EFFECTS OF INCREASED VELOCITY ON THE KINEMATICS OF V1 SKATING IN CROSS COUNTRY SKIING

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The "V1" or "alternate stride" skate has become the predominant skating method used in the cross country "free" technique races. The evolution of cross country skiing has developed away from the traditional techniques such as diagonal stride which require machine set tracks and toward faster skating techniques requiring only a packed surface. The techniques resemble ice skating strides in some respects and are generically labeled "skating." Several variations of skating technique are used in racing. V2 skating involves a poling thrust (both poles simultaneously) with the skating motion on each side. V1 skating involves a double poling thrust with only one side's skating action. On the alternate side, while the skating action occurs, the arms are in recovery, swinging forward in preparation for the next poling thrust. Thus V1 or alternate stride skating is an asymmetrical technique. On the "strong side," poling accompanies the skating action, while on the "weak side," only the skating leg provides propulsive force. The V2 skate tends to be used primarily on flat or slightly uphill terrain, whereas V1 skating is used across a wider range of terrain including moderately steep hills (Borowski, 1986).

The V1 skate has been widely used on the World Cup circuit since 1986 including the free technique races of the Calgary Winter Olympics, 1988. The move to skating techniques and away from traditional diagonal striding has resulted in increased race velocities of 15 to 23% (Street, McNitt-Gray & Nelson, 1986). While there have been some qualitative descriptions of skating technique (Borowski, 1986, 1987; Skard, 1986) and preliminary analysis of V1 skating kinematics (Smith, McNitt-Gray & Nelson, 1988), much remains to be studied about the continually evolving technique used by cross country ski racers. The purpose of this study was to determine the relationship of skiing speed to the basic components of the V1 skating cycle: cycle rate and length and the relative timing of the phases of the complete cycle.

Methods

In January, 1987, the U.S. Nordic Team tryouts for the World Championship races were held in Biwabik, Minnesota. Prior to the competitions, 12 national level skiers (8 females, 4 males) agreed to participate in a biomechanical study involving filming of each skier under controlled conditions. The testing situation was structured to fit the skiers' prerace training regimen with little interference. The film site, adjacent to the cross country stadium and training center at Giants Ridge, involved a 100 meter packed track of moderate uphill. The hill angle in the camera vicinity was approximately 7 degrees. This corresponds with slopes typically occurring on race courses. Two high speed cameras (Locam) were used in the filming. A side camera was oriented with optical axis perpendicular to the ski track while a front camera was positioned with axis parallel with the track. Each camera was operated at a nominal frame rate of 80 Hz. Prior to filming of the skiers, calibration poles were placed in the field of view for subsequent two dimensional scaling of distances in the image field.

The side camera view was used to determine each skier's cycle length, cycle time, and cycle phases. The front camera view was used as a secondary check on cycle times and phases. A complete V1 skating cycle was defined as beginning with pole plant of the weak side pole. Subsequent events included (in typical order) strong side pole plant, strong side ski down, weak side ski up, weak side pole release, strong side pole release, weak side ski down, strong side ski up and the succeeding weak side pole plant. Cycle length was defined as the distance between weak side basket positions at pole plant, beginning and ending of the cycle. Cycle time was the time (in seconds) from beginning to ending of the cycle (ie. pole plant to the next pole plant). Cycle rate was the reciprocal of cycle time. Cycle velocity was determined by the product of cycle length and cycle rate.

Cycle phases were initially determined in terms of the time at which the various events occurred (from beginning of cycle). Each cycle was subsequently normalized for comparison; event timing was converted to a percent of full cycle time. Phase times were then determined based on the respective beginning and ending points in the cycle; pole phases were based on the time from pole plant to pole release; ski phases were based on the time from ski down to ski up.

Each skier was filmed under three conditions. Subjects were instructed to ski at perceived exertion levels corresponding to "training pace," "marathon pace" and "5 kilometer pace." The skiers were all experienced racers and had no difficulty estimating different paces based on their perceptions of intensity. The packed track was initially almost flat, allowing the skier to get up to speed. The remaining 100 meters were of relatively constant grade (7 degrees).

The film records were analyzed in a conventional manner using projector and digitizing tablet. Coordinates were obtained for the pole plant locations; the displacement between pole plants was scaled appropriately using a conversion factor determined from the calibration poles. Events throughout a skating cycle were determined by frame number and subsequently converted to time units.

After calculation of the various kinematic variables for each subject and condition, several statistical analyses were performed to determine the relationship of skating velocity to each variable. Initially an analysis of variance was used comparing the mean values of each kinematic variable for the three conditions. In the case of significant differences between the means, follow up comparisons between means were done using the Scheffe F test. A type I error rate of .01 was used throughout the analysis.

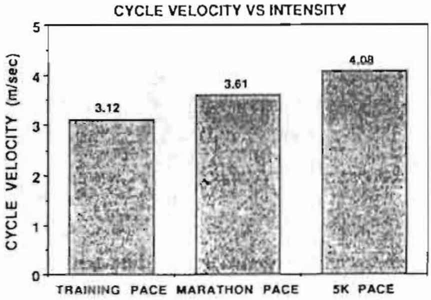
Additional follow up analyses were done looking at the results of each intensity level separately. Variables were correlated with cycle velocity to determine relationship. The error rate of .01 determined correlation significance at $r = .68$.

TABLE 1: DESCRIPTIVE STATISTICS OF THE KINEMATIC VARIABLES

MEAN (STANDARD DEVIATION) BY INTENSITY:			
	TRAINING PACE	MARATHON PACE	5 K PACE
CYCLE VELOCITY (m/sec) *	3.12 (.46)	3.61 (.55)	4.08 (.66)
CYCLE RATE (Hz) *	0.71 (.05)	0.81 (.08)	0.95 (.10)
CYCLE LENGTH (meters)	4.39 (.70)	4.49 (.84)	4.34 (.76)
WEAK POLE %	37.1 (6.0)	36.5 (6.3)	37.6 (8.6)
STRONG POLE %	40.8 (6.2)	41.2 (6.5)	40.8 (4.5)
WEAK SKI %	63.6 (4.5)	63.9 (2.9)	62.9 (6.7)
STRONG SKI %	59.9 (6.1)	58.1 (5.8)	56.1 (8.8)

* INDICATES SIGNIFICANT DIFFERENCES BETWEEN INTENSITIES ($p < .01$)

Figure 1



Results

Descriptive statistics of the kinematic variables are detailed in Table 1. The cycle velocities were found to significantly increase with the perceived intensity level (Figure 1), as one would expect. The velocities of 3 to 4 m/s were quite comparable to the 3.23 m/s (mean of 10 skiers) observed in a World Cup ski race on similar terrain. Likewise, the mean cycle rates (0.71, 0.81 and 0.95 Hz) and mean cycle lengths (4.39, 4.49 and 4.34 meters) were also similar to those observed elsewhere (Smith, McNitt-Gray and Nelson, 1988).

The mean cycle rates (Figure 2) were significantly different under the three conditions ($p < .01$). The trend was for cycle rate to increase with intensity (and velocity). However, cycle length (the other determiner of velocity) was found not to differ significantly under the intensity conditions (Figure 3). Mean cycle length was relatively constant for each intensity.

Figure 2

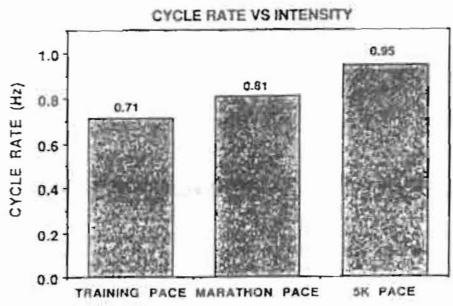
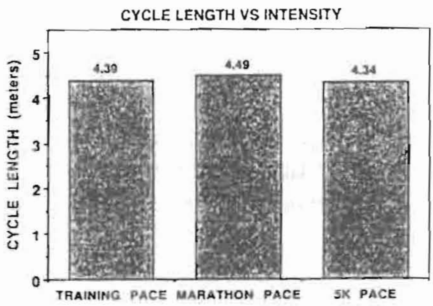


Figure 3



The cycle phases were influenced by cycle rate. As the rate increased (with intensity and velocity) and cycle time decreased, the phase times were found to decrease proportionately. However, the normalized cycle phase times (full cycle being 100%) were relatively constant across the three intensities. Thus the phase percentages were not significantly different: weak pole phase was approximately 37% of the complete cycle, for each condition; strong pole phase was approximately 41%, while weak and strong ski phases were approximately 63 and 58% respectively (Figure 4).

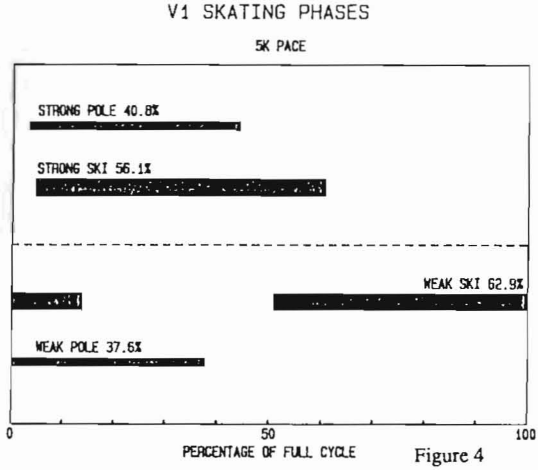


Figure 4

A further analysis of the cycle rate and length relationship to velocity was made for each intensity separately. At a given intensity, cycle length was found to correlate significantly ($p < .01$) with cycle velocity in each condition ($r = .87$, $.87$ and $.82$ respectively). The scatter plots (Figures 5 - 7) include the regression line best fitting the points. A similar correlation of cycle rate with velocity at each intensity found non-significant relationships of rate to velocity (for example $r = .10$ for training pace, Figure 8). Thus, cycle rates were relatively constant for a given intensity, while cycle lengths were found to increase with the individual velocities.

Figure 5

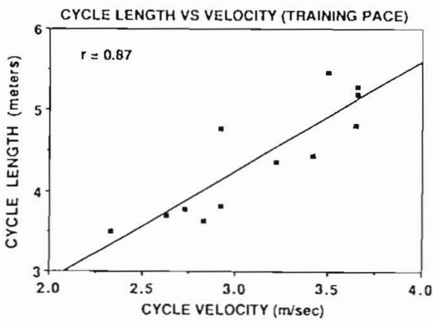


Figure 6

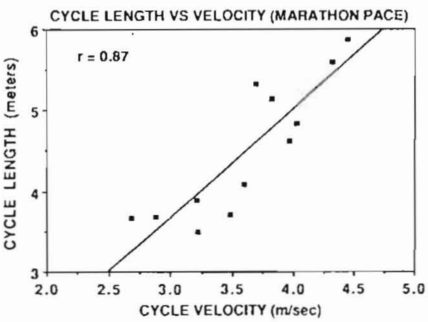


Figure 7

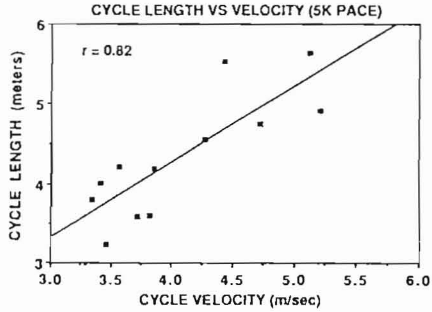
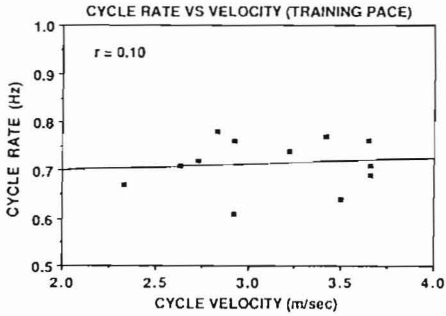


Figure 8



Finally, each skier's cycle rates (Figure 9) and cycle lengths (Figure 10) were plotted together versus cycle velocity. The clear trend individually was for cycle rate to increase as the skier went faster, while cycle length exhibited no clear individual trends as skiers increased speed.

Figure 9

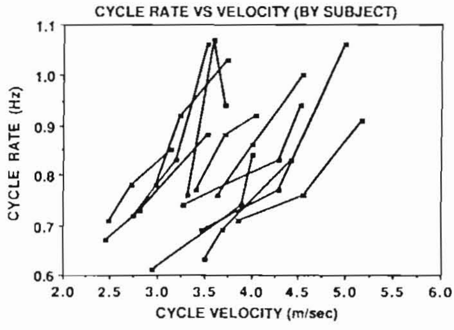
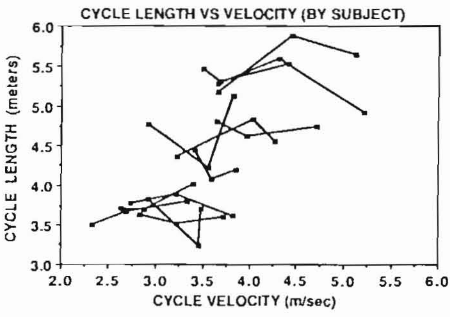


Figure 10



Discussion

The relationship of kinematic variables to velocity has been studied for other locomotions. For example, Astrand and Rodahl (1977) reported that in treadmill running of 8 to 30 km/hr a runner's stride length increased with velocity (from 80 to 220 cm) and stride frequency increased from 170 to 230 steps/min (data from Hogberg, 1952). In cross country skiing, several traditional techniques have been analyzed both during races and under controlled conditions: Soliman (1977) and Haberli (1977) each found diagonal stride length to be highly correlated with race velocity; Andres (1977) found double pole with stride technique to be more influenced by stride frequency; Martin's (1979) analysis of diagonal stride suggested that stride length be the emphasis for improving performance; and Smith (1985) found significant correlations of stride frequency with velocity for the double pole with stride and for the marathon skate techniques (mean stride lengths were relatively constant across velocities). This somewhat mixed picture of the relationship of velocity to locomotion patterns does not clearly answer one of the basic questions concerning any locomotion: What pattern changes are evident through an individual's range of velocities? This study sought to answer that question with respect to the V1 skating technique and in addition sought for distinguishing characteristics of the fastest skiers studied.

The results of this study present what at first glance appear to be conflicting relationship; analyzed across the three intensities, cycle rate clearly increased with cycle velocity, while cycle length was relatively constant across velocity. Analyzed by intensity level separately, cycle length was directly related to cycle velocity (at a given intensity) while cycle rate was relatively constant. Figures 9 and 10 can lead to an interpretation which reconciles the apparent discrepancy: the plot of each subject's cycle rate versus velocity exhibits a clear trend of increasing rate with velocity. However the skiers were spread across a range of velocities 2 to 3 times any individual's range. Furthermore, the individual cycle rate ranges were relatively similar, subject to subject. At a given intensity, the slower and faster skiers all had similar cycle rates. The plot of each subject's cycle length versus velocity (Figure 10) exhibits the lack of a clear trend (ie. relative constancy) of an individual's cycle length with velocity increases. However, the faster skiers of the sample tended to skate with longer cycle lengths. This resulted in the significant correlation of cycle length with velocity at a given intensity.

For any individual skier the pattern appears to be the following: velocity increases are primarily accomplished through cycle rate increases while maintaining relatively constant cycle lengths. The cycle phases are also relatively constant in proportion through a range of velocities. At a given intensity, the fastest skiers exhibited the greatest cycle lengths.

The implications for any individual skier are the following: at some point in time and training (for example, within a particular race), velocity increases are accomplished primarily by increasing the cycle rate (the "tempo" of skating). This should be the immediate focus of concentration. However, long term training attention should focus upon increasing one's normal cycle length. It is clear that faster skiers skate with longer cycle lengths. What is not so clear is the choice of training routine to accomplish this goal.

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