FATIGUE AND THE DIAGONAL STRIDE IN CROSS-COUNTRY SKIING

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Within the last decade, cross-country skiing has distinguished itself as a popular recreational pastime, method of aerobic conditioning and lifetime sport. The increased participation of individuals of all ages at a variety of skill levels, has generated interest in cross-country technique. However, a review of the literature reveals a limited amount of cross-country ski technique research, the majority of which was conducted with highly skilled male and female cross-country ski racers. Since the findings and conclusions reported from these studies cannot be assumed to be applicable to a less skilled, high school age skier, there existed a need for a study of this age group. Thus, this research was designed to determine the effects of fatigue on the biomechanical characteristics of the diagonal stride technique demonstrated by male, high school age skiers.

Learning to ski in an effective and skillful manner allows the skier to move at an increased velocity while using energy more productively. This fact becomes of great importance if the individual is involved with racing, either as a citizen racer or a high-school-team participant. Covering the race distance at a consistent pace with effective force production and conservation of energy will allow the skier to finish the race faster and less fatigued. Achieving an efficient skiing movement is dependent on the effective execution of cross-country ski technique.

Of the various cross-country ski techniques, the diagonal stride was selected for study since it is a common technique used repeatedly by skiers of all skill levels. Three aspects of the diagonal stride which are critical to maintaining efficient stride performance are the stride length, stride rate and the horizontal velocity achieved by the skier. A skier's velocity can be improved by increasing the stride length, stride rate, or both simultaneously (Dillman in Evans, 1980; Taylor, 1979). The major factor causing velocity differences between individuals is the length of the stride (Dillman, India & Martin, 1979; Haberli, 1977; Marino, Titley & Gervais, 1980). Lengthening the stride to achieve greater distance per stride is directly related to the energy generated during the kick phase (Haberli, 1977; Taylor, 1979). Better skiers create a greater thrust impulse in a shorter duration of time (Dillman, 1978; Ekstrom, 1979; Soliman, 1977; Waser, 1976). Comparisons of skilled and average skiers have shown that stride rate is responsible for only a small part of the velocity differences between the two groups. Covering more distance per stroke has a greater effect on the skier's velocity (Dillman, India & Martin, 1979).

Stride lengths varying from 1.88 meters to 2.83 meters were reported for elite male skiers by Waser (1976). Slightly shorter diagonal strides ranged from 1.74 meters to 2.29 meters for the highly skilled female cross-country ski racers filmed by Marino et al. (1979). Stride rates measured by Waser (1976) ranged from 91/minute to 135/minute for the male, highly skilled skiers. The horizontal velocities reported for a group of highly skilled men varied from 3.98 to 5.18 meters/second (Waser, 1976), while values from 3.31 to 4.28 meters/second were recorded for highly skilled women skiers by Marino et al. (1980).

Although stride length, stride rate and horizontal velocity are considered to be important components of the diagonal stride, they are not the only factors which may affect the striding technique. The amount of time a skier takes to complete the entire stride, as well as time in each of the phases of the stride, also reflects the efficiency of the skier. As noted, better skiers have a shorter kick time and are able to produce more force in a shorter amount of time than is a less-skilled skier (Dillman, 1978; Ekstrom, 1979; Soliman, 1977; Waser, 1976). The average kick time recorded for women by Marino et al. (1980) was 50.2 percent of the total time taken to complete the stride. Following the kick, the skier moves immediately into a glide on the opposite ski. Nigg and Waser (in Marino et al., 1980) found the glide phase to be longer (27 percent of the total stride) for the excellent and good skiers than for the less-skilled skiers. A considerably smaller mean glide time of 17.2 percent of the total stride time was recorded by Marino et al. (1980) for female subjects. From the glide phase, the skier moves to the pole planting portion of the stride which serves not only to provide balance for the less-skilled skier, but is a method of force production when performed correctly. Nigg and Waser (in Dillman, 1978) state that excellent cross-country skiers have the shortest pole planting phase.

The position of a skier's body is important in obtaining maximum efficiency. Investigators have emphasized several body angles in each of the phases which affect stride performance. During the kick phase, Fisher and Dillman (1980) state that the trunk should be slightly flexed so that a 45 degree angle to the horizontal is formed. At the same time there should be an open angle behind the knee and a flexed shin angle of less than 90 degrees. Such a body position places the center of gravity well over the toes so that an efficient kick will propel the skier forward down the track. Soliman (1977) reports lower leg angles varying from 58 to 70 degrees for the kick, while Waser (1976) places the optimum angle at 53 degrees. Following the kick, the skier moves into a balanced body position with the body weight on the opposite ski. Soliman (1977) reports that the mean center of gravity is raised during the glide by increasing the gliding leg's mean angle. Fisher and Dillman (1980) state that when gliding, all of the body's weight should be carried slightly behind the ball of the gliding foot. The shin should be in a more vertical position than where it was for the kicking phase. The gliding phase comes to an end as the skier plants the ski pole. Martin (1980) suggests that the pole be inserted into the snow close to the toe of the forward foot and the body's center of gravity angle, lower leg and trunk angles be kept fairly low.

Due to the scarcity of research using younger subjects, little is known about the young skier's technique as they begin to become fatigued. Research completed with highly skilled, or elite, skiers has suggested that the diagonal stride technique is affected by fatigue and possibly conditioning (Waser, 1976).

The diagonal stride technique of the top finishing world class skiers filmed by Waser (1976) on a 15 km course, experienced approximately equal amounts of shortening the stride length and decreasing the stride rate. In a comparison group of less-skilled skiers, loss of speed was caused by a shortening of the stride length. A similar shortening of stride length occurred during a 30 km race filmed by Shaposhnikova and Bozheninov (1973). In this race, the top skier's stride length decreased from 1.89 to 1.73 meters on a medium ascent course between the 22 and 28 km points. Even though the stride length decreased, the stride rate was increased, resulting in a maintenance of speed. The top ten skiers experienced a lower variability of average speed and relative speed changes, while the bottom ten skiers had a greater average speed variation and larger speed changes for the three 10 km loops of the race.

METHODS

The subjects filmed for this study were 21 male, high school, varsity, cross-country ski racers ranging in age from 15 to 18 years ($\bar{X}$ = 16.5 yrs.). Each skier had participated in approximately the same number of ski meets prior to the filming due to restriction by the Minnesota State High School League. Previous on snow practice, controlled by snowfall, was approximately the same for each skier.

The filmed race consisted of skiing a 5 km loop course two times. Each subject was filmed twice while performing the diagonal stride on a 30 foot section of the race course which had approximately a 5 percent grade. The filming of each subject occurred near the 4.4 and 9.4 km mark. The camera was placed 13.86 meters from the set ski track at a right angle to it. The skiers about to enter the filming sector were clearly visible to the investigator which allowed sufficient time in which to start the camera so that it reached the proper filming speed before the skiers were actually skiing in the film plane.

Data were collected by filming the subjects at 100 frames per second with a 16 mm Photosonic 1-PL high speed camera utilizing an Elgeet 13 mm f: 1.5 wide angle lens. Kodak RAR Estar-AH base 2498 film was used for this project. Additional film was kept nearby in an insulated cooler to protect the film from the 10 degree snow and air temperature. In an attempt to control the camera and film temperature, a hood from a down jacket was placed over the camera and film magazine. The lens was not covered. When necessary, changing of the film magazine was done as quickly as possible. A one-meter distance reference pole was placed in the filming sector five inches in front of the ski track. To prevent the pole in the foreground from sinking into the snow, the ends of the pole were set on two cardboard boxes and levelled with the ski track. The pole was filmed initially in both a horizontal and vertical position directly above the ski track to provide a reference distance in the film plane.

The procedure of digitizing at 33 frames per second throughout one complete diagonal stride from both rounds of the race was used to quantify 21 selected body and equipment points. The film was projected by a Lafayette Analyzer and points recorded by a Numonics 224 digitizer interfaced with a Hewlett-Packard 2647A Graphics Terminal. The recorded data were then transferred to a Cyber 174 computer for further analysis by a Fortran IV computer program written to calculate angular velocity and position, horizontal, vertical and resultant velocities, as well as the positions of the centers of gravity of each segment. From the information provided by the computer program, the skier's average stride length, stride rate and horizontal velocity was calculated. One tail dependent t tests were used to compare stride length, stride rate and horizontal velocity for the two rounds of the race. Correlation coefficients were calculated to determine the strength of the relationship between stride length and horizontal velocity, stride length and stride rate, and stride rate and horizontal velocity.

RESULTS

The descriptive data found in Table 1 for the stride lengths, stride rates and horizontal velocities for both rounds of the race included calculating means, standard deviations and t tests. The diagonal stride technique demonstrated by the high school skiers in this study revealed that they had shorter stride lengths, comparable stride rates and considerably less horizontal velocity than either highly skilled male or female cross-country ski racers. No significant differences were found to exist between the values recorded for the stride lengths, stride rates or horizontal velocities used on the two loops of the race.

Table 1

Means, Standard Deviations and T Test Coefficients for the Diagonal Stride Characteristics

	Round One		Round Two		Round One vs.
	Mean	St. Dev.	Mean	St. Dev.	Round Two
Stride Length, m	.78	.18	.82	.19	-.80
Stride Rate, strides/min.	116	16.2	108.5	15.3	1.62
Horizontal Velocity, m/sec.	1.48	.31	1.45	.25	.32

Significance needed at .05 level = 1.729, one tail, df = 19.

Measurement of the stride length, stride rate and horizontal velocities of the skiers for both rounds of the race allows for further analysis to be done. Coaches as well as skiers are interested in the relationship between stride length, stride rate and horizontal velocity in addition to the contribution of the stride length and rate to the total stride. Correlation coefficients reported in Table 2 reveal that on the first loop of the race, those skiers with the longest stride lengths tended to possess a greater horizontal velocity than those skiers with shorter stride lengths. The results also indicate that as a skier lengthens the stride, the stride rate decreases. Very low correlation coefficients were found for both rounds when the stride rates of the 21 skiers were correlated with horizontal velocity.

Table 2

Correlation Coefficients for Stride Length, Stride Rate and Horizontal Velocity Relationships for Round One and Round Two

	Round One		Round Two	
	Stride Rate	Horizontal Velocity	Stride Rate	Horizontal Velocity
Stride Length	-.53	.83	-.63	.55
Stride Rate		.02		.06

A skier's ability and efficiency has been shown to affect the amount of time used to complete the stride phases. The percent of the total stride time each phase required was substantially different for the high school age skier than found with highly skilled individuals. As shown in Table 3, a right leg kick comprised 16 percent of the total stride for both rounds of the race. The glide phase following the right leg kick was a considerably smaller 8 percent of the total stride for round one and round two of the race. These percentages were calculated from the length of time each phase lasted. The time it took to execute a right leg kick was significantly different ($t_d = -1.759$, significance needed at .05 level = 1.729, df = 19) between the two loops of the race as shown by a one tail dependent t test.

Table 3

Phase Percentages for the Right Stride Time

	Round One	Round Two
Kick	16	16
Glide	8	8
Pole	24	24

The young racers in this study exhibited body angles similar to those seen in the diagonal stride technique of highly skilled skiers. During the kick phase, the trunk position had a greater forward lean of 36 and 35 degrees for the two loops of the race. Just prior to the right leg kick, the lower leg was at 52 and 57 degrees for the two rounds, well within the range of angles reported by Soliman (1977) and Waser (1976). As the skier moved into the glide phase, the shin shifted to a more vertical position on both rounds. This action resulted in raising the body's center of gravity (Soliman, 1977).

Table 4

Mean Body Angles, Degrees

	Round One	Round Two
	Kick Phase	
Trunk	36	35
Right Lower Leg	52	57
Right Ankle	79	84
	Glide Phase	
Angle Between Legs	67	60
	Pole Phase	
Angle Between Legs	65	58

Two of the angles measured appeared to have been affected by fatigue. The angle of the right ankle and the angle measured between the legs on round one were significantly different from the same angles measured for the second round. The right ankle assumed a more vertical position immediately before the right leg kick during the second loop. This increased angle puts the body in a less-effective position to apply force and may result in a bobbing action of the body. During the glide and pole plant phases, the angle between the legs decreased significantly from round one to round two. This decrease was due to the kicking leg not being as extended as far back on round two as it had been carried on the first loop. It is reasonable to consider that fatigue may have caused the changes measured in these body angles between the two loops of the race.

DISCUSSION

The purpose of this study was to determine the changes in technique occurring between the two loops of a 10 km ski race. Analysis of high speed film of 21 high school male cross-country ski racers provided information concerning the technique found at this level. By contrasting the findings of this study with other research conducted with highly skilled men and women ski racers, it is possible to place the groups of skiers researched on a continuum. The technique exhibited by the highly skilled male skiers places them first, with the highly skilled female skiers close behind. The technique demonstrated by the skiers in this study, places the group below both of the highly skilled groups. The racers in this study had shorter stride lengths, comparable stride rates and considerably less horizontal velocity than either of the highly skilled groups.

Examining the data for similarities resulted in the appearance of several trends. The three groups displayed a like relationship between stride length and horizontal velocity, which suggests that the skiers with the greatest stride lengths possess greater horizontal velocities than the skiers with shorter stride lengths. The low correlation coefficients resulting from comparing stride rate with horizontal velocity for the high school skiers were much the same as those found for the highly skilled skiers. A third analysis, which correlated stride length with stride rate, followed the pattern of longer stride lengths being associated with lower stride rates found with highly skilled skiers.

Contrasting the findings of this study with research using highly skilled skiers, resulted in discovering differences as well as similarities. The younger, less-skilled skiers used more time to complete a kick, but less time to glide. The poling phase was also shorter for this group. Just prior to the kick, the upper body moved into a position with greater forward lean than observed with the highly skilled skiers.

Determining the differences in technique occurring between the two loops of the race revealed few changes. The only significant differences identified between the two loops of the race were the angle of the right ankle and the angle between the legs. The ankle angle increased, moving the lower leg into a more vertical position. This position is less-effective in applying force in the kicking action. The decreased angle between the legs resulted from the kicking leg not being carried back as far following the kick and throughout the glide. Both of these changes may have been due to fatigue.

Based on the findings of this study, several recommendations concerning the diagonal stride technique of high school male skiers may be made. In comparison to other research, the skiers in this study basically exhibited appropriate diagonal stride technique. The average stride length for both loops of the race for all skiers was short when compared to highly skilled racers, but may be very typical of high school age skiers. Since stride length has been shown to be an important factor to a skier's success, incorporating balance activities into the training program as well as improving leg strength, may aid in increasing the length of the glide phase. Research also indicated the importance of a short kick phase. Adopting conditioning and training methods which would develop explosive leg power would be beneficial to the ski racer. The importance of the poling phase to the entire diagonal stride has also been expressed in the literature. Strengthening the entire upper body would allow the skiers to use this portion of the stride as a propulsion phase rather than strictly for balance purposes.

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