



Case Study

Effect of prolonged racing on muscle activity and spatiotemporal variables: double-poling technique

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Abstract. [Purpose] The purpose of this study was to examine the effect of a 40-minute race on muscle activity and spatiotemporal cycle variables at four-time points during a 12-km roller skiing test using the double-poling technique. [Subjects and Methods] Five elite cross-country (XC) skiers on the Korean National reserve team participated in the study. Part of a biathlon course that consisted of both flat land and slopes was selected, and three measurements were recorded after every 4-km lap. Spatiotemporal variables, mean frequency and mean amplitude of 6 muscles were the chosen computational parameters. [Results] Significant differences were observed in cycle time and rate. The mean frequency of the upper-body muscles exhibited declining trends, with statistically significant differences for the triceps brachii. In addition, there were significant differences in the mean amplitude of the tibialis anterior and gastrocnemius. The activity of the triceps brachii, tibialis anterior, and gastrocnemius showed some degree of dependence on the technique. [Conclusion] Training and race strategies that improve the function of elbow extensors and ankle dorsiflexors are important in XC skiing; the application of roller-ski training research to actual XC skiing competitions is needed.

Key words: Cross-country skiing, EMG, Fatigue

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INTRODUCTION

Cross-country (XC) skiing is a Winter Olympic sporting event that requires a high level of power output and is characterized by repeated dynamic contraction of both upper and lower limbs. The skier utilizes various techniques depending on the terrain, and adapts by modifying the relative contributions of the upper and lower extremities to propulsive force^{1,2)}.

A key technique in classic XC skiing is double-poling (DP), which plays a crucial role in performance, particularly during sprint competitions or the mass start³⁾. The technique is primarily used on flatter terrain to achieve higher velocity³⁾. Forward propulsion during DP technique is characterized by higher pole forces mainly generated by the dynamic flexion-extension of the upper extremities, especially the elbow joint, with a very short ground contact period³⁾. Meanwhile, the lower extremities contribute to the application of body weight to pole forces^{1,2,4-6)}. Thus, as the DP technique involves continuous symmetrical and synchronous motion of both upper and lower extremities, there is a lack of recovery period between strokes, which

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increases the fatigue accumulation rate^{4, 6}).

Several studies have examined the underlying neuromuscular mechanisms of DP technique in XC skiing. Most of these studies were carried out in simulated conditions^{1, 3–11}). However, few studies have examined how muscular fatigue affects performance in a natural environment for complex movements, such as XC races^{12–15}).

To the best of our knowledge, there are no published studies on how muscle activity and spatiotemporal variables during prolonged racing affect performance by a skier in a natural setting. Therefore, the purpose of the study was to assess the effect of a 40-minute race on muscle activity and spatiotemporal cycle variables at four-time points during a 12-km roller skiing test using the DP technique.

SUBJECTS AND METHODS

Five male elite XC skiers from the Korean National reserve team participated in the study. The mean and standard deviation of height, weight, and age of the subjects were 177.2 ± 3.3 cm, 69.0 ± 2.4 kg, and 20.4 ± 1.1 years, respectively; their professional career length was 7.4 ± 1.8 years. The subjects had no acute musculoskeletal injuries or surgeries in the prior six months. Before the test, the experimental purpose, procedure, and possible risks were communicated verbally and in writing to the subjects, who then gave informed consent approved by the Institutional Review Board (IRB), to comply with the ethical principles of the Declaration of Helsinki (1975, revised 1983).

The experiment was conducted on a biathlon course in Pyeongchang, Korea. The experiment was conducted over the course of 2 days. Three subjects participated on the first day of the experiment, and the two subjects participated on the second day. The average temperatures on the first and second day were $24^\circ \pm 2.8^\circ\text{C}$ and $28^\circ \pm 4.2^\circ\text{C}$, respectively. A part of the biathlon course that consisted of both flat land and slopes was selected (4 km per lap \times 3 measurement trials = 12-km course) for the overall run. But, the measurement was conducted only on the flat land, where DP technique was possible (*Measurement area length on the flat land: 30 m*).

Prior to the experiment, the subjects performed warm-up and stretching exercises for about 30 min upon arriving at the arena. The skin was prepared for attachment of electrodes by shaving the site and cleaning with sterile alcohol swabs to reduce any skin impedance. Disposable, self-adhesive Ag/AgCl snap surface dual electromyography (EMG) electrodes (Seedtech Inc. Seoul, Korea) with diameter 1 cm were attached at a total of six areas on the right side of the body, including two upper body areas (triceps brachii, latissimus dorsi) and four lower-body areas (vastus lateralis, tibialis anterior, biceps femoris, gastrocnemius lateralis). The intra-electrode distance was 25 mm. Telemetry DTS Wireless system (Noraxon, USA) was used for EMG measurement. The cotton adhesive tape was used to fix the sensors to the skin. The EMG sampling frequency was set to 3,000 Hz. For all subjects, the ski equipment was matched to the same brand and model (roller skis: aluminium, XLA 900 Series, V2, USA; boots: model RC Carbon, Salomon, USA). Subjects used carbon graphite poles (model Triac CTO 500, Swix, Norway), but chose the length that they preferred to use during competition.

All participants were briefed on the procedural order of the test. The subjects were requested to maintain a normal pace throughout the 12-km course. In order to maintain a normal pace, the subjects were informed about their lap time every 2 km. In the measurement zone (M_{start} to M_{end}), the subjects were asked to perform DP technique at maximum capacity. The subjects were informed that they could not rest until the completion of the 12-km course. Three measurements from M_{start} to M_{end} were recorded after every 4-km lap. Three DP cycles of 20 m each were selected for further analysis from M_{start} to M_{end} .

A digital camcorder (Sony, Japan) was set up approximately 50 m to the side of the course to analyze cycle variables in the sagittal plane. The sampling rate of the digital camcorder was set to 30 Hz.

The analytical parameters considered were categorized as spatiotemporal cycle variables or muscle activity variables. The spatiotemporal cycle variables included the cycle time, cycle length, cycle rate, time ratios by phase (push vs. gliding), and mean velocity in the measurement section (30 m). Here, we have defined one cycle as a phase between two consecutive pole plants. The cycle time was the average for 3 cycles with DP technique. The average number of cycles was calculated by dividing the total time for the 30-m interval by the cycle time, and the 30-m length was divided by the average number of cycles to compute the cycle length. The cycle rate was the number of cycles per second during the cycle time, and the push-time ratio was calculated as the push-phase time divided by the cycle time, expressed as a percentage.

The EMG variables chosen were the mean frequency and mean amplitude. The raw data from the EMG were band-pass filtered at 80–250 Hz. The mean frequency was the average value of 3 cycles analyzed after converting time-scale signals into frequency-scale signals by fast Fourier transform (FFT) analysis. The mean frequency for each lap was expressed as a percentage after being normalized with respect to the value of the first lap. The mean amplitude was the mean of rectified EMG data during the 3 cycles. For EMG analysis, MR3.6 (Noraxon, USA) software was used.

A non-parametric test (Friedman) was conducted to examine the differences between all the variables using the data obtained for 3 laps. A post-hoc test was carried out using the Bonferroni method and statistical significance was set at $\alpha < 0.05$. SPSS ver. 22 (IBM, USA) software was used for statistical analysis.

RESULTS

The results of lap time are shown in Table 1. No significant differences were observed in the time between each lap.

Table 1. Lap records for every 4 km lap (0–4 km, 4–8 km, 8–12 km) (unit: minutes)

Distance	Lap time
1st lap: 0 (start) to 4 km	13:57 ± 00:38
2nd lap: 4 km to 8 km	13:17 ± 00:34
3rd lap: 8 km to 12 km	13:04 ± 00:38
Total duration	40:17 ± 01:18

Mean ± SD; N=5

Table 2. Results for non-parametric test (Friedman) for spatiotemporal cycle variables in each lap

Variables	1st lap	2nd lap	3rd lap
Cycle time (s)	0.85 ± 0.1	1.01 ± 0.38	0.94 ± 0.11
Cycle length (m)	5.36 ± 0.57	6.24 ± 0.76	6.16 ± 0.50
Cycle rate (Hz)	1.21 ± 0.14	1.04 ± 0.14	1.08 ± 0.14
Push time ratio (%)	31.37 ± 3.79	29.18 ± 3.93	30.43 ± 2.91
Mean velocity (m/s)	6.42 ± 0.28	6.41 ± 0.27	6.60 ± 0.45

Mean ± SD; N=5 Significant difference at $p < 0.05$ only in cycle time (s) and cycle rate (Hz)

Table 3. Results of non-parametric test (Friedman) for normalized mean frequency of six muscles of the right limb in each lap (unit: %)

Muscles	1st lap	2nd lap	3rd lap
Triceps brachii	100	94.3 ± 3.5	63.9 ± 16.2
Latissimus dorsi	100	82.8 ± 48.7	69.6 ± 44.6
Vastus lateralis	100	91.8 ± 24.6	90.8 ± 35.5
Tibialis anterior	100	91.8 ± 8.6	97.1 ± 4.9
Biceps femoris	100	132.6 ± 96.8	157.6 ± 76.5
Gastrocnemius	100	100.4 ± 16.3	108.5 ± 13.0

Mean ± SD, N=5, Significant difference at $p < 0.05$ in triceps brachii

Table 4. Results of non-parametric test (Friedman) for EMG mean amplitude of six muscles of the right side in each trial (unit: %).

Muscles	1st lap	2nd lap	3rd lap
Triceps brachii	100	45.1 ± 7.7	43.8 ± 60.2
Latissimus dorsi	100	85.3 ± 100.6	147.2 ± 107.6
Vastus lateralis	100	53.6 ± 9.8	28.3 ± 67.5
Tibialis anterior	100	58.8 ± 12.8	13.2 ± 57.7
Biceps femoris	100	60.9 ± 62.9	100.9 ± 105.6
Gastrocnemius	100	91.1 ± 12.8	27.8 ± 61.9

Mean ± SD, N=5, Significant difference at $p < 0.05$ in Tibialis anterior and Gastrocnemius

Therefore, it can be concluded that the overall pace was consistent throughout the 12-km race.

The results obtained through analysis of the cycle variables are presented in Table 2. Significant differences were observed in cycle time and cycle rate. Although cycle time increased compared to that in the first lap, cycle rate showed a decreasing trend. No significant differences were observed in cycle length, push-time ratio, and mean velocity.

The results of normalized mean frequency for each muscle in the first lap are presented in Table 3. The mean frequency of the upper body muscles exhibited a declining trend, and there was a statistically significant difference for the triceps brachii ($p < 0.05$). However, no significant differences were observed in post-hoc analysis.

Table 4 shows a significant difference in the mean amplitude percentage of maximum voluntary contraction (MVC) for the tibialis anterior and gastrocnemius ($p < 0.05$). A declining trend over time is evident. However, no significant differences were observed in the post-hoc analysis.

DISCUSSION

DP is an essential classic racing technique and has steadily evolved to enhance athletic performance. It can increase speed up to 8 m/s, which is twice as fast as the maximum speed possible with a diagonal stride technique^{5, 9, 13, 16}. The present study aimed to assess the effect of a 40-minute race on muscle activity and spatiotemporal cycle variables at four-time points during a 12-km roller-skiing test using the DP technique.

The analysis of spatiotemporal variables related to the DP technique indicated that from the first through the third lap, while the overall cycle time increased, cycle rate showed a decreasing trend. Zory et al., reported that a decrease in the cycle rate and an increase in the push and gliding durations was the result of fatigue during a XC skiing sprint competition¹². In addition, they reported that even when the cycle time was maintained, the corresponding push-time ratio would increase. The push-phase time is a time segment during which force is generated by poling. In general, high performance is characterized by a short push-phase time and large force generation¹⁷. In the present study, the push-time ratio tended to increase over time, but no significant differences were observed.

Mean frequency for each lap was analyzed as an indicator of muscular fatigue. The mean frequency for upper body muscles decreased, and a significant decrease was observed in the triceps brachii. As DP technique is widely adopted in XC skiing, greater emphasis is being placed on upper body training for skiers³. Previous studies have reported that upper body muscular strength is highly correlated with performance in DP technique^{16, 18}. According to Smith et al.¹⁹, high-speed skiers had relatively wider ranges and higher angular velocities of elbow motion; these involve the triceps brachii, and can affect elbow joint movement. As the triceps brachii contributes to extension of the elbow joint, the effect in XC skiing is to generate explosive poling force. A large poling force is related to high performance within a short poling time because it produces a

large ground reaction force. A short push-phase time and large force generation have been reported to be characteristics of relatively high performance¹⁷⁾.

The mean amplitude percentage of MVC, an indicator of the activity level of muscles, displayed a declining trend in different laps, and significant decreases in the mean EMG amplitudes of the tibialis anterior and gastrocnemius were observed. Such decreases are attributed to the declining rate of fast-twitch muscle fiber mobilization due to fatigue^{14, 20)}. Holmberg, Lindinger⁵⁾ reported that the DP technique can enhance athletic performance, as it facilitates not only the movement of the upper limbs but also that of the lower limbs. They also reported that use of the DP technique can reduce energy consumption, which highlights the functional importance of the lower limbs.

According to previous studies, better athletic performance is achieved at a submaximal DP velocity of 85% when the lower limbs are given a high degree of freedom. In other words, when the lower limbs can move freely, larger pole-planting forces and impulses can be generated and recovery times are longer⁵⁾. These findings suggest that active movement of the lower limbs during DP increases performance. As the heels of XC ski boots are not attached to the ski plates, there is a frequent activity of the tibialis anterior, which affects dorsiflexion of the ankle joints. Therefore, fatigue and decreased activity of the tibialis anterior is considered to adversely affect performance.

In conclusion, a decrease in activity over time was observed in the triceps brachii (upper body) and tibialis anterior and gastrocnemius (lower body). The activity of the triceps brachii, tibialis anterior, and gastrocnemius showed some degree of dependence on technique. Therefore, it can be concluded that training and race strategies that improve the functions of elbow extensors and ankle dorsiflexors are important in XC skiing; the application of roller-ski training research to actual XC skiing competitions is needed.

Conflicts of interest

The authors report no conflict of interest.

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