were instructed to perform the intervals with their maximal sustainable intensity. Training intervention started with a 15-minute warm-up on roller-ski at 60 percent HRmax. All training sessions were performed on roller-ski on asphalt. All intervals were carried out with a 15-minute active rest (jogging on downhill) periods in between. Training was standardized on the days before pre and post-testing.

All data were obtained before and after 8-week intervention periods. Skiers were tested for isokinetic right and left leg strength and 2-km time-trial performance. Due to fact that all tests were achieved at maximum performance, skiers were informed and familiarized with the tests. Skiers performed all tests with 48-hours of rest between tests. All subjects used the same type of roller-ski (Pro-Ski C2, Sterners, Nyhammar, Sweden with 80 mm wheel diameter), and each skiers used their own skating poles, boots and helmets. Free skating techniques (V1 and V2) were used during the study.

Isokinetic Knee Extension and Flexion Peak Torque

Isokinetic strength was assessed with the "ISOMED 2000" (D&R FershGmbh. GERMA-

NY), which recorded isokinetic knee extension and flexion peak torques at various preset constant angular velocities. Before testing, each subject completed a standardized warm-up consisting of 10-minute submaximal (~60%) on treadmill followed by quadriceps and hamstrings stretching with a 20-second pause for each repetition (5-6 static stretches). The subjects were placed in a comfortable upright seated position on the Isomed dynamometer chair and secured using knee, pelvic, and torso straps to minimize extraneous body movements. Movement center of the dynamometer was at the level of lateral condyle and the calibration was made for each subject individually. Lower fixed component of dynamometer was placed on distal tibia above the approximately 3-finger of ankle. The isokinetic knee extension and flexion was assessed at 60^0/sec. Test started with five submaximal exercises followed by two to three maximal repetitions for warm up purposes. The skiers started with their dominant leg. Once dominant limb has been tested, each subject was given a brief period of volitional recovery (about 3-minute) and then asked to perform the non-dominant limb at 60^0/sec. Only the highest peak torque values of the flexors and extensors of the legs were used in the analysis. Torques were gravity-corrected for each subject when the gravity effect was greatest. All subjects were encouraged to avoid pacing and to sustain their supramaximal efforts throughout the test. The peak torque rate to body mass was recorded in (PT/VA) Newton-meter/kilogram (nm/kg).

2-km Time-Trial Performance Test

The measurements of all-out 2-km time-trial were obtained using the roller-ski (Pro-Ski C2 – Sterners, Nyhammar, Sweden) in the skating techniques (V1 and V2). The test was performed at on uphill asphalt, and had a 30-second start interval between the skiers in a random order. Before the test all skiers performed a 20-minute warm-up on roller-ski. Skiers used the same pair of roller skis at pre- and post-testing and, used their own skating poles, shoes, helmets, and glasses. A rest period of 15-minute was given between the intervals.

Statistical Analysis

Statistical analysis was processed using Microsoft Excel and IBM SPSS (Ver. 20) statistical software. Mean and standard deviation were calculated for each variable, Skewness and Kurtosis Tests were performed for normality. Wilcoxon Test (2-related samples) was used to determine significant changes from pre-to post-test values. Also percentage changes (%) were calculated to detect skiers' improvements from pre-to post-test values. P-value <0.005 was considered statistically significant. All values were listed as pre-to post-test mean (±SD), significant level, and percentage changes (%).

RESULTS

Pre-to post-testing changes in leg strength, and also 2-km time trial performance are shown in Tables 1 and 2, for female and male skier, respectively. Within the both female and male skiers group, all parameters were significantly higher during all post-test trials ($p<0.005$).

The female skiers and male skiers improved right leg quadriceps by 9.75 ± 8.92 percent and 17.6 ± 9.19 percent, right leg hamstring by 6.39 ± 11.75 percent and 10.9 ± 11.28 percent, left leg quadriceps by 9.36 ± 9.13 percent and 21.3 ± 11.36 percent, left leg hamstring by 6.12 ± 11.46 percent and 6.9 ± 7.23 percent, respectively, from pre-to-post-testing (all $p<0.05$) (Tables 1 and 2). The strength increased between pre- and post-test in all the training groups but the changes in hamstring right and hamstring left at 60^0/sec differences were greater than in quadriceps right

Table 1: Comparison between pre and post-test in female athletes

Parameters	*Pre-test* *x±sd*	*Post-test* *x±sd*	*p*
RL/Quadriceps N.m	98.12± 28.7	108.25± 26.3	0.012*
RL/Hamstring N.m	45.88± 14.82	55.5± 14.54	0.011*
LL/Quadriceps N.m	91.63± 16.81	101.37± 17.0	0.012*
LL/Hamstring N.m	47.5± 10.88	56.75± 11.23	0.011*
2-km time trial (sec)	17.3± 2.15	16.58± 0.88	0.012*

RL: Right leg; LL: Left leg

*Significant difference ($p<0.05$).

Table 2: Comparison between pre and post-test in male athletes

Parameters	*Pre-test* *x±sd*	*Post-test* *x±sd*	*p*
RL/Quadriceps N.m	180.5±19.94	198.5±22.76	0.005*
RL/Hamstring N.m	88.1±15.95	100.7±13.14	0.005*
LL/Quadriceps N.m	175.9±25.66	194.9±22.83	0.005*
LL/Hamstring N.m	84.9±13.03	96.2±12.51	0.005*
2-km time trial (sec)	13.45± 2.15	12.58± 1.11	0.005*

R: Right leg; LL: Left leg

*Significant difference ($p<0.05$).

and quadriceps left at 60^0/sec from pre to post-testing in both groups.

Eight-week of roller-ski uphill training decreased 2-km time trial performance from 17.3±2.15 to 16.6±0.88 (4.16%) in female skiers and 13.5±2.15 to 12.6±1.11 (6.47%) in male skiers (Tables 1 and 2).

DISCUSSION

It was hypothesized in this study that the in-preseason roller-ski uphill interval training would allow to increase isokinetic leg muscle strength and 2-km time trial performance in cross-country ski athletes. As previous studies have reported, adding two interval sessions per week for 4 to 8-week improves performance by 2 to 4 percent among well-trained endurance athletes (Seiler 2010). The main findings of the current study suggest that adding high-intensity interval training to traditional training within the preparation session is an effective method and can improve leg strength independently of the gender in cross-country skiers. It can be said that high-intensity interval trainings (HIIT) can result in the best improvement of body fitness among athletes in the shortest possible time. (Fatemeh 2016). Previous study (Tsitkanou et al. 2016) showed that muscle strength and quadriceps cross-sectional area were significantly and similarly increased after both resistant and resistant training plus high-intensity interval cycling groups. They suggested that high-intensity interval cycling training prompts aerobic capacity and muscle capillarization. Mathunjwa (2016) observed improvement of body composition, cadio respiratory response and physical performance after 4-week of high-intensity intermittent training in Taekwondo athletes. Robineau et al. (2016) detected lower muscular strength gains.

World-class and Olympic distance cross-country skiers demonstrate similar aerobic capacity (Sandbakk 2014). Besides; a certain level of strength is required, particularly ski-specific strength (Daussin et al. 2007; Hebert-Losier 2016). For example, in connection with sprint skiing, speed over a short distance and maximal strength correlate closely with performance (Stöggl et al. 2007). Stöggl et al. (2011) analyzed the relationships between general strength, maximal skiing speeds, pole and leg kinetic and kinematics of a group of elite male skiers, revealing that the general strength and power per se seem not to be major determinants of performance in elite skiers. Mikkola et al. (2007) showed that in male cross-country skiers, concurrent explosive strength and endurance training led to improvements in explosive force associated with increased rapid activation of trained leg muscles. And they also observed an increase in 30-m double poling test performance. The dynamic strength has also been related in double poling, diagonal stride, and V2 skate technique (Mikkola et al. 2010).

In the current study the improvement in 2-km time-trial performance was observed in both groups. It seems likely that the increases in time-trial performance are mainly explained by the improvement in leg strength. Furthermore, previous studies reported that it might also be induced by higher training speeds during intervention periods performed as roller-ski in level terrain (Billat 2001; Sandbakk et al. 2011). One of these studies by Sandbakk et al. (2011) found that intervention group improved sprint performance (1.5-km) 13-second after 8-week high-intensity intervention period in elite junior cross-country skiers.

CONCLUSION

This study has shown that leg strength was increased during the pre-season by a specific training program based on roller-ski uphill intervals at high-intensity. Besides, this study shows improvements in time-trial performance. The applications from this study apply both for coaches and scientists by showing that leg strength can be improved both by adding roller-ski aerobic high-intensity interval sessions with a long duration at a higher intensity.

RECOMMENDATIONS

With reference to the training effects found in this study, we suggest that the skiers should integrate the roller-ski aerobic high-intensity interval models in their training programs. Additionally, future studies are needed to carry on with a control group in order to detect differences between all groups.

LIMITATIONS

There are some limitations to the researchers' study that need to be addressed. Without a control group it is difficult to state that the intervention period will further improve leg strength and time-trial performance. However, this reflects a real-world setting where it is unethical, and impractical for practitioners to withhold training interventions from skiers, and difficult to find appropriately matched controls.

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