KINEMATIC CONSIDERATIONS OF ELITE ALPINE SLALOM SKI RACERS

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INTRODUCTION

Success at the national and international levels in alpine ski racing is dependent, in part, upon a skier's ability to maintain a particular line through a course. Alpine slalom ski racing requires a powerful yet controlled collection of lower body movements specific to the requirements of the turn encountered. Changes in leg, thigh, hip, and pelvic displacements, velocities, and accelerations are responsible for lower body technique, which is an axiom of turn (line) requirements. In essence, technique of the elite skier is established by appropriate lower body kinematics throughout a turn which effectively optimize speed, the criterion for success in alpine ski racing.

While there have been many theoretical articles on technique, little empirical work on technique analysis in any of the alpine events is available. Ikai (1970), Yatabe (1972), Nachbauer (1986), Forg-Rob and Nachbauer (1988) have published papers on slalom skiing. Thus, the objectives of this investigation were to quantitatively explain the mechanics involved in negotiating an alpine slalom ski turn and determine strength of relationships between the variables. Specifically studied were lower body location and linear and joint angular velocities, as they apply to the techniques and course line choices of international slalom ski racers competing in the men's special slalom event at the 1989 World Alpine Ski Championships in Vail/Beaver Creek, Colorado (USA).

METHODOLOGY

High speed cinematography was conducted using two Locam II 16 mm cameras equipped with 12-120mm zoom lenses. Camera 1 was 18.49 m from the slalom gate and 1.09 m above the snow on a line perpendicular to the fall line. Camera 2 was 18.16 m from the slalom gate and 0.94 m above the snow on an arc below camera 1. Camera separation was 5.64 m. The lens f/stop was set at 9 for both cameras. Zoom lens settings for camera 1 and camera 2 were 28 and 32, respectively. Film synchronization was achieved by timing marks placed on the exposed film from interval timing light generators operating at 100 hertz. The film speed was 100 frames per second. A direct linear transformation (DLT) method was applied to reconstruct three-dimensional coordinates from two sets of two-dimensional data (Abdel-Aziz and Karara, 1971).

The camera tripod legs were buried approximately 10 cm deep to prevent platform settling. Fall line slope, diagonal slope to camera 2, and slope perpendicular to diagonal slope were measured as 24.29°, 7.17°, and 23.93°, respectively. Camera 1 required only a fall line leveling while camera 2 required a tripod platform tilt in both a direct line optical axis and perpendicular line optical axis. Slope topography was taken to be consistent throughout the sample area.

A DLT octopus was used to determine the three-dimensional reference field of comparator points. This device consisted of a hinged center pole, a fourteen sided polyhedron, and thirteen marked arms that project from the surface of the polyhedron. The first 21 skiers to start the second run were scientifically filmed for approximately two seconds over a three gate combination of the course. At completion of the run, the slalom gate was removed and the DLT octopus was placed directly in the slalom pole hole and filmed to establish the reference field. The selection process of subjects for this study was made based on race finish position. The top sixteen finishers were considered as the subject pool.

The film records were digitized using a Vanguard Motion Analyzer film projection system. Digitized points of anatomical or reference landmarks were electronically located by a Numonics Digitizing Unit. Surface resolution of the digitizing unit was rated as ≈ 0.05 inches.

RESULTS AND DISCUSSION

Digitizing error determined the DLT reference accuracy based on selected DLT octopus points. The average mean square errors for x, y, and z of the 11 points were 0.007 m, 0.029 m, and 0.012 m, respectively. The average mean square error for the resultant position was 0.032 m.

Eight dependent variables considered to be critical to efficient slalom technique were investigated. The variables were: a) right boot toe resultant velocity (RBTRV); b) right boot toe fall line velocity (RBTFLV); c) right boot toe traverse velocity (RBTTV); d) right hip angle (RHA); e) right hip angular velocity (RHAV); f) right knee angle (RKA); g) right knee angular velocity (RKAV); and h) right boot toe position, y direction at gate contact (RBTPyc).

Pearson Product-Moment correlation levels were based on a 1-tailed significance test. Very high relationships existed if the significance level was 0.001. A moderate relationship existed if the significance level was 0.01. Table 1 presents the variable relationship strength between pairs of variables. Figure 1 presents the group results of the more significant variables.

Table 1. Selected Variable Pearson Product-Moment Correlations.

Variable Pair		r-value
RBTFLV	RBTPyc	0.7950 **
RBTRV	RBTTV	0.6773 *
RBTRV	RBTPyc	0.6714 *
RBTTV	RKAV	0.6608 *
RBTRV	RHAV	0.5610
RBTRV	RKA	0.5610
RBTRV	RKAV	0.5131

1-tailed Significance: * - 0.01 ** - 0.001

In this particular turn, the line chosen close to the gate appears to be slow because subjects 4, 5, 7, and 11 skied this line and had the slowest RBTRV and RBTFLV. An ideal distance away from the slalom pole base for this turn appears to be 0.400 m or farther away, as these skiers maintained the highest rate of RBTFLV. The correlated value (r=0.7950) between RBTFLV and RBTPyc supports this contention. This investigator also speculates that the lack of a relationship between RBTRV and RHA (r=-0.2473) resulted from anatomical considerations that were not investigated. The dynamic movements at the hip are most likely unique to the individual, whereas knee movements appear to be more general among the subjects.

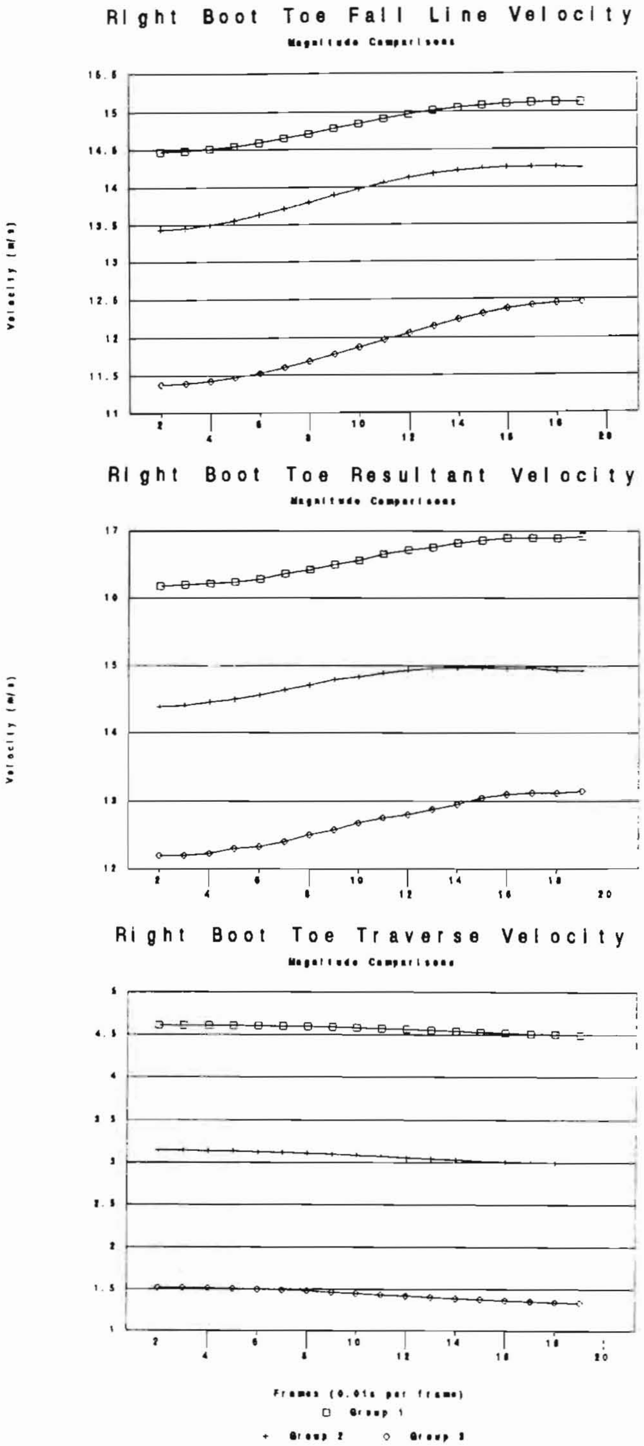

Figure 1. Graphical representations of the three most significant variables of the turning leg during a slalom turn.

Forward foot thrust of the turning leg at the end of a turn helps the ski maintain a tracking arc through the snow, eliminating side slip which reduces velocity. If set up by the correct line choice and timed properly, this maneuver should occur approximately at gate contact. As forward foot thrust occurs below the body's center of gravity (CG), the upper body of the skier rotates forward, reducing the hip angle slightly. Subjects 1, 3, 12, 13, 14, 15, and 16 exhibit a slight decrease in RHA. Subjects 2, 4, 5, 6, 7, 8, 9, 10, and 11 appear more upright from the angles measured over the course of the turn, and actually show a slight increase in hip angle. Extension at the hip could possibly be a result of side slip where the skier momentarily is correcting for unexpected centripetal forces acting to flatten his skis on the snow and pull him outside the turn. Subjects 4, 5, 6, 7, and 11 had consistently low velocities through this turn suggesting some side slip was occurring.

A moderate change in RHAV is expected as the skier extends out of the turn. A carving ski provides the platform for the extension. A rapid change in RHAV would be seen when a skier moves his CG inside of a turning ski that begins to side slip. As the weight is shifted to the inside ski, the right hip angle increases because the ski is lost to the side slip. A large disparity in RHAV was seen over the turn sequence.

All subjects showed an increase in the knee angle of the turning leg (right) over the turn sequence. Hip extension and forward foot thrust of the turning leg contribute to the change in this variable. Subjects 4, 5, 6, 10, 11, and 15 display only a small change over the turn sequence. Subjects 1, 7, 12, 13, 14, and 16 show a moderate change, and Subjects 2, 3, 8, and 9 demonstrate a large change in the RKA. Subjects 2, 3, 8, and 9 appear to have completed the turn earlier, benefiting from forward foot thrust. They also maintained the highest rates of velocity through the turn.

RKAV decreases over the course of the turn, however, at different rates. Three distinct levels of activity are present. Subjects 2, 3, 9, and 14 drop from a high level of activity, Subjects 1, 7, 8, 11, 12, and 13 drop from a lower level of activity, and Subjects 4, 5, 6, 10, 15, and 16 show a constant angular velocity in the right knee joint. These large differences are seen prior to contact with the slalom pole and may reflect the position of the racer on the course or individual differences in technique. By the time the turn sequence is finished, all three groups are very similar in activity levels. The high initial level of activity in RKAV appears to be advantageous because the subjects also had the highest levels of RBTRV through the turn. A moderate correlation exists (r=0.6608) between RBTTV and RKAV.

RBTRV is considered the most important variable investigated because it reflects the absolute speed of the skier through the course. The determination of groups for RBTRV, RBTFLV, and RBTTV over the turn sequence were based on magnitude comparisons. Subjects were grouped according to increasing, constant, and decreasing velocity over the course of the turn. The same trends appeared in RBTFLV and there was a slight decrease by all subjects for RBTTV. Groups formed for knee and hip angles were based on magnitude differences and trends in change of the magnitude. Groups formed for angular hip velocity were based on trends in change of magnitude alone. Finally, magnitude differences determined the groups for angular knee velocity. Groups for y (traverse) positions were based on distance away from the gate throughout the turn. Generally, excluding RBTPyc, Group 1 contained members with the highest magnitudes for all variables, Group 2 with magnitudes closer to the mean of all skiers, and Group 3 of skiers with magnitudes below the other two groups.

CONCLUSIONS

High levels of RKAV early in the turn associate well with high RBTRV through the turn. Four subjects who initiated the turn sequence with a RKAV of about 8 rad/s all fell in the RBTRV group which average 16.6 to 16.9 m/s through the turn. Collectively, a RKA ranging from 1.81 rad to 2.44 rad, a RKAV above 4.00 rad/s, a RHA ranging from 1.66 rad to 2.01 rad, and a constant RHAV around 1.00 rad/s associate with the highest right boot toe velocities.

No clear relationship was present with RHAV, as three trends were observed. The only associations to velocity were that more subjects who maintained a fairly consistent rate ranging from 0.74 rad/s to 1.03 rad/s also maintained velocities above 14.4 m/s for RBTRV, 13.4 m/s for RBTFLV, and 3.0 m/s for RBTTV. There was evidence to support a gradual decrease in right knee activity over the course of the left turn. This particular turn required a level of activity in the knee of 3.90 rad/s prior to gate contact, which reduced to less than 1.00 rad/s after the turn was completed.

RBTRV differences may be partly attributed to the RBTTV differences. RBTTV ranged from 0.52 m/s to 5.69 m/s. The resultant component, RBTFLV, appears to be at least as significant. The five subjects with the highest RBTRVs also had the highest RBTFLVs. Additionally, six skiers maintained velocities above the mean ranges for both fall line (13.3 m/s - 14.1 m/s) and traverse (3.1 m/s - 2.9 m/s) directions.

Some variability in position of the right boot toe was seen and appeared to be critical in maintaining speed. Three subjects were positioned more than one standard deviation inside the 0.455 m mean to the slalom pole base (0.470 m, -0.050 m, -1.285 m). Each of these subjects was unable to achieve the mean velocity ranges for both fall line and traverse directions, suggesting their line was too close to the gate for this turn.

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