ACCELERATION OF ELITE ICE HOCKEY PLAYERS

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The ability to accelerate quickly from a stationary or "gliding" position is an important element of Ice Hockey performance. American skaters have typically been characterized as "slow" relative to their international opponents and therefore, this study was undertaken to identify the biomechanical factors which contribute to acceleration performance.

Both coaches and reseachers have addressed this problem. Lariviere (1968) observed that a greater velocity was associated with a larger angle of propulsion, a smaller angle of forward lean, and a greater stride length. Page (1975) reported that longer right stride length, greater width between strides, greater abduction of the leg, quicker return of the skate to the ice, quicker set of the inside edge, quicker extension of the knee, greater flexion of the knee prior to the propulsion, and greater forward lean of the trunk and lower body were all related to increased velocity. Marino (1977) observed that skaters were more upright and had a longer glide at slow and medium speeds as compared with faster speeds. He also found increased stride rate and decreased double support and single support times to be related to velocity.

A regression equation to predict time to skate six meters was produced by Marino (1983). Significant predictor variables were forward lean of the trunk at touchdown, angle of the leg at take-off, stride rate, and height.

A similar regression equation for prediction of acceleration as developed by Marino (1975, 1978) served as the basis for the present study. The highest value for the multiple correlation coefficient was found when the mean values over the first three strides were used as opposed to values from an individual stride. The regression equation was as follows:

$$\text{Average Acceleration} = -2.47\,X1 - .06\,X2 + .01\,X3 + .44\,X4 - .007\,X5 + 2.07\,X6 + 2.94$$

WHERE: X1 = toe to hip distance (the horizontal distance between the hip and the toe of the recovery leg at touch-down)

X2 = angle of take-off (the angle formed by the leg relative to the horizontal at take-off)

X3 = body weight (in kilograms)

X4 = stride rate (strides per second)

X5 = trunk position at touch-down (the angle formed by the trunk relative to the horizontal at touch-down)

X6 = leg length (in meters)

Skaters with a wide range of ability were analyzed in the development of the equation.

The question raised by the present study was whether the acceleration regression equation proposed by Marino would apply to elite skaters. If the equation proved to be reasonably accurate, could the predictor variables provide insight into performance factors which could significantly improve acceleration cabability. In addition, could a regression equation more specific to elite skaters be developed and if so, what factors contribute to the acceleration performance of that group.

METHODOLOGY

All filming for the present study was conducted at Memorial Park Ice Center in Colorado Springs. Initially, eleven members of the 1983 National Team were filmed. In a subsequent study, film records were obtained for 69 participants in the 1983 National Sports Festival Ice Hockey competition.

In both instances, the first 20 feet of a 120 foot acceleration test were filmed using standard two-dimensional cinematography techniques. A Locam camera, operating at 80 frames per second (as verified by marks placed on the film by an internal timing light generator) was positioned perpendicular to the plane of motion. For the National Team, a second camera was located in line with the skater's path of motion to provide a head-on view. The purpose of this camera was to evaluate the lateral deviation of the skating stride. Subjective analysis of the films indicated that the lateral deviations, especially in the early stages of the acceleration, were not great enough to produce a significant perspective error.

The subjects began the test from a stationary position using the start of their choice. A light placed within the field width of the camera served as the stimulus for the start. Each skater was asked to complete two trials with the mean of the trials used wherever possible.

All of the National Team members wore full hockey uniforms. The Sports Festival Participants were dressed in either the full uniform or pads and sweats. All skaters carried a stick although no restrictions were imposed relative to its position on the ice or the carrying technique.

The films were projected from a Vanguard projection head onto a Talos digitizing surface. The digitized coordinates were sent directly to an Apple Computer programmed to receive the coordinate data and perform the required calculations. The raw displacement data was smoothed using a fourth-order Butterworth Low-Pass filter with a cut-off frequency of 3 Hz as determined by plots of the velocity data. Horizontal and vertical displacement, velocity, and acceleration data for the center of gravity of the skater were obtained for the first twenty feet. From this data, the time to skate 20 feet, instantaneous horizontal velocity at 20 feet, and average horizontal acceleration over 20 feet were recorded. In addition, for the first three strides, selected kinematic parameters were evaluated and the mean over the first three strides computed. For the National Team, the variables selected were those included in the acceleration regression equation of Marino (1975), specifically stride rate, angle of take-off, trunk flexion at touch-down, and toe to hip distance at touch-down. For the Sports Festival group, several additional variables were added to the analysis for later inclusion in the development of a regression equation. These were single support time, double support time, non-support time, trunk angle at take-off, and hip flexion at both take-off and touch-down. Body weight (kilograms), height (meters), and leg length (meters) were also recorded for all skaters.

RESULTS AND DISCUSSION

Preliminary analyses of the National Team data were undertaken to evaluate the accuracy of the testing and analysis procedures. Table 1 summarizes the results. For those subjects with test/retest scores, high correlation values and low mean differences were observed. Low mean differences were also noted when films from two skaters were analyzed twice.

A t-test for dependent samples showed no significant difference (at the .01 level) between the actual and predicted acceleration measures (Table 2). A mean difference of 0.54 m/s/s was observed.

TABLE 1

Test/Retest Correlations and Mean Differences

(National Team N=6)

Variable	Trial 1	Trial 2	Correlation	Mean Difference
	(means)			
Time to skate 20 feet (s)	1.52	1.50	r=.72	0.05
Velocity at 20 feet (m/s)	7.07	6.93	r=.95	0.22
Average Acceleration (m/s^2)	4.37	4.38	r=.99	0.05
Stride Rate (per s)	4.02	4.21	r=.71	0.20
Toe-Hip Distance (m)	0.11	0.10	r=-.10	0.02
Leg Angle at Take-off (deg)	52.72	51.28	r=-.54	4.00
Trunk Flexion at Touch-down (deg)	66.73	65.32	r=.64	5.62

TABLE 2

Evaluation of Prediction Equation

(National Team N=11)

	Actual	Predicted	Difference
Mean Value	4.13	3.59	0.54

Non-significant difference: $t = 2.95$

$({}_{.99}t_{10} = \pm 3.169)$

Seven of eleven subjects had actual accelerations within one standard error of the estimate.

Seven of the eleven subjects (64%) had predicted acceleration values which fell within one standard error of the estimate.

In Marino's original sample, a wide range of skating abilities was included. Using his mean values as indicative of the average skater, criterion measures were established which were one standard deviation "better" than the mean. When the results of the present analysis were compared with the criterion measures, the majority of the skaters reached the criterion score for all of the parameters evaluated with the exception of leg angle at take-off and trunk flexion at touch-down (Table 3).

The mean values for the predictor variables of the regression analysis as derived from the eleven National Team members were placed in the equation. The resulting predicted acceleration was 3.59 m/s/s. Of the two factors for which the National Team failed to meet the criterion scores, leg angle at take-off is a more significant predictor variable than is trunk flexion. This is indicated by the regression coefficients and confirmed by manipulation of the mean values for these variables in the regression equation.

The effect of altering the angles of take-off and trunk flexion both independently and in combination is presented in Table 4. A 15 degree alteration in trunk flexion (from a mean of 65.5 to a hypothesized value of 50 degrees) produced only a 0.10 m/s/s improvement in acceleration. However, an 8 degree changes in the angle of take-off produced a 0.40 m/s/s increase in acceleration.

With the larger sample population tested during the National Sports Festival the obvious question was whether the findings from this group would be consistent with the results from the National Team. Once again, the test/retest values showed low mean differences and high correlations (Table 5). The dependent t-test showed no significant difference between the predicted and actual values (Table 6). The mean difference was 0.308 m/s/s. The majority of the skaters (67%) had actual accelerations within one standard error of the estimate. In addition, as compared to the criterion values of one standard deviation "better" than the mean values from Marino's study, none of the skaters reached the value for leg angle at take-off and only two of the skaters reached the criterion value for trunk angle at touch-down (Table 7).

The effect of altering the values for these variables in the regression equation are shown in Table 8. To achieve a trunk flexion angle of 50 degrees required only a 3 degree change as the Sports Festival skaters were already in a position of greater trunk flexion. Consequently, the change in acceleration was small (0.02 m/s/s). Altering the leg angle approximately 9 degrees produced a 0.56 m/s/s change in acceleration.

TABLE 3

Comparison with Criterion Measures

(National Team N=11)

Variable	Mean	Criterion	Number (of 11) at Criterion
1. Time to skate 20 feet (s)	1.53	1.80	11 (100%)
2. Velocity at 20 feet (m/s)	6.71	6.60	7 (64%)
3. Average Acceleration (m/s^2)	4.13	3.60	8 (73%)
4. Stride Rate (per s)	4.25	3.70	11 (100%)
5. Toe-Hip Distance (m)	0.09	0.18	11 (100%)
6. Leg Angle at Take-off (deg)	53.1	47.0	0 (0%)
7. Trunk Flexion at Touch-down (deg)	65.5	43.0	0 (0%)

TABLE 4

Effects of Altering Leg Angle and Trunk Flexion on Predicted Acceleration

(National Team N=11)

Condition	Predicted Acceleration (m/s^2)
1. Mean Values	3.59
2. Trunk Flexion altered to 50 degrees	3.69
3. Leg Angle altered to 45 degrees	4.09
4. Leg Angle altered to 45 degrees and Trunk Angle altered to 45 degrees	4.23

$\bar{X}$ Leg Angle at Take-off = 53 degrees

$\bar{X}$ Trunk Flexion at Touch-down = 65.5 degrees

TABLE 5

Test/Retest Correlations and Mean Differences

(National Sports Festival Participants N=54)

Variable	Trial 1	Trial 2	Correlation	Mean Difference
	(means)			
Time to skate 20 feet (s)	1.51	1.55	r=.06	0.13
Velocity at 20 feet (m/s)	6.26	6.21	r=.64	0.25
Average Acceleration (m/s^2)	3.56	3.51	r=.22	0.37
Stride Rate (per s)	4.07	4.09	r=.67	0.20
Toe-Hip Distance (m)	0.14	0.14	r=.62	0.03
Leg Angle at Take-off (deg)	53.74	54.14	r=.54	2.47
Trunk Flexion at Touch-down (deg)	53.44	53.08	r=.56	5.45

TABLE 6

Evaluation of Prediction Equation

(National Sports Festival Participants N=69)

	Actual	Predicted	Difference
Mean Value	3.53	3.49	0.04

Non-significant difference: $t = .957$

$({}_{.99}t_{68} = \pm 2.660)$

Forty-six of sixty-nine subjects had predicted accelerations within one standard error of the estimate.

TABLE 7

Comparison with Criterion Measures

(National Sports Festival Participants N=69)

Variable	Mean	Criterion	Number (of 69) at Criterion
1. Time to skate 20 feet (s)	1.52	1.80	69 (100%)
2. Velocity at 20 feet (m/s)	6.25	6.60	13 (19%)
3. Average Acceleration (m/s^2)	3.53	3.60	34 (49%)
4. Stride Rate (per s)	4.04	3.70	64 (93%)
5. Toe-Hip Distance (m)	0.14	0.18	58 (84%)
6. Leg Angle at Take-off (deg)	54.1	47.0	0 (0%)
7. Trunk Flexion at Touch-down (deg)	52.8	43.0	2 (3%)

TABLE 8

Effects of Altering Leg Angle and Trunk Flexion on Predicted Acceleration

(National Sports Festival Participants N=69)

Condition	Predicted Acceleration (m/s^2)
1. Mean Values	3.51
2. Trunk Flexion altered to 50 degrees	3.53
3. Leg Angle altered to 45 degrees	4.07
4. Leg Angle altered to 45 degrees and Trunk Angle altered to 45 degrees	4.12

$\bar{X}$ Leg Angle at Take-off = 54.1 degrees

$\bar{X}$ Trunk Flexion at Touch-down = 53 degrees

The results of both analyses indicate that the regression equation developed by Marino to predict average acceleration in skating 20 feet provides a reasonable fit to the data obtained from elite skaters. This is confirmed by the non-significant differences between the predicted and actual accelerations as well as the large portion of the skaters with actual accelerations within one standard error of estimate of the predicted value. It is interesting to note that for both groups a major weakness in the skating technique of the players tested would appear to be in the variables of trunk flexion and forward lean of the leg at take-off. In both analyses, a change of only 8 or 9 degrees in the angle of the leg at take-off produced a sizeable improvement in acceleration, all other factors remaining constant.

Despite the relatively accurate predictions of acceleration obtained from Marino's equation, the question remained whether a more suitable equation could be found for the elite skaters. A stepwise regression was performed with thirteen variables included in the selection process. The "best" equation as determined by the multiple correlation coefficient was as follows:

$$\text{Average Acceleration} = 7.49 - 1.9\,X1 - 4.92\,X2 - 2.28\,X3 - .02\,X4 - .02\,X5 - .65\,X6$$

Where:

X1 = Single support time

X2 = Double support time

X3 = Non-support time

X4 = Leg angle at take-off

X5 = Trunk angle at touch-down

X6 = Leg Length

The multiple correlation coefficient was $R=.48$ with a standard error of estimate of 0.28. The cross-validation coefficient was estimated using a formula developed by Stein (Olkin et al., 1975). The resulting value was 0.23.

Statistically, Marino's equation appears to be a stronger model as indicated by the multiple correlation coefficient and the cross-validation coefficient. However, these results are not surprising in light of the homogeneity of the subjects analyzed in the production of the second equation. In a sample with a similar ability level, the variability is generally minimal and the correlation coefficients are low. Consequently, large values for the multiple correlation coefficient would not be expected. Since extrapolation beyond the range of values for the sample from which the equation was derived is questionable, perhaps the best fitting equation could be derived from combining the data from both Marino's study and the present study. This would also yield a sample size of 149 subjects.

Several similarities may be noted between the two equations. In each, either stride rate or the various support times (which sum to the reciprocal of stride rate) was present. This agrees with previous findings of Page (1975) who observed that a quicker return of the skate to the ice, a quicker set of the inside edge, and a quicker extension of the knee were all related to greater velocity. Marino (1977) reported that skating velocity increased with both increased stride rate and decreased single support times.

Two other performance related factors were also present in both equations, notably leg angle at take-off and trunk angle at touch-down. Although their contribution to the new equation is not as great as in the original equation, the two angle measures must be considered as a potential area of improvement with regards to acceleration capability. One approach to further evaluation of these parameters would be to conduct pre- and post-testing in a controlled environment with a skating coach working to make the desired adjustments. Modification of technique in this manner would appear to be advantageous in in that it would put the skater in position to exert greater horizontal force and therefore benefit from a greater ground reaction force in the direction of desired movement. In addition, the greater flexion would place the extensor muscles in a stretched position thus increasing their physiological capabilities.

In summary, the results of the present study would indicate that regression analysis provides a reasonable approach to the study of sport performance. The use of statistical models allows the inclusion of biomechanical, anthropometrical, physiological, and psychological variables, all of which contribute to the final performance outcome.

As pertaining to acceleration in Ice Hockey, the results of the regression analyses indicate that improvements in skating acceleration could be achieved by decreasing the leg angle at take-off, decreasing the trunk angle at touch-down, and increasing the stride rate. Emphasis should be placed on these factors at all levels of skating ability but perhaps most importantly in the Youth Hockey programs. Finally, regression equations need to be developed over a wide range of skating abilities which should enhance the accuracy of the predicted values.

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