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Cinematographical Analysis of Selected Parameters of the Diagonal Cross Country Ski Stride on Uphill Terrain

by

(C) Craig Curtis Johnny Wronko

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Cinematographical Analysis of Selected Parameters of the Diagonal Cross Country Ski Stride on Uphill Terrain submitted by Craig Curtis Johnny Wronko in partial fulfillment of the requirement for the degree of Master of Science.

Wendy Bedingfield

Supervisor

H. A. Scott

Douglas Kerr

Date August 20, 1982

DEDICATION

For my parents, John and Betty-
For so many things.
My love, deep respect and thanks.

"Anyone who has had a bull by the tail," observed Mark Twain, "knows five or six things more than someone who hasn't."

ABSTRACT

The purpose of this study was to conduct a temporal and kinematic analysis of the segmental movement patterns in elite cross country skiers and thus identify variables which significantly contribute to the production and maintenance of horizontal velocity of the center of mass during the uphill diagonal ski stride. Panned cine analysis was conducted using 27 (15 male, 12 female) elite cross country ski racers at the 1981 Cyprus-Anvil World Cup in Whitehorse, Yukon, Canada. One 16 mm pin registered Photo Sonic 1 PL camera was used for the acquisition of cinematographic data. A Lafayette pin registered film analyzer, Bendix digitizing board, and a Hewlett Packard 9825 B micro computer were utilized for analysis. The raw data were smoothed using a Butterworth second-order low pass filter (Walton, 1981). The data were treated statistically by the coefficient of determination (McNemar, 1962) to analyze and compare mechanical parameters that affect performance. The results of the study reflected a relationship between selected parameters (Trunk, Hip, Knee and Ankle angles) and the relative horizontal velocity of the center of mass.

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CHAPTER I

INTRODUCTION

Cross country skiing is a rapidly growing sport in Europe and North America both as a form of recreation and as spirited competition. With the increase in popularity in cross country skiing there has been a parallel increase in the demand for a greater understanding of the biomechanical and physiological components that are inherent to the sport. In recent years biomechanists have been utilizing mechanical principles in order to evaluate human movement. The purpose of biomechanical research of movement is to describe, analyze and assess the performance of a subject during the execution of a skill. As a result of such research, scientists move toward an understanding enabling optimization of the efficiency of human movement.

A common technique used for quantification of human movement has been cinematographical analysis. The film data collected is of two dimensional spatial coordinates to provide raw data in the analysis of the body segment parameters. The kinematic data is then treated statistically and conclusions are derived relative to mechanical principles.

Cross country skiing incorporates a variety of techniques which are relative to the terrain skied. The ski technique can be placed into three categories 1) diagonal stride; most commonly used technique for flat terrain as well as inclines, 2) double poling; the technique used on level terrain or slight downgrades with the option of incorporating the one step phase or skating step, and 3) downhill running.

In a time interval study conducted by Rusko and Kantola (1970), the researchers concluded "that victory seemed to take place on uphill terrain." This hypothesis was researched by Martin et al. (1980). The time interval analysis showed that the percent of total time spent on a 15 kilometer race course was 23.1% for variable terrain and 45.8% for uphill terrain. The correlation between the total race time and the time intervals for uphill and variable terrain was r=.98. The relationships of Martin et al. (1980) indicated the uphill sections of a race course discriminated the most in terms of total race performance.

The present study employed the coefficient of determination statistic (McNemar, 1962) to determine the relationship between the mechanics of technique and performance criteria of the uphill diagonal cross country ski stride.

Marino (1975) discussed that the use of statistics limits itself to probablities and therefore becomes less precise than establishing a deterministic model for human movement. However, Marino (1975) states the use of statistics requires no simplification of the body into a linkage system, but rather allows direct analysis of mechanical parameters as they actually occur in the planes of movement.

The performance criterion of cross country skiing from a mechanical perspective is the achievement and maintenance of maximum horizontal velocity of the center of mass. Therefore, questions arise concerning the extent to which variables have a relationship with the attainment of the highest and/or most efficient horizontal velocity of the center of mass. With temporal and kinematic analysis, the data collected will try to resolve the questions put forth.

Statement of the Problem

The purpose of this study was to conduct a kinematic and temporal analysis of the segmental movement patterns in elite cross country skiers and thus identify variables which significantly contribute to the production and maintenance of horizontal velocity of the center of mass during the uphill diagonal ski stride.

Limitations

The following are limitations of this study.

a) The mechanical variables selected that influence horizontal velocity of the center of mass may have been affected by other parameters such as anthropometrical measures, waxes used by the subjects, friction of the snow at the time of filming and slope angle.

b) A major assumption of this study is that technique was the aspect that affected performance and the physiological condition of the subjects was assumed to be equal for each performer at the film site and therefore was disregarded.

c) The data collected were analyzed for one uphill section only. A race course varies in length and gradients of slope.

d) Cinematographical analysis has inherent errors associated with data collection. This primarily concerns itself with dimensional, perspective and human error associated with the analysis.

e) Experimental control of sport skills is difficult. Between subject and within subject variations are often due to uncontrolled sources of variance rather than to the variable being manipulated. Segmental analysis has been used as a descriptive technique rather than as a method of experimentation.

g) The proximal and distal segmental endpoints are at times difficult to locate. The ability for accurate approximation of the center of mass was limited to the Humanscale Anatomical Data (Diffrient, 1979).

h) Data smoothing reduced random error introduced by the measurement process during the collection of raw data.

Delimitations

a) Evaluation of the system was restricted to one field study on the single sport skill.

b) The investigation has been delimited to data collected through cinematography, therefore, it is a kinematic analysis of the movement only.

c) The sample size is small and a larger sample may be more indicative of the relationship of selected variables to the criterion variable.

d) The measurement of parameters listed under "Methodology" delimit the study.

e) A sampling frequency of 20 Hz was chosen for the analysis of the film depicting the diagonal ski stride on uphill terrain.

f) The data analyzed were derived from the sagittal plane of movement.

Definition of Terms

The major terms employed in ths study were defined as follows:

Legs Together is the body position when the thighs and legs of the skier are parallel to one another.

Toe Off is the body position at the point of the last contact between the ski at the toe and the ground (Martin, 1979).

Pole In is the body position at the point of the first contact between the ski pole and the ground (Martin, 1979).

A Stride is defined as beginning at a position of legs together and continuing until the next position of legs together (Martin, 1979).

Kick Action is that portion of the stride which begins at a position of legs together and ends at the position of toe off. (Figure 1).

Stride Length is the displacement of the body center of mass parallel to the skiing plane from a position of legs together to the next position of legs together (Martin, 1979).

Foot Stop is the body position when the recovery leg ends its movement and becomes stationary.

Stride Rate is the number of strides completed in one second and is defined as the inverse of the time for a single stride (Martin, 1979).

Stride Velocity is the average velocity of the body center of mass parallel to the skiing plane for one stride.

Angular Velocity is the rate of relative angular displacements about the hip, knee and ankle joints.

Noise is the term used to describe components of the final signal that are not due to the process itself (Winter, 1979).

Force Production Phase is the duration of time where the subject moves the body in the direction of the desired motion. Thus, the skier begins to apply forces which propel the skier forward either by the use of kick action or pole implantation. (Figure 1).

Glide Phase is the duration of time where the kicking leg and poles are not in contact with the ground.

Recovery Phase is the duration of time where the subject continue the motion after force production (toe off) and the return of the limb to legs together. (Figure 1).

Center of Mass is the equilibrium point of a supported body when all its weight is concentrated.

Free Body Diagram is an isolated portion of a structure used during free body analysis for the purpose of studying the effect of forces acting on the free body.

Kinematics is the branch of mechanics that deals with motion of a body without reference to force or mass.

Saggital Plane is the median plane of the body or any plane parallel thereto.

Horizontal Velocity is the displacement of the center of mass divided by time over which displacement occurs in the horizontal direction.

Absolute Angles (α, β, γ and ϕ) are the angles formed by two segments about the trunk, hip, knee and ankle.

Trunk Angle (α) is the angle formed by the trunk (acromian process of the scapula and greater trochanter of the femur) and the right horizontal. (Figure 2).

Hip Angle (β) is the angle formed by the thigh (the greater trochanter of the femur and the femoral-tibial articulation of the knee) and the right horizontal. (Figure 2).

Knee Angle (γ) is the angle formed by the thigh and leg (femoral-tibial articulation and lateral maleolus of the fibula). (Figure 2).

Ankle Angle (ϕ) is the angle formed by the femoral-tibial articulation of the knee, the lateral maleolus of the fibila, and the toe of the ski shoe. (Figure 2).

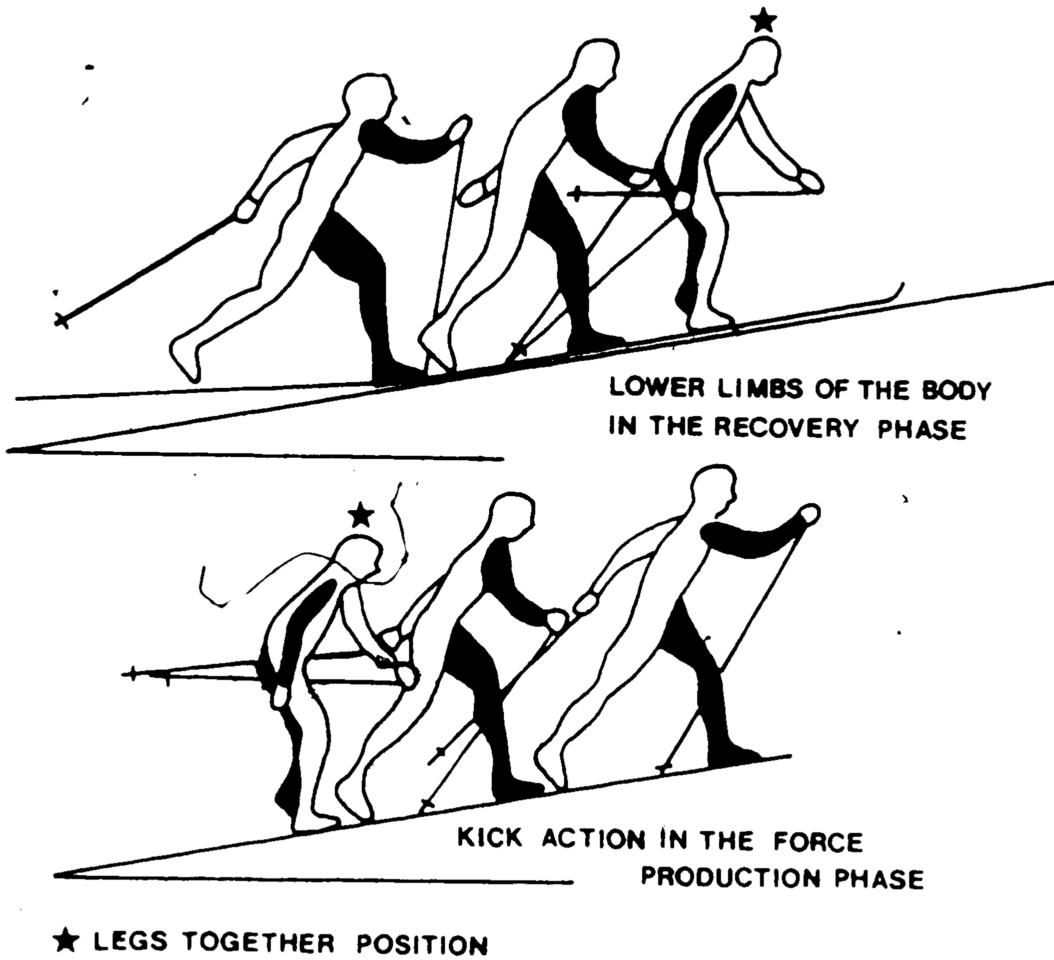

Figure 1. Illustration of the phases in the mechanism of propulsion in cross country skiing.

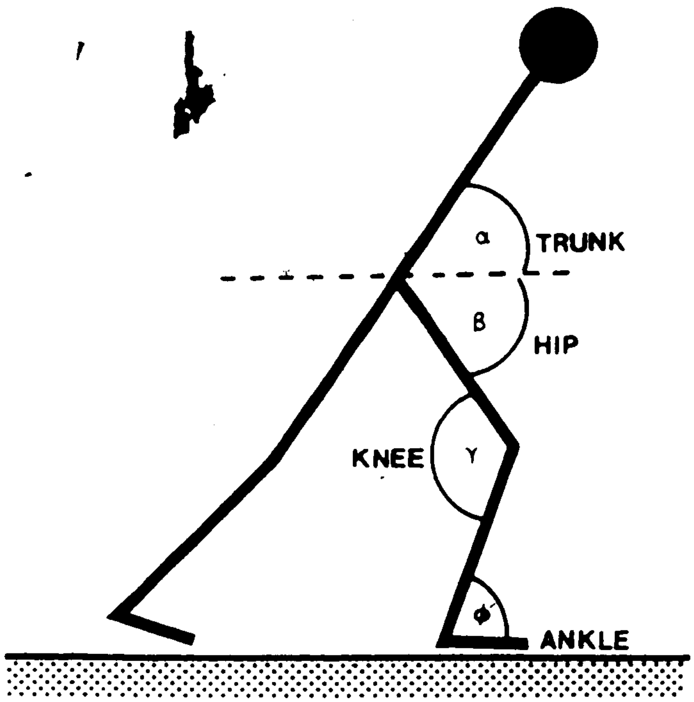

Figure 2. Free body diagram of the body segment angles.

CHAPTER II

REVIEW OF LITERATURE

In the past few years there have been more biomechanical investigations in cross country skiing than the total of all ski research combined in the fifteen years preceeding this increased interest. During this short time cross country skiing has developed changes in movement patterns and posture as a result of increased technology in the development of the racing ski. The performance of the skill must be executed with the least expenditure of energy and strength to perform at a standard of excellence (Maier and Reiter, 1980).

The technique used by competitors to ski inclines and flat terrain is the diagonal ski stride. This is performed when the skier's forward movement is obtained through leaning slightly forward with the upper part of the body and extending the pushing leg at the hip, knee and ankle joints (Ekstrom, 1980). Once extension of the pushing leg is complete, the recovery of the leg and opposite ski pole is applied for propulsion.

Temporal Analysis

Dillman (1978) stated the initial step in any biomechanical analysis is to formulate the objective of the activity into mechanical terms. The performance objective of cross country skiing from a mechanical point of view is the development and maintenance of velocity.

VELOCITY = STRIDE LENGTH (SL) x STRIDE RATE (SR)

The next step in a biomechanical investigation is to determine selected motion or force aspects of the skill which have a direct influence upon the objective of the activity (Dillman, 1978).

Dillman (1981) observed a high correlation (r=.81 significant at the .05 level) between stride length and velocity of the skier. There was no significant correlation between stride rate and velocity (r=-.02). When Dillman correlated stride length and stride rate there was a slight inverse relationship (r=-.60).

Waser (1976) analyzed various performance parameters associated with the diagonal ski stride on flat terrain. The subjects in his study were elite international skiers competing in a World Cup ski race. Waser found that the velocity of the center of mass was greatest at the end of the kick action during the force production phase. He also demonstrated that the elite skiers spent less time in the force production phase of the ski stride than the less skilled competitor. Soliman (1977) also investigated the diagonal stride on flat terrain and achieved the same results as Waser.

Dillman et al (1978) conducted an analysis of the diagonal stride and found that stride length was more important that stride rate in discerning the differences in technique between the two groups. Dillman implied that the greatest difference in stride length occurred during pole implantation and not during action of the force production phase.

Kinematic Analysis

Novosad (1975) researched the segmental angles formed by the body during the individual phases of the diagonal stride. He found there was little difference in the comparison of angular measurements of the body between the top ten and the last ten finishers in an international ski competition. However, there were large differences between the skilled and the lesser skilled groups for certain parameters. Novosad found that the ankle angle and the trunk angle were nearly identical in the legs together stance during the kick action of the force production phase. The trunk angle (1.01 radians) was slightly less than the ankle angle (1.15 radians).

Martin (1979) studied the diagonal ski stride on uphill terrain using multiple regression analysis as a model for performance. He found that only the velocity of the trailing foot and ankle angle at legs together were significant predictors of the distance covered during the kick action in the force production phase. Martin (1979) states that the velocity of the trailing foot appeared to have a slightly greater influence on the distance covered during the kick action than did the angle of the lower leg. He also stated that the ankle angle at legs together was the only significant predictor of time of the kick action during the force production phase.

Soliman (1977) identified optimal values for two segment angles associated with the force production phase (kick action). These were 1.22 radians for the ankle angle at legs together during the force production phase and 1.43 radians for the center of mass angle at the end of the force production phase.

Soliman (1977) employed a regression analysis and found during the diagonal stride that the elite skier spent less time in the kick action of the force production phase. Soliman also concluded that the leg opening angle at the beginning and at the end of the glide phase had a significant effect on performance.

The work of Martin (1979) demonstrated the time spent in the pole and kick actions during the force production phase were significant predictors of stride rate. Martin states the time of pole implantation had greater influence on stride rate than the time spent during the kick action. Along with time of pole implantation Martin found the mechanical components of the pole action had slightly more influence on velocity than the mechanical components of the kick in force production.

In conjunction with the kick and recovery actions, a third means of force production in diagonal striding is the arms. Their effectiveness is dependent upon coordination with the legs in terms of timing, positioning and strength of their movements (Maier and Reiter, 1977). Maier and Reiter stated that the purpose of the pole plant in the diagonal ski stride is to maintain the momentum derived from the kick. When studying elite cross country skiers Novosod (1975) showed that the time period of the pole plant is approximately 65-80 percent of the total time of the stride. In contrast the average time of the kick action is approximately 20-30 percent of the entire stride. During the pole implantation phase Soliman (1977) found the force transmitted by the upper body was greater when the elbow angle was less (range 1.79-2.53 radians). He also found that the greater the horizontal distance from the pole to the foot at pole plant, the better the speed production. Dillman et al. (1978) obtained similar results. The skilled skiers planted the pole forward of the support foot (15 to 25 centimeters) with the pole in a more vertical position.

The movement of the upper and lower limbs play an active role in the recovery and force production phases. If the recovery leg is not actively swung forward after the completion of the kick, inertia is lost therefore slowing the glide of the ski (Maier and Reiter, 1977). Maier and Reiter (1977) stated that present day technique calls for the knee to be straightened somewhat at the end of the glide phase, an action that forces the calf forward, sometimes until it becomes perpendicular to the ground. This creates the following advantages:

> - Straightening the glide leg lifts the hips, allowing for free, effective forward swing of the recovery leg. If the hips are too low the knee of the recovery leg must be bent too severely, and the body weight will not be applied to the ski early enough, thus losing impulse.
> - The additional forward push of the leg is aided by simultaneous start of the opposite arms poling action. This lengthens the glide phase.
>
> (Maier and Reiter, 1977).

Kinetic Analysis

In cross country skiing the diagonal stride is dependent on the skier making a movement which transfers the necessary force from the arms and legs (Ekstrom, 1980).

Carlsen (1975) found that for the diagonal stride on uphill terrain in the force production phase the lower limbs produced a greater resultant force than did the upper body with the use of the ski poles. Carlsen concluded that the initial position in the force production phase (legs together) significantly affects the resultant force for propulsion.

Ekstrom (1980) found that the vertical force during the kick action was two to three times the body weight of an experienced skier and 1.2-1.8 times the body weight of an average skier, depending on the hardness of the ski track. The maximum vertical force measured in the ski pole during pole implantation of an experienced skier was approximately twenty five to thirty percent of the subjects body weight. The aim in diagonal skiing is to achieve as high a resultant force as possible to increase the propulsion of the skier.

The application of biomechanics in cross country skiing is a relatively young field. Therefore, the amount of literature pertaining to specific problems of this study is limited. The change in stride position may seem to be a simple modification to cross country ski technique, however, the consequences of such changes may be amplified over racing distances of five to fifty kilometers. Evaluation of characteristics and their relationship is needed in order to solve the problem.

CHAPTER III

METHODOLOGY

Subjects

This study included fifteen male and twelve female elite international cross country ski racers, who used the uphill diagonal ski stride on the test area during the fifteen kilometer (male) and five kilometer (female) ski race at the 1981 Cyprus-Anvil World Cup in Whitehorse, Yukon, Canada.

Source of Data

The site selected for filming the diagonal stride was 0.36 radian slope at the four kilometer secton. A Photosonic 1 PL 16 mm camera equipped with an electronic timing light generator set at 10 Hz was used. The subjects were filmed with Kodak Video News Film 7239 (ASA 160). The camera was placed perpendicular to a flat-measuring section at a distance of 15 meters from the predetermined path of movement. The camera height was set at 1.25 meters with a focal length of 40 mm. The focal length provided for a 3 meter field of view and stationary vertical and horizontal reference objects were placed 2 meters apart for a field width of 22 meters.

The camera was operated at 100 frames per second with a shutter angle of 30 degrees, exposure time of 1/1200 second and the f/stop set at f/5.6.

The subjects were filmed by the "panning technique" (Gervais et al., 1982). This technique was used to eliminate a small image size due to the large field that was selected for analysis. (Figure 3).

Evaluation of the Film

The data film was analyzed using a Hewlett Packard 9852A Computer handwired to a Hewlett Packard 9864A Digitizer and a Bendix Digitizing Board. The system allows determination of cartesian coordinate points accurate to 0.0056 cm. The total accuracy of the film analysis was dependent on the resolution of the film and skill of the operator.

A Lafayette Motion Film Analyzer was used for projection onto the Bendix Digitizing Board.

All computer programs were written in Hewlett Packard Language (HPL).

Calculation of Center of Mass

The Humanscale Anatomical Data (Diffrient, 1979) was used to calculate center of mass locations.

Data Smoothing

The data obtained from film were displacement-time functions. The raw data were smoothed by a Butterworth second order low pass filter (Walton, 1981). Corresponding velocity functions were calculated using finite differences.

Time Parameters

The film speed was calculated by using the timing marks placed on the film at 10 Hertz/second by the internal light emitting diodes. For each trial the number of frames and timing marks were counted. The frame rate was then found using the following equation.

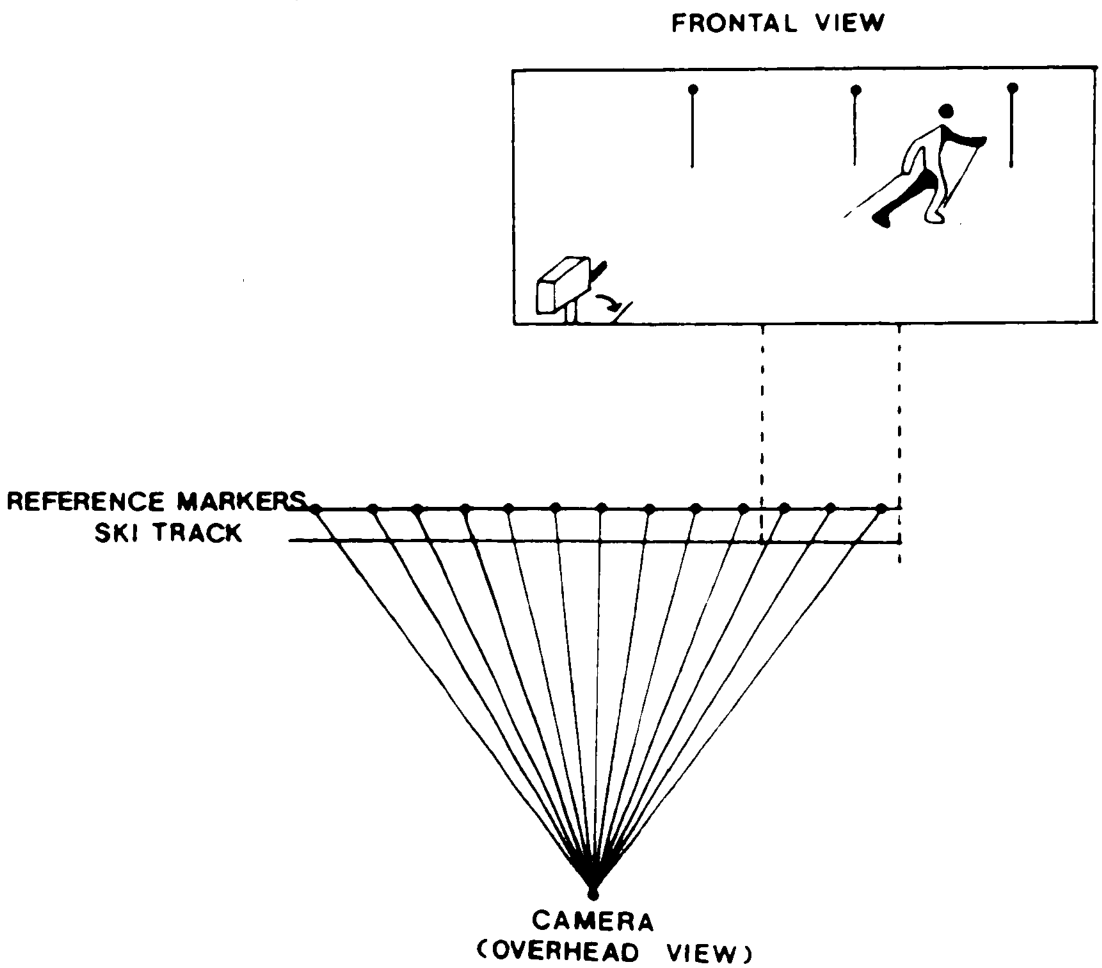

Figure 3. Film Set

$$\text{Frame Rate} = \frac{\text{number of frames}}{\text{number of timing marks} \times 0.01 \text{ sec.}}$$

Film data was taken from every fifth frame of film. The time interval between frames was calculated by the following:

$$\text{Time Between Frames} = \frac{5}{\text{frame rate}}$$

Data Analysis

Two complete cycles of the diagonal stride in cross country skiing on uphill terrain were analyzed to generate the raw data. The force production phase and recovery/glide phase of the cycles for the men and women elite skiers were separately investigated. The common variance between the segmental angle positions and the relative horizontal velocity of the center of mass were determined.

The following steps were used to find the coefficient of determination between an absolute segmental angle position and the horizontal velocity of the center of mass:

a) A correlation coefficient was found between the two parameters for the performance of the diagonal stride on uphill terrain for each subject.

b) The correlation coefficients were converted to z scores using the following equation:

$$(1) \quad z = 1/2 \ln \frac{1+r}{1-r}$$

c) A weighted average of the z scores was taken

$$(2) \quad z_{av} = \frac{\Sigma(N_i - 3)\, z_i}{\Sigma(N_i - 3)}$$

where N_i = the number of data points per subject for the force production and recovery/glide phase.

d) The z_{av} was converted back to a correlation coefficient and squared to provide a measure of the coefficient of determination.

$$(3) \quad r = \frac{e^{2 z_{av}} - 1}{e^{2 z_{av}} + 1}$$

coefficient of determination = r^2

The coefficient of determination was calculated between the absolute segmental angles of the trunk and lower limbs, and the relative horizontal velocity of the center of mass. The absolute segmental angle displacements correlated were the trunk angle, hip angle, knee angle and ankle angle in relation to the relative horizontal velocity of the center of mass.

CHAPTER IV

RESULTS AND DISCUSSION

The purpose of this study was to investigate selected mechanics of the diagonal ski stride on uphill terrain. The force production phase and recovery/glide phase were analyzed to determine the variables that significantly contributed to the production and maintenance of horizontal velocity of the center of mass.

Smoothing and Fitting of Data

The data derived from the film analysis are refered to as "raw data". The raw data have inherent errors or additive noise associated from the collection of data. The noise is from many sources - vibration in the cine camera, projector, random error due to the conversion process. Therefore, noise was removed by a Butterworth second-order low pass filter (Walton, 1981). Filtering of any signal is aimed at the selection-rejection or attentuation of certain frequencies (Winter, 1979). A comparison of smoothed versus raw data using a Butterworth second-order low pass filter with a frequency cutoff set at 5 Hz is illustrated in Figure 4. The frequency response of the filter is the ratio of the output filter, to the input filter, at each frequency present. This means that the input signal passes through the filter unattenuated (Winter, 1979). However, when the frequencies are above the cutoff frequency the signal then becomes severely attenuated. It should be noted that the higher frequency noise has been severely reduced but not rejected. The best fit of the smoothing technique

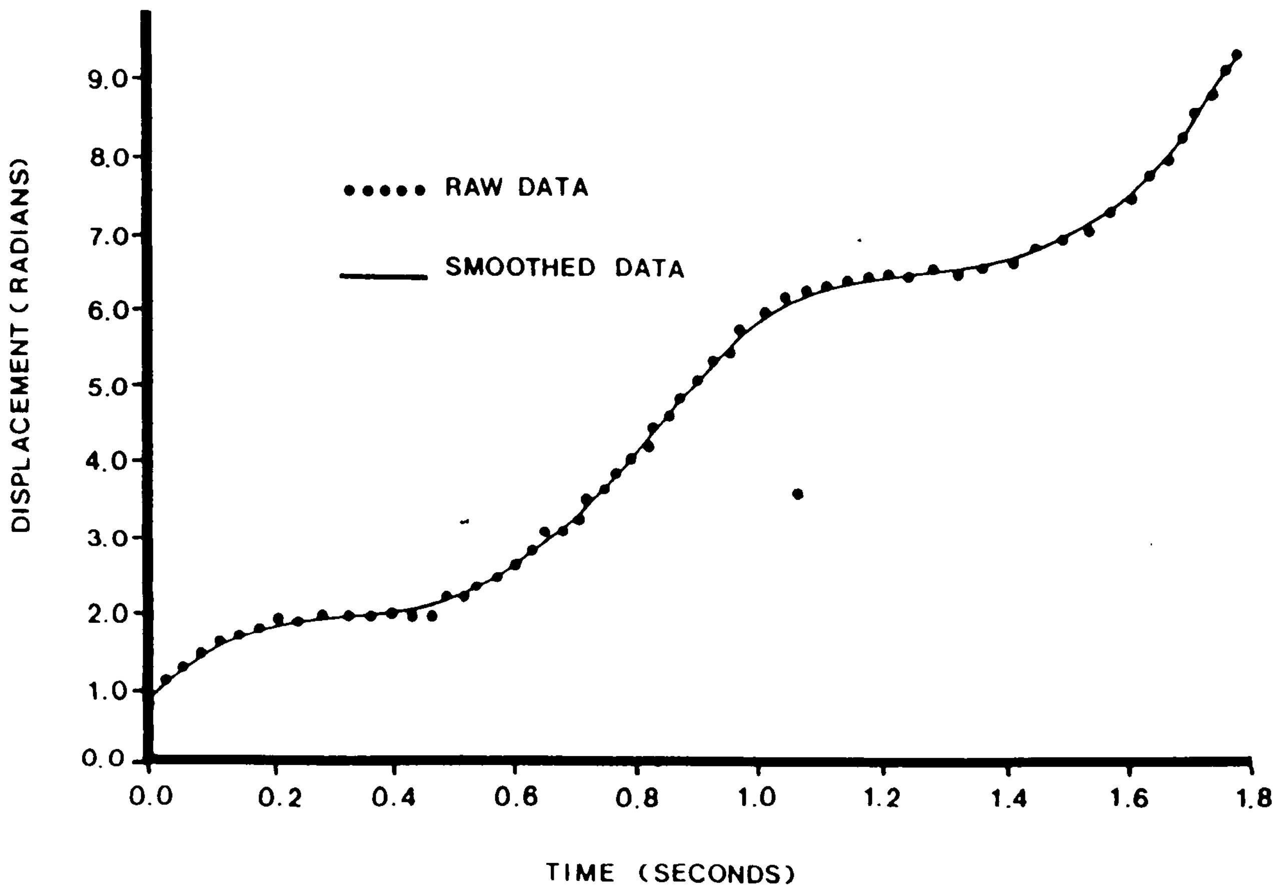

Figure 4. Comparison of raw versus filtered angular displacement data during extension/flexion movement patterns in the right ankle.

appeared at 5 Hz. The rationale for the selection of the described frequency cutoff was based upon the following criteria. If the cutoff frequency is set too high, less signal distortion occurs but too much noise is allowed to pass. Conversely, if the frequency cutoff is too low, noise is drastically reduced, but at the expense of increased signal distortion (Winter, 1979). Although the selection of the cutoff frequency was subjective it was evident that the data resulting from using the filter were compatible with the event occuring during performance.

Temporal Analysis

For the purpose of analysis the diagonal stride on uphill terrain was divided into three phases; force production phase, recovery phase and glide phase. The recovery and glide phase were combined because the length of a cycle and the velocity of the skier on an incline is reduced and thus the glide phase of one limb occurs simultaneously with the recovery phase of the other. The average time to complete one cycle of the diagonal ski stride in the present study was 1.80 seconds for the males and 1.93 seconds for the females. The results obtained in the present study were typical of performances of other skiers analyzed Dillman (1981) found the average time to complete one cycle of the diagonal ski stride was 1.97 seconds for males and 2.00 seconds for females. Martin (1979) reported a time of 2.03 seconds to complete a cycle on uphill terrain. The percentage of distance covered in stride length in the kick phase (34.6% = M, 32.7% = F) and pole phase (45.6% = M, 48.3% = F) in force production and in the glide/recovery phase (19.8% = M, 19.0% = F) also reflect the same temporal characteristics found by other researchers. (Table 1).

Kinematic Analysis

The objective of this study was to discern the details of the movement itself and their relationship to the particular phase in question.

Since more than one segment moves during the cycle of the diagonal stride the analysis of movement was based on the relationship between segmental movements and the relative horizontal velocity of the center of mass. Coefficient of determination statistical analysis infers the relationship between the absolute segmental angles and the relative horizontal velocity of the center of mass. Listed in Table 2 are the percentage values (r^2 x 100) to describe the relationhips.

In the force production phase (kick action) percentages of the coefficient of determination were found to be 72.3, 77.4, 67.8, and 60.3 in elite male skiers in the trunk, hip, knee and ankle angles respectively. For elite female skiers during the same phase percentages of 62.5, 90.7, 76.4 and 66.4 in variance of the same respective angles as above.

The above results do not imply any causal relationships but infers the change in the relative horizontal velocity of the center of mass is strongly associated with changes occuring in the other variables investigated.

Figure 5 illustrates the temporal sequence of the body segments during the cycle of the diagonal ski stride. In human movement the timing of various segments is influenced by the strengths and accelerations

TABLE 1

THE PERCENTAGE OF DISTANCE COVERED DURING THE PHASES

OF THE DIAGONAL SKI STRIDE

Athletic Sample	Terrain	Group	Kick Phase	Glide/Recovery Phase	Pole Phase	Reference
Cyprus-Anvil 1981 World Cup Whitehorse, Yukon, Canada	Uphill	M F	34.6% 32.7%	19.8% 19.0%	45.6% 48.3%	Present Study
1980 Lake Placid Olympic Games	Flat	Elite Good	28.4% 29.6%	22.9% 20.6%	48.7% 49.8%	Dillman, 1981
1979 Pre-Olympic Games, Lake Placid, N.Y.	Uphill	M	36.7%	16.4%	46.9%	Martin, 1979

TABLE 2

COEFFICIENT OF DETERMINATION BETWEEN ABSOLUTE SEGMENTAL ANGLES AND THE RELATIVE HORIZONTAL VELOCITY OF THE CENTER OF MASS OF ELITE SKIERS DURING TWO COMPLETE CYCLES OF THE DIAGONAL SKI STRIDE ON UPHILL TERRAIN

PHASE OF CYCLE	SEX	TRUNK ANGLE (α)	HIP ANGLE (β)	KNEE ANGLE (γ)	ANKLE ANGLE (ϕ)
FORCE PRODUCTION PHASE	M**	72.3	77.4	67.8	60.3
	F***	62.5	90.7	76.4	66.4
RECOVERY/GLIDE PHASE	M**	16.1	33.3	71.2	57.4
	F***	12.5	24.7	58.9	49.8

* Coefficient of Determination = $r^2 \times 100$
** Number of Males = 15
*** Number of Females = 12

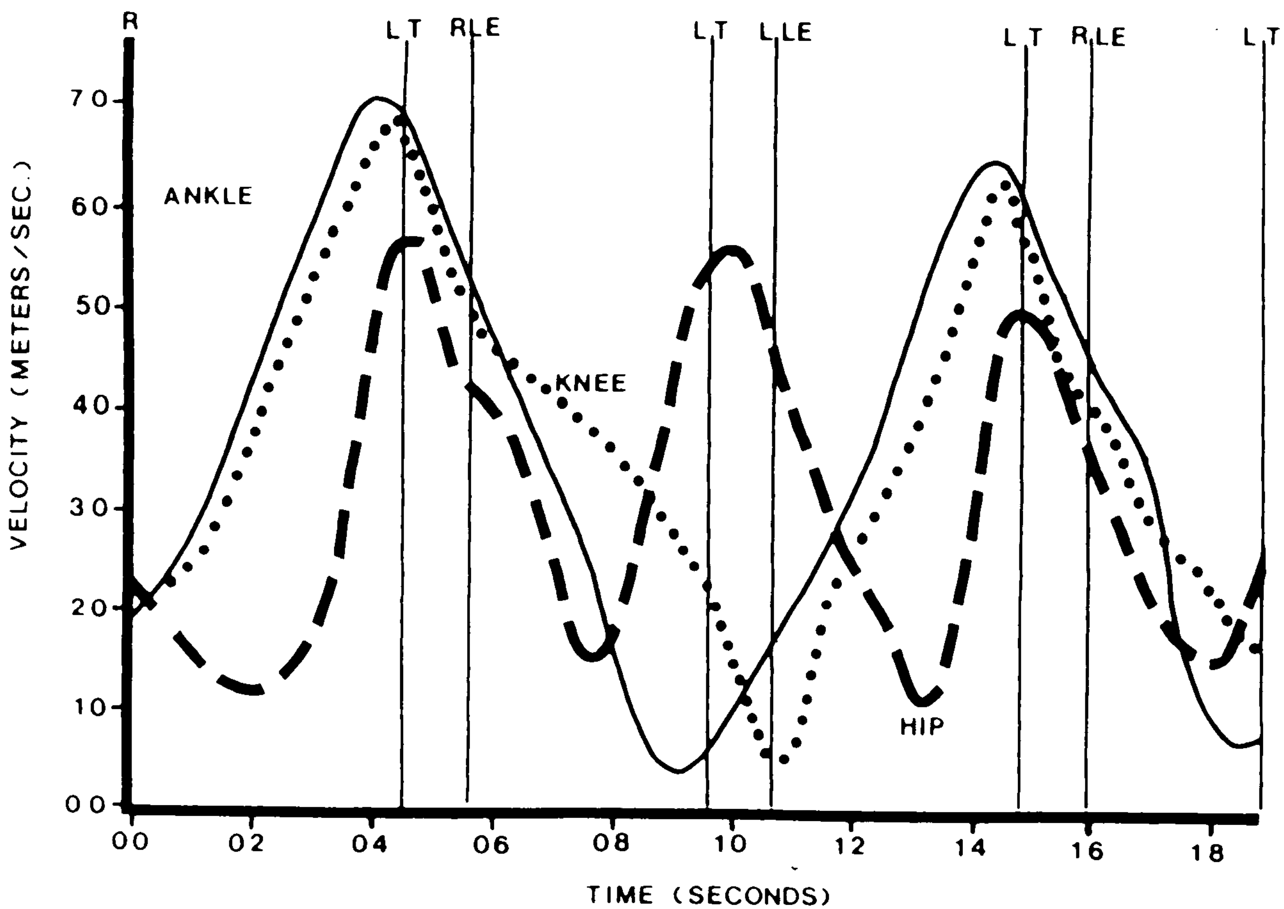

Figure 5. Velocities of the Right Hip, Knee and Ankle versus time depicting the linkage of the body segments in the diagonal ski stride. Phase Marks; R = Recovery, LT = Legs Together, RLE = Right Leg Extension, and LLE = Left Leg Extension.

of these parts. From the figure the ankle attains its maximum velocity 0.08 seconds after the legs together (preparatory) stance. The knee reaches its maximum velocity approximately 0.08 seconds after the ankle. The maximum velocity of the hip occurs 0.07 seconds following the knee. The transfer of momentum through the sequential action of the various muscles and levers enables the skier to generate a resultant force for propulsion.

Martin (1979) in a study incorporating multiple linear regression models related various mechanical and structural variables to performance criteria. He found stride length was dependent upon pole plant distance and the distance covered during the kick action in the force production phase. Martin also stated that pole plant distance appeared to have a much greater influence on stride length than distance covered by the kick action. Dillman (1978) also indicated that the pole implantation distance is one factor which distinguishes the better skiers from the poorer ones. He states that fifty to sixty percent of the difference in stride length between highly skilled and average skiers occurs during this time on flat terrain. The results from the present study contradict the findings by Martin and Dillman. The difference in stride length (0.48-0.61 meters) occured more in the kick action than in the pole plant. The impulse generated during the kick action is high since the horizontal velocity of the center of mass reaches its maximum during this sequence. It would appear that the momentum of the skier attained during the force production phase (kick action) has an influence on the length of the overall stride thereby increasing the length of the pole implantation distance.

An investigation by Ekstrom (1980) measured the vertical and horizontal forces between the skier, the skiis, and the ski poles in the diagonal ski stride. The magnitude of the maximal vertical force applied by the pole plant in the force production phase was one-third the body weight of the skier and the force applied over time was much less when comparing with the differences in force produced during the kick and the recovery/glide phase. The maximum vertical force applied during the kick was approximately three times the body weight. During the pole plant the recovery of the extended leg during the kick provides a maximal propulsive force of 50 newtons. Therefore, the pole plant distance is influenced not only by the force generated by pole implantation but also by the force generated during the kick and recovery of the kicking leg. Ekstrom (1980) has shown that the average vertical force exerted by the arms is only approximately 10 percent of that achieved by the lower limbs. This is related to two factors (1) the muscle mass involved is less and (2) the upper limbs are a rather inefficient system of leverage in the diagonal ski stride. The distance achieved during the early portion of the pole plant was the result of the translation of the body on the gliding ski. It was during this time that the greatest distance in the pole phase occured. Once the ski stops, the rest of the distance attained in the pole phase is the result of the body rotating over the stationary foot. Martin (1979) has shown the same results in reference to the distance covered by the pole plant. The differences between male and female skiers in the distance of the pole plant is not significant in this study.

The coefficient of determination between segmental angles and displacements is related to the horizontal velocity of the center of mass. Martin (1979) found that the velocity of the trailing foot and ankle angle at legs together were significant predictors of distance covered in force production. Martin also states that ankle angle at legs together was the only significant predictor of thrust phase time. The results of the present study suggest movements should be analyzed as a linkage of segments and their influence over the total performance not as isolated segments.

During the recovery/glide phase on uphill terrain a more powerful and longer kick must be instituted to overcome resistance produced by the incline. The glide phase, or absence of it was to be expected because of the gradient (0.36 radians) of the slope. From the results in Table 2, the coefficient of determination between the absolute segmental angles (trunk, hip, knee and ankle) and horizontal velocity of the center of mass for men and women represented 16.1, 33.3, 71.2, 57.4 (men) and 12.5, 24.7, 68.9, 49.8 (women) percents respectively. The relationship of the change in knee and ankle angle of the recovery leg demonstrates how the segments influence the horizontal velocity of the center of mass. This result confirms those of Ekstrom (1980). He measured a propulsive force between the skier and snow surface when the kicking leg was actively swung forward. The low values of coefficients of determination displayed by the trunk and hip segments agree with data collected by Novosad (1975). Novosad found that if the recovery of the kicking leg was emphasized with a flexed swing of the hip and thigh, power was lost through a breaking action. If the leg is slightly flexed at the knee and ankle and quickly swung through, the inertia developed can increase the force on the ski five to seven times more than if executed with the emphasis placed on the hips.

The results of this study reflected a relationship between selected parameters and their influence on the relative horizontal velocity of the center of mass. The study may not have produced definitive answers but has proved useful in constructing ideas and questions in order to achieve a better understanding of the sport.

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to conduct a temporal and kinematic analysis of segmental movement patterns in elite cross country skiers and thus identify variables which significantly contribute to the production and maintenance of horizontal velocity of the center of mass. The film data were analyzed from a field width of 22 meters incorporating the "panning" technique to eliminate a small image size due to the large field selected for analysis. Subjects selected for analysis were 15 male and 12 female elite cross country skiers at the 1981 Cyprus Anvil World Cup in Whitehorse, Yukon, Canada. One 16 mm pin registered Photo Sonic 1PL camera was used for the acquisition of cinematographic data. A Lafayette pin registered film analyzer, Bendix digitizing board, and a Hewlett Packard 9825B micro computer were utilized for analysis. The data were input into a computer program to determine the center of mass and its motion. In addition, the following parameters were computed: 1) The trunk, hip, knee and ankle absolute angles; and 2) The horizontal velocity of the center of mass. The kick action of the force production phase and the recovery of the lower limbs in the recovery/glide phase were separated prior to statistical analysis. There are differences in the mechanics of the diagonal stride on uphill terrain for each individual skier. Parameters selected for study influenced the length of the diagonal ski stride. However, as previously stated the question arises as to whether or not the position is better if one cannot generate the force needed by the ski to grip the snow. The differences found by Waser, Novosad, Dillman and others are apparent in the analysis of selected measures but a knowledge of forces is necessary for a deeper understanding of the cause of the movement.

Based on the results obtained in this study, within the limitations of this research, the following conclusions are warranted.

1) The method employed in this study does provide a valid and reliable technique which can be used in determination of movement patterns, in the context of biomechanical research.

2) The results of the study infered a positive relationship between the absolute angles of the trunk, hip, knee and ankle during the force production phase on the horizontal velocity of the center of mass. During the recovery/glide phase the knee and ankle angles were associated with the horizontal velocity of the center of mass.

Recommendations

The following recommendations are suggested for further research:

1) A comprehensive study of force interplay in the different phases of cross country skiing is needed.

2) An analysis of elite and non-elite skiers should be conducted to describe differences between the two groups.

3) The incorporation of mathematical modelling and optimization would provide more knowledge in efficiency and potential of human movement.

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APPENDIX A

KINEMATIC DATA

KINEMATIC DATA - FORCE PRODUCTION PHASE

SUBJECT/SEX	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1/M	4.29	1.32	3.96	0.79	0.75	0.04	1.49	2.14	0.65	4.33	2.11	2.30	0.19	1.27	1.54	1.70	0.16	1.07
2/M	4.48	1.37	4.03	0.66	0.77	0.11	1.40	2.25	0.85	5.67	2.05	2.80	0.75	5.00	1.55	2.09	0.54	3.60
3/M	4.30	1.31	3.98	0.70	0.69	0.01	1.41	2.15	0.74	4.63	2.14	2.69	0.55	3.44	1.52	2.16	0.64	4.00
4/M	4.35	1.30	3.81	0.71	0.78	0.07	1.42	2.20	0.78	4.59	2.07	2.77	0.70	4.12	1.59	2.23	0.64	3.76
5/M	4.18	1.27	3.66	0.59	0.76	0.17	1.45	2.28	0.83	4.15	2.16	2.76	0.60	3.00	1.63	2.10	0.47	2.35
6/M	4.59	1.35	4.13	0.79	0.80	0.01	1.30	2.35	1.05	6.18	2.02	2.79	0.77	4.53	1.34	2.13	0.79	4.65
7/M	4.55	1.59	3.98	0.69	0.79	0.10	1.38	2.26	0.88	4.89	2.07	2.77	0.70	3.89	1.50	2.29	0.79	4.39
8/M	4.20	0.88	3.36	0.53	0.66	0.13	1.56	2.14	0.58	5.80	2.24	2.88	0.64	6.40	1.64	2.17	0.53	5.30
9/M	4.12	1.25	3.61	0.68	0.78	0.10	1.40	2.22	0.82	5.13	2.14	2.77	0.63	3.94	1.58	2.11	0.53	3.31
10/M	4.19	1.30	3.67	0.79	0.87	0.08	1.37	2.14	0.77	4.81	2.06	2.62	0.56	3.50	1.41	1.98	0.57	3.56
11/M	4.68	1.69	4.33	0.66	0.82	0.16	1.37	2.12	0.75	5.00	2.09	2.65	0.56	3.73	1.44	1.90	0.46	3.07
12/M	4.31	1.29	3.99	0.64	0.71	0.07	1.39	2.16	0.77	5.13	2.04	2.75	0.71	4.73	1.46	2.15	0.69	4.60
13/M	4.33	1.40	4.01	0.65	0.73	0.08	1.40	2.22	0.82	5.47	2.01	2.84	0.82	5.47	1.55	2.26	0.71	4.73
14/M	4.57	1.40	4.23	0.59	0.73	0.14	1.31	2.22	0.91	4.55	2.20	2.75	0.55	2.75	1.57	2.03	0.46	2.30
15/M	4.72	1.67	4.37	0.78	0.83	0.05	1.40	2.17	0.77	4.53	2.02	2.74	0.72	4.24	1.37	1.70	0.33	1.94
Mean	4.41	1.36	3.87	0.68	0.76	0.09	1.40	2.20	0.80	4.99	2.09	2.73	0.63	4.00	1.51	2.07	0.55	3.51
Standard Deviation	0.18	0.19	0.38	0.08	0.06	0.05	0.06	0.06	0.19	0.58	0.07	0.13	0.15	1.21	0.09	0.18	0.17	1.19

Legend

1 = Average Velocity of Center of Mass (meter/sec)
2 - For[illegible] Production - Kick Action Distance (meters)
3 = St[illegible] Length (meters)
4 - Trunk (Legs Together) Angle (rad)
5 - Trunk Extension Angle (rad)
6 - Δ Trunk Angle (rad)
7 = Hip (Legs Together) Angle (rad)
8 - Hip (Extension) Angle (rad)
9 - Δ Hip Angle (rad)
10 = v Hip (meters/sec)
11 - Knee (legs Together) Angle (rad)
12 - Knee (Extension) Angle (rad)
13 - Δ Knee Angle (rad)
14 - v Knee (meters/sec)
15 - Ankle (Legs Together) Angle (rad)
16 = Ankle (Extension) Angle (rad)
17 - Δ Ankle Angle (rad)
18 - v Ankle (meters/sec)

KINEMATIC DATA - FORCE PRODUCTION PHASE

SUBJECT/SEX	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1/F	4.51	1.08	3.38	0.92	0.93	0.01	1.39	2.06	0.67	5.15	2.08	2.71	0.63	4.85	1.56	2.01	0.45	3.46
2/F	3.99	1.14	3.39	0.86	0.90	0.04	1.31	2.02	0.69	4.60	2.09	2.70	0.61	4.07	1.41	1.95	0.54	3.60
3/F	3.62	1.32	3.35	0.73	0.78	0.05	1.36	2.02	0.66	4.13	2.16	2.73	0.57	3.56	1.45	2.10	0.65	4.06
4/F	4.09	1.24	3.58	0.75	0.80	0.05	1.36	2.12	0.76	5.07	2.08	2.73	0.65	4.33	1.46	2.09	0.65	4.33
5/F	3.92	1.21	3.43	0.70	0.74	0.04	1.37	2.14	0.77	5.13	2.15	2.76	0.61	4.07	1.41	2.00	0.59	3.93
6/F	3.99	1.32	3.39	0.68	0.80	0.12	1.32	2.29	0.97	4.85	2.18	2.80	0.62	3.10	1.42	2.01	0.59	2.95
7/F	3.38	1.03	2.88	0.92	0.97	0.05	1.35	2.12	0.77	4.81	2.02	2.73	0.71	4.44	1.46	2.04	0.58	3.63
8/F	4.04	1.04	3.83	0.82	0.90	0.08	1.32	2.11	0.79	5.27	2.11	2.73	0.62	4.13	1.46	2.04	0.58	3.87
9/F	3.57	1.14	3.03	0.88	0.88	0.00	1.39	2.08	0.69	4.93	2.09	2.72	0.63	4.50	1.58	2.07	0.49	3.50
10/F	3.59	1.27	3.32	0.86	0.89	0.03	1.38	2.13	0.75	4.17	2.04	2.74	0.70	3.89	1.60	2.14	0.54	3.00
11/F	3.62	1.06	3.35	0.79	0.93	0.14	1.37	2.16	0.79	5.27	2.14	2.81	0.67	4.47	1.35	1.89	0.54	3.60
12/F	3.69	1.20	3.14	1.00	1.01	0.01	1.20	2.11	0.91	6.50	2.02	2.79	0.77	5.50	1.44	1.97	0.53	3.79
Mean	3.83	1.09	3.34	0.83	0.88	0.05	1.34	2.11	0.77	4.99	2.10	2.75	0.65	4.24	1.47	2.03	0.56	3.64
Standard Deviation	0.31	0.30	0.25	0.10	0.08	0.04	0.05	0.07	0.09	0.61	0.05	0.04	0.05	0.61	0.08	0.07	0.06	0.40

Legend

1 = Average Velocity of Center of Mass (meter/sec)
2 = Force Production - Kick Action Distance (meters)
3 = Stride Length (meters)
4 = Trunk (Legs Together) Angle (rad)
5 = Trunk Extension Angle (rad)
6 = Δ Trunk Angle (rad)
7 = Hip (Legs Together) Angle (rad)
8 = Hip (Extension) Angle (rad)
9 = Δ Hip Angle (rad)
10 = $\bar{v}$ Hip (meters/sec)
11 = Knee (Legs Together) Angle (rad)
12 = Knee (Extension) Angle (rad)
13 = Δ Knee Angle (rad)
14 = $\bar{v}$ Knee (meters/sec)
15 = Ankle (Legs Together) Angle (rad)
16 = Ankle (Extension) Angle (rad)
17 = Δ Ankle Angle (rad)
18 = $\bar{v}$ Ankle (meters/sec)

KINEMATIC DATA - RECOVERY PHASE

SUBJECT/SEX	1	2	3	4	5	6	7	8	9	10	11	12
1/M	2.07	1.49	0.58	4.14	2.28	2.11	0.17	1.21	1.68	1.54	0.14	1.00
2/M	2.04	1.40	0.64	6.40	2.25	2.05	0.20	2.00	1.80	1.55	0.25	2.50
3/M	2.07	1.41	0.66	4.40	2.36	2.14	0.22	1.47	2.00	1.52	0.48	3.20
4/M	2.18	1.42	0.76	5.43	2.35	2.07	0.28	2.00	1.92	1.59	0.33	2.36
5/M	2.25	1.45	0.80	4.00	2.51	2.16	0.45	2.25	1.84	1.63	0.21	1.05
6/M	2.13	1.30	0.83	5.19	2.41	2.02	0.39	2.44	1.78	1.34	0.44	2.75
7/M	2.05	1.38	0.67	3.72	2.42	2.07	0.35	1.94	2.05	1.50	0.45	2.50
8/M	2.31	1.56	0.75	4.17	2.71	2.24	0.47	2.61	2.16	1.64	0.52	2.89
9/M	2.19	1.40	0.79	4.94	2.59	2.14	0.45	2.81	1.94	1.58	0.36	2.25
10/M	2.14	1.37	0.77	4.28	2.36	2.06	0.30	1.67	1.83	1.41	0.42	2.33
11/M	2.22	1.37	0.85	4.47	2.55	2.09	0.46	2.42	1.82	1.44	0.38	2.00
12/M	2.16	1.39	0.77	4.28	2.34	2.04	0.30	1.67	1.80	1.46	0.34	1.89
13/M	2.23	1.40	0.83	5.53	2.45	2.02	0.43	2.87	2.00	1.55	0.45	3.00
14/M	2.21	1.31	0.90	5.63	2.55	2.20	0.35	2.19	1.87	1.57	0.30	1.88
15/M	2.25	1.40	0.85	5.67	2.33	2.02	0.31	2.07	1.81	1.37	0.44	2.93
Mean	2.17	1.40	0.76	4.82	2.43	2.10	0.34	2.11	1.89	1.51	0.37	2.30
Standard Deviation	0.08	0.06	0.09	0.78	0.13	0.07	0.10	0.48	0.12	0.09	0.11	0.66

Legend

1 = Hip (Extension) Angle (rad)
2 = Hip (Legs Together) Angle (rad)
3 = Δ Hip Angle (rad)
4 - v Hip (rad/sec)
5 - Knee (Extension) Angle (rad)
6 - Knee (Legs Together) Angle (rad)
7 = Δ Knee Angle (rad)
8 - v Knee (rad/sec)
9 = Ankle (Extension) Angle (rad)
10 - Ankle (Legs Together) Angle (rad)
11 - Δ Ankle Angle (rad)
12 - v Ankle (rad/sec)

KINEMATIC DATA - RECOVERY PHASE

SUBJECT/SEX	1	2	3	4	5	6	7	8	9	10	11	12
1/F	2.04	1.39	0.65	4.33	2.48	2.08	0.40	2.67	1.86	1.56	0.30	2.00
2/F	2.02	1.31	0.71	4.73	2.46	2.09	0.35	2.33	1.85	1.41	0.44	2.93
3/F	2.10	1.36	0.74	4.11	2.53	2.16	0.37	2.06	1.87	1.45	0.42	2.33
4/F	2.17	1.36	0.81	4.50	2.58	2.08	0.50	2.78	2.00	1.46	0.54	3.00
5/F	2.08	1.37	0.71	3.94	2.44	2.15	0.29	1.61	1.89	1.41	0.48	2.67
6/F	2.35	1.32	1.03	4.12	2.67	2.18	0.49	1.96	1.86	1.42	0.44	1.60
7/F	2.15	1.35	0.80	4.44	2.41	2.02	0.39	2.17	1.85	1.46	0.39	2.17
8/F	2.14	1.32	0.82	3.90	2.59	2.11	0.48	2.29	1.93	1.46	0.47	2.24
9/F	2.09	1.39	0.70	3.50	2.48	2.09	0.39	1.95	2.01	1.58	0.43	2.15
10/F	2.10	1.38	0.72	4.00	2.60	2.04	0.56	3.11	2.02	1.60	0.42	2.33
11/F	2.17	1.37	0.80	4.00	2.49	2.14	0.35	1.75	1.80	1.35	0.45	2.25
12/F	2.08	1.20	0.88	4.89	2.43	2.02	0.41	2.28	1.92	1.44	0.48	2.67
Mean	2.12	1.34	0.78	4.21	2.51	2.10	0.42	2.25	1.91	1.47	0.44	2.36
Standard Deviation	0.09	0.05	0.10	0.39	0.08	0.05	0.77	0.44	0.07	0.08	0.06	0.40

Legend

1 = Hip (Extension) Angle (rad)
2 = Hip (Legs Together) Angle (rad)
3 = Δ Hip Angle (rad)
4 = $\bar{v}$ Hip (rad/sec)
5 = Knee (Extension) Angle (rad)
6 = Knee (Legs Together) Angle (rad)
7 = Δ Knee Angle (rad)
8 = $\bar{v}$ Knee (rad/sec)
9 = Ankle (Extension) Angle (rad)
10 = Ankle (Legs Together) Angle (rad)
11 = Δ Ankle Angle (rad)
12 = $\bar{v}$ Ankle (rad/sec)