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Effects of Fatigue Related to Uphill on Kick Double Pole Kinematics of Young Cross Country Skiers

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Abstract

The purpose of this study was to examine the effect of fatigue due to uphill on the kick double pole technique. Ten young male subjects volunteered to study. Subjects' cross country sprint times were taken using a kick double pole technique with maximum effort for 1 km in a climbing course with an average slope of 4%. In accordance with these measured times, a separate average speed for each subject was modified, and the subjects were tested on the treadmill at these specified speeds, with the same duration, slope, and technique. Each participant was asked to perform three trials with half an hour between them. Kinematic data were obtained using a three-dimensional motion capture system (Vicon Peak, Oxford, UK). Statistical analysis was performed by separating the variables into 3 separate groups: a) periods of time b) distance data c) joint angles. In conclusion, in kinematic data analyzed according to the fatigue of climb, there was a significant difference between the duration of the poling times, duration of the first cycles with the left leg propulsion and the last cycles, and the duration of the first cycles with the right leg propulsion and left leg propulsion. Significant differences were found in the hip, shoulder, elbow and trunk angles. Significant differences were also found among all the identified distances.

Keywords: Cross country skiing, kinematics, simulated competition, sports biomechanics

Introduction

Contemporary skiing races are characterized by higher skiing speed and performance, with higher and lower body capacities being higher (Saltin, 1997), the development of neuromuscular and technical skills. The majority of cross-country (XC) skiing techniques have undergone significant changes over the past decade (Holmberg, 2005; Holmberg et al., 2005; 2006; Mikkola et al., 2007, Stöggl et al., 2008; Lindinger et al., 2009a). Kick double poling is characterized by a propulsive leg push between double poling actions for momentum conservation in light uphill conditions (Smith, 2002) and leg push is similar to diagonal skiing (Lindinger et al., 2009b).

Sprint races in XC skiing was first held in the mid-1990s. In short, a sprint contest in the XC skiing is divided into two parts: the first one is a qualification heat in the form of a time trial, and the second one is a three series final competition with about 20-25 minutes between, after a 1-3 hour break. The fastest 16 or 30 skiers qualify for the final competition, where each heat competes with four to six athletes (depending on the mode), only the fastest two being the next level. In the past few years, with regard to the classic WC sprint races in the XC skiing, a single sprint run has a mean distance of 1350 m and a qualification duration of 2 minutes and 50 seconds. In order to be in the first eight in a sprint competition, an athlete must pass four heats with a race time of about 3-4 hours (Smith, 2002). With sprint events becoming more popular, different approaches to specific sprint training, testing, and skiing techniques have begun to emerge. To date, the published literature on physiological stress and biomechanical properties measured in the XC skiing sprint race is not sufficient.

Technical changes have been developed in the XC skiing over the past decade (eg Stöggl and Müller, 2009). For example, Holmberg et al. (2005) introduced the new, “modern” double-poling technique characterized by smaller joint angles, higher flexion velocities, and higher pole forces applied during a shorter poling time compared to “traditional” double-poling technique. One of the most important sub-techniques of the classical style, the kick double poling technique, in the skiing run, is due to the better transfer of thrust to the baton (Losnegard et al., 2017). It is also frequently used at the start and finish of all competitions, except for the classic sprint ski run competitions. In addition, it can be assumed that the XC sprint is determinant for ski performance. Therefore, it can be said that neuromuscular characteristics and kick double poling performance characteristics are important in competition performance.

Simulated XC sprint skiing induces muscle fatigue (reduction in sprinting performance, leg force, and upper limb power output; Zory et al., 2006). Furthermore, Vesterinen et al. (2009) observed a decrease in the spurt velocity associated with decreased neural muscle activation during the heats. The fatigue accumulation in a sprint race also depends on the recovery times between the series. Zory et al. (2009) suggested that fatigue in a sprint race alters kinematic patterns (greater trunk, hip, and pole angles) of double poling leading to a decreased cycle (and sprinting) velocity. However, the extent to which fatigue affects the power output in the XC sprint ski race has not been reported.

When the investigations were examined, it was observed that they carried out with the athletes on the elite level. In addition to the importance of increasing the number of repetitions applied to the substructure for the perfection of the technique. It is also one of the main objectives to adapt to the factors such as the physiological changes that take place when applying the technique. In addition to the biomechanical analysis of the technical movements of the elite level athletes, it is very important that the kinematic variables exhibited by young athletes during this technique are observed and evaluated. Therefore, the aim of this study is to examine the effect of fatigue due to uphill on the kick double pole technique.

Methods

Participants

Ten XC skiers from the Turkish national team (mean age = 17,6 ± 1,3 yr, body weight = 65.6 ± 8.0 kg, body height = 175.0 ± 4.0 cm) volunteered to participate in the study. The selected skiers were familiarized with the skiing on the treadmill. All participants were fully acquainted with the nature of the study before they gave their written, informed consent to participate.

Experimental procedure

XC sprint times of subjects were taken using a kick double pole technique with maximum effort for 1 km in a climbing course with an average slope of 4%. The trial times were recorded by a stopwatch (Seiko Interval Timer, Tokyo, Japan). In accordance with these measured times, a separate average speed for each subject was modified, and the subjects were tested on the treadmill at these specified speeds, with the same duration, slope, and technique. Each participant was asked to perform three trials with half an hour between them.

Trials were performed on a treadmill (h/p/Cosmos Saturn 4.0, Germany) customized for XC roller skiing, with speed and steepness controlled by a computer. After a 20-min warm-up skiing at a self-selected but low intensity (under lactate threshold), a rest period of 20 min was observed during which small reflective spherical markers (diameter 17 mm) were attached to the participant's left and right front heads (over the left and right temple), left and right back heads (on the back of the head, roughly in a horizontal plane of the front head markers), 7th cervical vertebrae, 10th thoracic vertebrae, clavicle (Jugular Notch where the clavicles meet the sternum), sternum (Xiphoid process of the sternum), right back (in the middle of the right scapula), left and right shoulders (on the Acromio-clavicular joint), left and right upper arms (on the upper arm between the elbow and shoulder markers), left and right elbows (on lateral epicondyle approximating elbow joint axis), left and right forearms (on the lower arm between the wrist and elbow markers), left and right wrists (A: left and right wrist bar thumb side, B: left and right wrist bar pinkie side), left and right fingers (on the dorsum of the hand just below the head of the second metacarpal), pelvis (left and right ASIS: over the left and right anterior superior iliac spines, left and right PSIS: over the left and right posterior superior iliac spines), left and right knees (on the lateral epicondyle of the left and right knees), left and right thighs (over the lower lateral 1/3 surface of the thigh, just below the swing of the hand), left and right ankles (on the lateral malleolus along an imaginary line that passes through the transmalleolar axis), left and right tibial wands (over the lower 1/3 of the shank), left and right toes (over the second metatarsal head, on the mid-foot side of the equinus break between fore-foot and mid-foot), left and right heels (on the calcaneous at the same height above the plantar surface of the foot as the toe marker).

The simulation consisted of three 1000 m trials (with an average incline of 4º) using kick double pole technique. Participants skied at their own average speeds from beginning of the test to the end. Participants were instructed to ski as naturally as possible, using kick double pole technique and to adopt the ski technique that was most comfortable under the current condition. Similar models of roller skis (NORD, SkiSkett, Italy) and poles (CT1, Swix, Norway) were used by the participants.

The positions of the anatomical markers were continuously sampled using a motion capture system (200 Hz) with eight MX T10-S cameras (Vicon Motion Systems Ltd, UK) placed around the treadmill in order to locate the markers whatever their positions. At the beginning of the test, calibration measurements were taken for the reconstruction of the 3D coordinates of the anatomical markers.

Data treatment

Three-dimensional reconstruction of the coordinates of the markers was obtained, digitized and modeled with the Vicon Nexus software (Nexus 1.8.4, Vicon, Oxford, UK) with an error of about 1 mm in each dimension. Marker trajectory data were filtered using a Woltring quantic spline filter with a predicted mean square of 20 mm (Woltring, 1986).

Statistical analysis was performed by separating the variables into 3 separate groups: a) periods of time b) distance data c) joint angles. Wilcoxon paired two-sample test was used to determine whether there was a significant difference in the variables, and the level of significance was determined as $P < 0.05$.

Results

Time characteristics

All time variables and differences are shown in Table 1 and 2. Left foot push cycle time and poling time was greater than right foot push. Especially, poling time is the main focus of this study and it was significantly different between first 5 cycles (right leg stroke and left leg stroke, 1,35 ± 0,14 and 1,35 ± 0,13 sec) and first and last cycles during left leg stroke (1,37 ± 0,14 and 1,36 ± 0,12 sec).

Distance characteristics

All distance variables and differences are shown in Table 3 and 4. Significant differences were found at all other distances except the right shoulder-treadmill distance in the first cycles with the left and right leg propulsion ($P<0.05$). Differences were determined by the distance between the right foot-pole and the left foot-pole relative to the thrust foot in the initial cycles. The left foot-pole distance is longer than the right foot-pole distance (left foot-pole distance is 1.00 ± 0.17, and right foot-pole distance is 0.49 ± 0.12 m) in the first cycles with the left leg propulsion. However, in the first cycles, it was determined that the distance between the elbow and the treadmill and the distance between the shoulder and the treadmill were greater in the cycles with the left leg propulsion than the cycles with the right leg propulsion (Left leg propulsion and right leg propulsion respectively, left elbow-treadmill distance is 1.27 ± 0.05 and 1.26 ± 0,05 m; right elbow-treadmill distance is 1.28 ± 0.05 and 1.26 ± 0.04 m; left shoulder-treadmill distance 1,45 ± 0,05 and 1,44 ± 0,06 m).

Significant differences were found in the other parameters except right hand-right shoulder and right shoulder-treadmill distance in the last cycles with the left and right leg propulsion. As in the initial cycles, the right foot-pole distance in the last cycles with the right leg propulsion, the left foot-pole distance in the last cycles with the left leg propulsion is longer than the other pole and foot distances (In the last cycles of the right foot propulsion, the left foot-pole is 0.46 ± 0.10 m and the right foot-pole is 0.96 ± 0.19 m; in the last cycles of the left foot propulsion, the left foot-pole is 0.94 ± 0.17 and the right foot-pole is 0.46 ± 0,12 m). The distances in the variables determined in the last cycle of the left foot impulse were found to be longer than those of the right foot impulse.

When the start and end cycles of the same limb are compared; a more significant difference was detected in the left propulsive cycles than the right leg propulsive cycles. A significant decrease was detected at only the right foot-pole distance in the first and last cycles of the right leg propulsion (First cycles with right leg propulsion 1,02 ± 0,18 m, last cycles 0,96 ± 0,19 m). In the first and last cycles of the left foot propulsion, a significant decrease in the right hand-shoulder (0,34 ± 0,05 and 0,33 ± 0,05 m), the left foot-pole (1,00 ± 0,17 and 0,94 ± 0.17m), right foot-pole (0.49 ± 0.12 and 0.46 ± 0.12 m), right hand-treadmill (1.36 ± 0.03 and 1.35 ± 0, 04 m) have been detected.

Angle characteristics

All angle variables and differences are shown in Table 5 and 6. There was a significant difference in the hip, shoulder and trunk-treadmill joints in the first cycles of right and left leg propulsion. The hip joints on the side of the propulsive leg are larger than the hip joint on the other side (In the right leg propulsion cycles, right hip joint angle is 163,4 ± 6,9º, left hip joint angle is 148,9 ± 8,1º; in the left leg propulsion cycles, left hip joint cycle angle is 168,1 ± 5,8º, right hip joint angle is 144,9 ± 8,6º). Conversely, the shoulder joint angle at the side of the propulsive leg is smaller than at the shoulder joint angle at the other side (In the right leg propulsion cycles, right shoulder joint angle is 67,2 ± 7,2º, left shoulder joint angle is 69,4 ± 7,8; in the left leg propulsion cycles, left shoulder joint angle is 67,9 ± 8,7º, right shoulder joint angle is 68,8 ± 6,2º). In the initial cycles, the trunk-treadmill angle was greater in the left leg thrust (In left leg thrust, 60,7 ± 5,2º; and in right leg thrust, 59,8 ± 5,4º).

There was a significant difference between the hip, shoulder and left elbow joints in the last cycles. As in the initial cycles, the hip joint angles on the thrusting leg side are larger than the hip joint angles of the other side (In the right leg propulsion cycles, right hip joint angle is 167,1 ± 9,3º, left hip joint angle is 143,8 ± 8,4º; in the left leg propulsion cycles, left hip joint angle is 166,4 ± 7,6º, right hip joint angle is 143,6 ± 8,1º). Conversely, the angle of the shoulder joint at the side of the thrusting leg is smaller than at the angle of the shoulder joint at the other side (In the right leg propulsion cycles, right shoulder joint angle is 66,9 ± 8,8º, left shoulder joint angle is 70,3 ± 8,3; in the left leg propulsion cycles, left shoulder joint angle is 68,3 ± 9,8º, right shoulder joint angle is 69,4 ± 8,5º). In the end cycles, the angle of the left elbow joint was larger in the left leg propulsion (In left leg thrust, 70,4 ± 8,6º; and in right leg thrust, 68,4 ± 7,4º).

When the start and end cycles of the same limb are compared; there was no significant difference in left leg thrust cycles. In the first and last cycles of the right leg propulsion, there was a significant difference in the hips, left elbow, and trunk-treadmill sides. In the last cycles of right leg thrust compared to the beginning, the left hip, left elbow and trunk-treadmill angles were decreased (Left leg propulsion and right leg propulsion respectively, left hip joint angles were 148,9 ± 8,1º and 143,8 ± 8,4º; left elbow joint angles were 70.2 ± 8,1º and 68,4 ± 7,4º; trunk-treadmill angles were 59,8 ± 5,4 and 58,5 ± 5,4), and the right hip joint angle has increased (First and last cycles respectively, 163,4 ± 6,9º and 167,1 ± 9,3º).

Table 1. Time characteristics during XC double poling (n=10, the cycle number for each subject=60, Total cycle number for each parameters=600)

Time (second)	Right Leg First 5 cycle	Left Leg First 5 cycle	Right Leg Last 5 cycle	Left Leg Last 5 cycle
Cycle time	1,35 ± 0,14	1,35 ± 0,13	1,37 ± 0,14	1,36 ± 0,12
Poling time	0,40 ± 0,05	0,41 ± 0,05	0,40 ± 0,04	0,40 ± 0,05
Recovery time	0,95 ± 0,15	0,94 ± 0,14	0,97 ± 0,16	0,97 ± 0,14

Table 2. The P values of the time characteristics

	Right vs. Left First 5 cycle	Right vs. Left Last 5 cycle	Right vs. Right First 5-Last 5	Left vs. Left First 5-Last 5
Cycle time	0,922	0,492	0,332	0,232
Poling time	0,004*	0,846	0,77	0,037*
Recovery time	0,375	0,557	0,492	0,084

*: *P<0,05*

Table 3. Distance characteristics during XC double poling (n=10, the cycle number for each subject=60, Total cycle number for each parameters=600)

Distance (m)	Right Leg First 5 cycle	Left Leg First 5 cycle	Right Leg Last 5 cycle	Left Leg Last 5 cycle
Left hand-left shoulder	0,35 ± 0,04	0,35 ± 0,04	0,35 ± 0,04	0,36 ± 0,04
Right hand-right shoulder	0,34 ± 0,05	0,34 ± 0,05	0,33 ±0,04	0,33 ± 0,05
Left foot-pole	0,46 ± 0,10	1,00 ± 0,17	0,46 ± 0,10	0,94 ± 0,17
Right foot-pole	1,02 ± 0,18	0,49 ± 0,12	0,96 ± 0,19	0,46 ± 0,12
Left hand-treadmill	1,34 ± 0,04	1,34 ± 0,04	1,33 ± 0,05	1,32 ± 0,05
Right hand-treadmill	1,34 ± 0,03	1,36 ± 0,03	1,34 ± 0,03	1,35 ± 0,04
Left elbow-treadmill	1,26 ± 0,05	1,27 ± 0,05	1,27 ± 0,05	1,28 ± 0,05
Right elbow-treadmill	1,26 ± 0,04	1,28 ± 0,05	1,27 ± 0,05	1,27 ± 0,06
Left shoulder-treadmill	1,44 ± 0,06	1,45 ± 0,05	1,44 ± 0,05	1,45 ± 0,06
Right shoulder-treadmill	1,44 ± 0,06	1,45 ± 0,06	1,44 ± 0,06	1,45 ± 0,06

Table 4. The P values of the distance characteristics

	Right vs. Left First 5 cycle	Right vs. Left Last 5 cycle	Right vs. Right First 5-Last 5	Left vs. Left First 5-Last 5
Left hand-left shoulder	0,014*	0,037*	0,695	0,846
Right hand-right shoulder	0,049*	0,322	0,131	0,037*
Left foot-pole	0,002*	0,002*	1	0,037*
Right foot-pole	0,002*	0,002*	0,010*	0,049*
Left hand-treadmill	0,010*	0,006*	0,625	0,275
Right hand-treadmill	0,002*	0,006*	0,846	0,020*
Left elbow-treadmill	0,002*	0,010*	0,064	0,232
Right elbow-treadmill	0,049*	0,846	0,232	0,557
Left shoulder-treadmill	0,004*	0,027*	0,922	1
Right shoulder-treadmill	0,064	0,432	0,625	0,557

*: *P<0,05*

Table 5. Angle characteristics during XC double poling (n=10, the cycle number for each subject=60, Total cycle number for each parameters=600)

Angle (Degree)	Right Leg First 5 cycle	Left Leg First 5 cycle	Right Leg Last 5 cycle	Left Leg Last 5 cycle
Left hip	148,9 ± 8,1	168,1 ± 5,8	143,8 ± 8,4	166,4 ± 7,6
Right hip	163,4 ± 6,9	144,9 ± 8,6	167,1 ± 9,3	143,6 ± 8,1
Left shoulder	69,4 ± 7,8	67,9 ± 8,7	70,3 ± 8,3	68,3 ± 9,8
Right shoulder	67,2 ± 7,2	68,8 ± 6,2	66,9 ± 8,8	69,4 ± 8,5
Left elbow	70,2 ± 8,1	71,3 ± 8,6	68,4 ± 7,4	70,4 ± 8,6
Right elbow	68,7 ± 13,9	69,5 ± 13,6	67,2 ± 13,6	68,1 ± 13,7
Left knee	139,4 ± 6,2	143,1 ± 8,5	140,0 ± 6,2	142,6 ± 7,9
Right knee	140,9 ± 7,0	138,9 ± 8,7	136,1 ± 10,8	131,9 ± 18,5
Trunk-treadmill	59,8 ± 5,4	60,7 ± 5,2	58,5 ± 5,4	59,2 ± 6,1

Table 6. The P values of the angle characteristics

Angle (Degree)	Right vs. Left First 5 cycle	Right vs. Left Last 5 cycle	Right vs. Right First 5-Last 5	Left vs. Left First 5-Last 5
Left hip	0,002*	0,002*	0,002*	0,232
Right hip	0,002*	0,002*	0,049*	0,232
Left shoulder	0,014*	0,020*	0,375	0,625
Right shoulder	0,004*	0,004*	0,846	0,77
Left elbow	0,084	0,049*	0,027*	0,275
Right elbow	0,16	0,232	0,131	0,084
Left knee	0,064	0,322	0,625	0,557
Right knee	0,432	0,557	0,557	0,922
Trunk-treadmill	0,0,27*	0,375	0,037*	0,084

*: *P<0,05*

Discussion and Conclusion

The purpose of this study is to examine the effect of fatigue due to uphill on the kick double pole technique. The kick double pole in skiers is the most complicated technique especially applied in classical style technique. But it is important to use that in technical transitions and acceleration. Transitions in the classical technique are mostly made by kick double poles. The more this technique is, the better the speed transfer will be. In a competition, the result can be determined in milliseconds. It is also extremely important in terms of not losing time between techniques and making it accelerate gradually. In this study, phase durations, joint angles, and distances of the subjects in the kick double pole technique were examined in the beginning and ending cycles (as the right and the left leg propulsion cycles). When the start and end cycles were compared, there was a significant decrease related to fatigue between the hip, shoulder, elbow joints and trunk-treadmill angles. This difference in angles brought about changes in the distance between the right and left leg thrust cycles as well as the starting and ending distances. This also affected the cycle characteristics.

A significant decrease in fatigue between the hip, shoulder, elbow joints and trunk-treadmill angles was determined when the initial and final cycles were compared. The most significant decrease in the beginning and end of the right leg propulsion cycles was observed at the left hip joint angle (First and last cycles respectively, 148,9 ± 8,1º and 143,8 ± 8,4º, %3). However, a 2% decrease in the angle of the left elbow joint and a 1% decrease in the body-treadmill angle were determined (Respectively, 70,2 ± 8,1º and 68,4 ± 7,4º; 59,8 ± 5,4º and 58,5 ± 5,4º). As mentioned by Holmberg et al. (2005), the analysis of angle patterns showed that skiers before the beginning of the poling phase used a strong extension of the hip and knee followed by flexion of hip, knee, and ankle during the entire poling phase. Conversely, the poling phase began by a slight flexion of the elbow in the sagittal plan followed by a considerable extension. This flexion–extension alternation reflects the use of the stretch–shortening cycles which constitute an advantageous movement pattern for the triceps brachii muscle driving elbow extension (Smith et al., 1996). Despite the absence of modifications of angular patterns between the first and the last bouts, fatigue significantly modified some angle values. As shown by Holmberg et al. (2005) during double poling, the entire body works as a chain of segments and muscles that are engaged in sequential order starting with trunk and hip flexors, followed by shoulder extensors and the elbow extensor triceps brachii. The alteration of angle patterns of one segment or articulation could induce a series of adaptations for all the other segments. It is thought that this decrease in joint angles may be caused by fatigue. However, if this technique is thought to be better applied by high-level athletes; it can be said that the athletes in this age group are more challenged when applying this technique.

As a result, significant differences in time, angle and distance characteristics were determined depending on the fatigue of the subjects in the study in which biomechanical differences were investigated in relation to fatigue in the climbing of kick double pole technique in young XC skiers. While there have been a lot of studies about biomechanical analysis of elite athlete's technique in the literature (Zory et al., 2006; Zory et al., 2009; Mikkola et al., 2013; Stöggl et al., 2007; Stöggl et al., 2008; Göpfert et al., 2013; Holmberg et al., 2005) not enough research has been found on young athletes. Therefore, these findings are important for practitioners. Also, if biomechanical analyses are performed by elite athletes using the kick double pole technique; the difference between the technical pattern applied by young athletes and elite athletes; will set the course for young athletes to achieve the optimal technique.

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Conflicts of Interest

The authors have no conflicts of interest to acknowledge.

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