BIOMECHANICS OF FORWARD SKATING IN ICE HOCKEY

A Thesis

Presented to

the Graduate Faculty of

the School of Physical Education

Dalhousie University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Pierre Page

September, 1975

We, the undersigned, hereby certify our approval of this thesis and recommend its acceptance by the Faculty of Graduate Studies.

DALHOUSIE UNIVERSITY

Date September, 1975

Author Pierre Page

Title Biomechanics of Forward Skating in Ice Hockey

Department or School Physical Education

Degree M.Sc. Convocation Fall Year 1975

Permission is herewith granted to Dalhousie University to circulate and to have copied for non-commercial purposes, at its discretion, the above title upon the request of individuals or institutions.

Signature of Author

TABLE OF CONTENTS

CHAPTER		Page

APPENDIXES Page

ABSTRACT

Title of Thesis: Biomechanics of Forward Skating in Ice Hockey

Pierre G. Page: Master of Science, 1975

Thesis Advisor: Dr. Laurence E. Holt
Coordinator of Biomechanics Laboratory
School of Physical Education
Dalhousie University

The purpose of this thesis was to conduct a biomechanical analysis of hockey players skating at top speed in a direct line. Fourteen subjects from four different levels of ice hockey competition were chosen for this experiment.

The stepwise multiple regression analysis indicated that width of the stride and total recovery time of the skate blade were the most important factors to account for the variance in velocity. The stepwise multiple discriminant analysis also revealed that width of the stride and total recovery time of the skate blade were the most discriminating factors between fast and slow skaters.

These results showed that observable and measurable variables accounted for the various velocities even though it might be necessary in a further study to provide more accurate measurements of angles through the use of three-dimensional film and elgons.

ACKNOWLEDGEMENTS

I would like to express my appreciation to many people for their valuable assistance during various phases of this work.

To all of the subjects who took part in this study,

to my cameraman, Ted Faulkner,

to Jim Hoyle for his help with the computer programming and interpretation,

to Bill MacLeod, Ted Scrutton, and Ron Naud for their assistance in the collection of the data,

to Dr. Alexander Young and Dr. Brent Rushall for serving on the thesis committee,

to my advisor, Dr. Laurence E. Holt, for his quidance assistance, and motivation throughout the completion of this thesis,

I express my thanks.

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

Skating skills are such an integral part of the game of ice hockey that they may be considered the essential locomotor maneuvers for hockey players. Numerous books and articles have been written in an attempt to improve the acquisition of skating skills. Unfortunately, there appears to be little biomechanical evidence to support the teaching methods advocated by these authors.

Russian ice hockey researchers support the theory that speed of skating depends on strength and speed of execution of body mechanics such as, placing the thrusting blade on the ice at a 45°-60° angle from the line of direction, maintaining the knee of the thrusting foot forward, and the low and quick recovery of the skate blade.

Lariviere (1969) and Marcotte (1963) have studied skating skills and have concluded that faster skaters lean forward more with the lower part of the body, abduct their skates more, and take longer strides than slower skaters.

Marino (1974) reported that faster skaters compared with slower skaters recorded larger stride rates, smaller angles of knee flexion, and smaller vertical displacement of the skate blade during the recovery period. He also indicated that an increase in stride length might not be associated with an increase in horizontal velocity.

This study compared slow and fast skaters from the bantam, university and professional levels of competition who recorded velocities ranging from 18.1 feet/second to 35.1 feet/second.

Statement of the Problem

The purpose of this study was to conduct a biomechanical analysis of hockey players skating at top speed in a direct line in order to discover some factors which might account for any observed differences in speeds of skating.

Significance of the Study

This study could shed light on the mechanics involved in obtaining maximum speed in ice hockey skating, and as a result should benefit both players and coaches. Many game situations consist of rushing to cover an opponent, to recover the puck, or to position oneself for a pass. The skill of skating very rapidly in a direct line is most essential for performing these tasks.

Skating speed was considered by most coaches to be very complex and as a result was given very little attention. Players were often left wondering how they could specifically train to improve their speed of skating. Most of the factors which were considered by coaches and athletes to account for velocity of forward skating were non observable and non measurable. This thesis attempted to identify a number of observable and measurable variables which could easily be available to coaches. This would increase confidence among coaches concerning how to observe, measure, and evaluate the proper mechanics involved in speed of forward skating.

Such findings would undoubtedly bring a new dimension into the ice hockey skating clinics as coaches could establish more realistic levels of skating instruction, depending on the complexity of the skills. As a result, players could soon be able to evaluate themselves through self-motivating programs.

Few scientific studies have dealt with the speed of skating since it was considered by coaches, for many years, to be an inherited phenomenon. European countries have paid greater attention to the development of the correct technique of skating as they were faced with the teaching of this new skill to their youngsters. Unfortunately, most of their publications and findings are not available in Canada or the United States.

Delimitations

This study was delimited to 14 ice hockey players, six from the bantam level of competition (TASA team from Timberlea, Nova Scotia), which formed the youth skaters; three from the university varsity level of competition (Dalhousie University, Nova Scotia); two from recreational level of play (Dalhousie University, Nova Scotia); and three from the professional level of competition (Nova Scotia Voyageurs, Halifax, Nova Scotia). These final eight subjects comprised the adult skaters.

Each of these 14 players were selected on the basis of fast or slow skating velocity (feet/second) within each group of adults and youths.

Limitations

1. The temperature of the ice varied.

2. The type of skates varied.

3. The "rockered" condition of each blade was dissimilar from one skate to another and from one ice hockey skater to another.

4. The weight, height, and shape of skates were not part of the computer program analysis.

5. The computer analysis was not three dimensional, therefore, causing some of the angular measurements to be subject to error.

Definition of Terms

Velocity is the rate of travel measured in displacement per unit time (feet/second)

Speed line is the center line, forty feet in length and two inches in width, which was traced perpendicularly to the start and finish lines.

Angle of curvature of the stride is the measurement in degrees of the deviation of the stride from a straight line obtained by joining the greatest point of curvature in the stride to the beginning and end prints of the stride on the ice (see Figure 1).

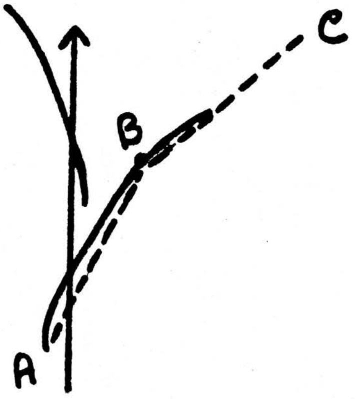


FIGURE 1. Angle of Curvature of the Stride (ABC)

Angle of thrust is the measurement in degrees of the angle between two successive strides taken from the ice prints of the skates (see Figure 2).

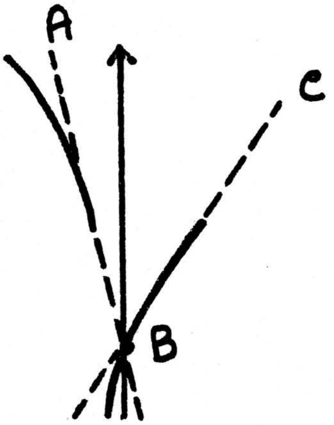


FIGURE 2. Angle of Thrust (ABC)

Length of the stride is the measurement in inches of the distance from the initial print to the end print of the skate blade on the ice, including its variations from a straight line.

Length of the stride along the speed line is the measurement in inches of the distance between two perpendicular lines crossing the speed line at the beginning and at the end of the stride, taken from the ice prints of the skates (see Figure 3).

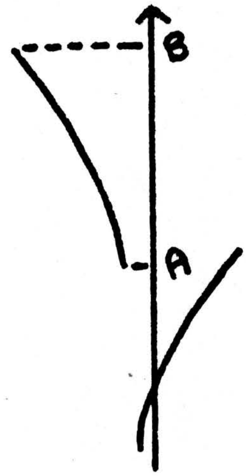


FIGURE 3. Length of the Stride Along the Speed Line (AB)

Width of the stride is the measurement in inches of the perpendicular distance between two lines, parallel to the speed line, the first being drawn at the beginning of the stride and the second being drawn at the end of the stride, taken from the ice prints of the skates (see Figure 4).

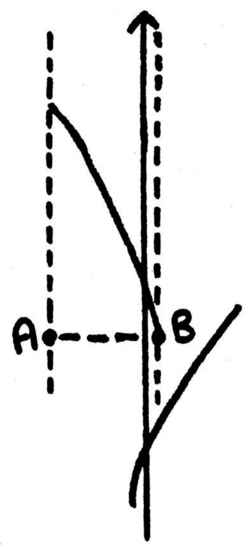


FIGURE 4. Width of the Stride (AB)

Length between strides is the measurement in inches of the distance between two perpendicular lines crossing the speed line at the end of a stride and at the beginning of the following stride, taken from the ice prints of the skates (see Figure 5).

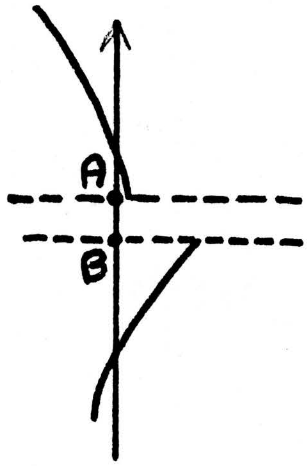


FIGURE 5. Length Between Strides (AB)

Width between strides is the measurement in inches of the perpendicular distance between two lines, perpendicular to the speed line, the first being drawn at the end of a stride and the second being drawn at the beginning of the following stride, taken from the ice prints of the skates (see Figure 6).

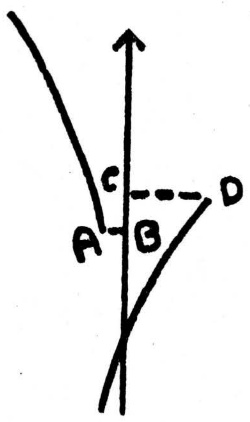


FIGURE 6. Width Between Strides (AB + CD)

<u>Angle of abduction of the skate blade</u> is the measurement in degrees of the maximum observed angle of the outward rotation of the blade from a line parallel to the speed line during knee extension (see Figure 7).

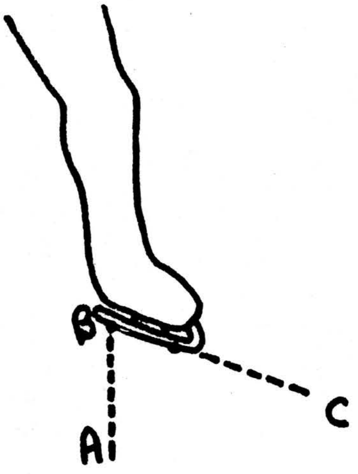


FIGURE 7. Angle of Abduction of the Skate Blade (ABC)

<u>Angle of inclination of the lower leg</u> is the measurement in degrees of the deviation of the thrusting lower leg from the vertical, prior to the initial thrusting action obtained by joining the middle of the knee to the middle of the ankle (see Figure 8).

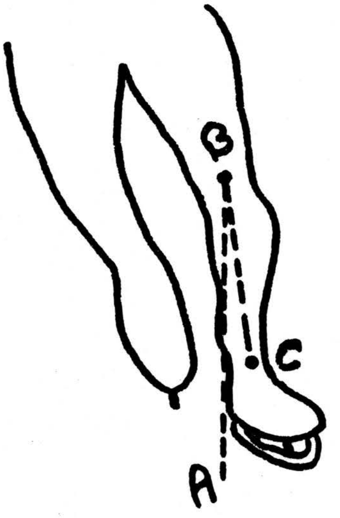


FIGURE 8. Angle of Inclination of the Lower Leg (ABC)

Angle of abduction of the leg is the measurement in degrees of the lateral deviation of the leg, prior to the skate blade lifting off the ice, obtained by joining a vertical line with the middle of the hip which is joined with the middle of the toe (see Figure 9).

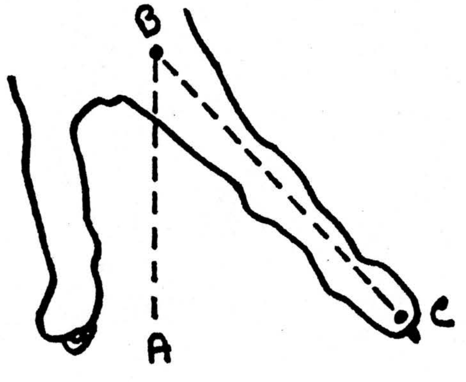


FIGURE 9. Angle of Abduction of the Leg (ABC)

Angle of extension of the leg to the back is the measurement in degrees of the backward position of the leg from the vertical determined by joining the middle of the hip to the middle of the toe taken from a lateral view of the film prior to the skate blade lifting off the ice (see Figure 10).

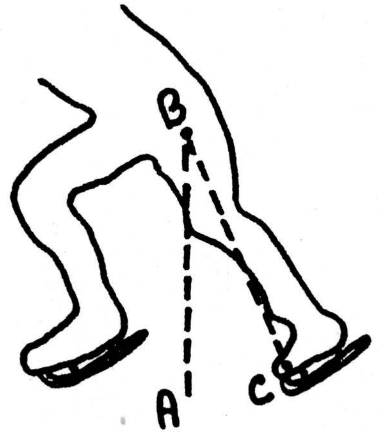


FIGURE 10. Angle of Extension of the Leg to the Back (ABC)

Angle of the leg at extension is the measurement in degrees of the angle of the knee, prior to the skate blade lifting off the ice, determined by joining the middle of the hip to the middle of the knee and finally to the middle of the ankle taken from a lateral view of the film (see Figure 11).

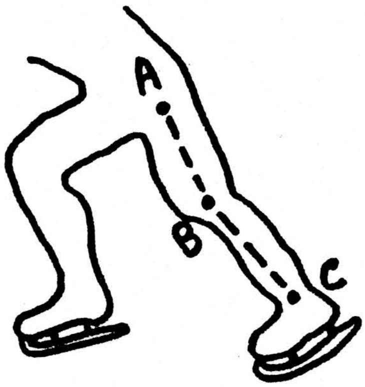


FIGURE 11. Angle of the Leg at Extension (ABC)

Angle of knee flexion is the measurement in degrees of the angle between the lower and upper part of the leg, prior to the initial thrusting action, determined by joining the middle of the hip to the middle of the knee and finally to the middle of the ankle taken from a lateral view of the film (see Figure 12).

FIGURE 12. Angle of Knee Flexion (ABC)

Early recovery time of the skate blade is the elapsed time between the lift-off of one skate blade and the initial touchdown of the same skate blade, determined by counting the number of frames from lift-off to touchdown taken from a lateral view of the film (1 frame equals 0.022 seconds).

Mid-recovery time of the skate blade is the elapsed time between the lift-off of one skate blade and the position of the same skate blade under the center of gravity, determined by counting the number of frames from lift-off to the position under the center of gravity taken from a lateral view of the film (1 frame equals 0.022 seconds).

Total recovery time of the skate blade is the elapsed time between the lift-off of one skate blade and the setting of edges of the same skate blade prior to its initial thrusting action, determined by counting the number of frames from lift-off to setting of edges taken from a lateral view of the film (1 frame equals 0.022 seconds).

Angle of forward inclination is the measurement in degrees of the forward lean of the lower body from the line of direction on the ice by joining the middle of the hip to the middle of the toe and finally to the horizontal line, prior to the lift-off of the skate blade taken from a lateral view of the film (see Figure 13).

Angle of the trunk is the measurement in degrees of forward upper body lean from the line of direction, determined by joining the middle of the head to the middle of the hip and finally to the horizontal line, prior to the lift-off

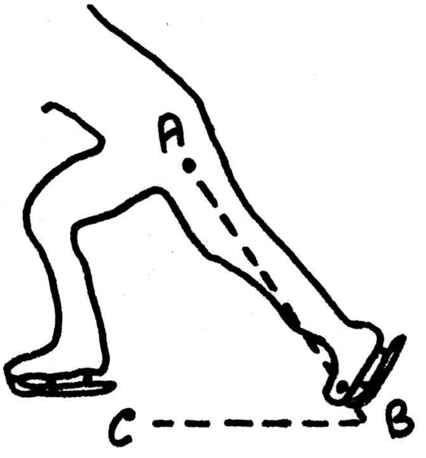


FIGURE 13. Angle of Forward Inclination (ABC)

of the skate blade taken from a lateral view of the film (see Figure 14).

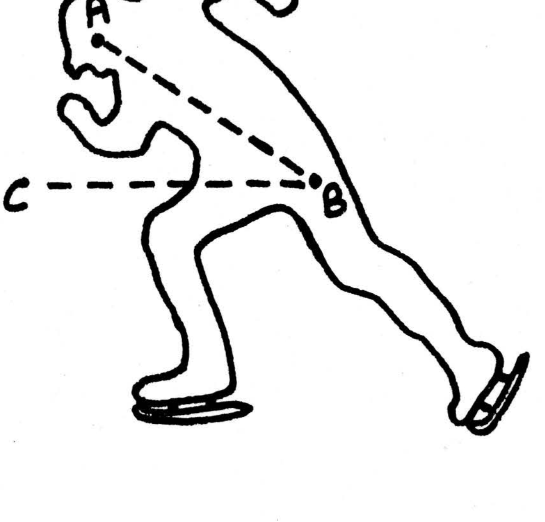


FIGURE 14. Angle of the Trunk (ABC)

Angle of trunk to thigh is the measurement in degrees of the lower and upper body flexion obtained by joining the middle of the foot to the middle of the hip to, finally, the middle of the head taken from a lateral view of the film, prior to lift-off of the skate blade (see Figure 15).

FIGURE 15. Angle of Trunk to Thigh (ABC)

Time of knee extension is the recording of the number of frames from the beginning to the end of knee extension taken from a lateral view of the film.

Range of knee extension is the measurement in degrees of the difference between the angle of the knee at extension and the maximum angle of the knee during flexion prior to the initial thrusting action.

Review of Literature

Scientific investigation in ice hockey is limited to a few select areas. Most notable are studies dealing with mechanical efficiency and analysis of non-skating skills, the design and evaluation of skills tests, and those associated with physiological phenomena.

Marcotte (1963) noticed that the angle of propulsion decreased considerably from the initial acceleration at the start to the maximum velocity. The decrease was not rapid between the second and sixth stride where the angle formed finally ranged from 36°-45°.

Marino (1974) analyzed how maximum speed is attained. Measurements of stride rate, stride length, duration of glide phase, and degree of lower leg flexion about the thigh were made through the use of a Vangard motion analyser. The results indicated that stride rate increased as the horizontal velocity of power skating increased. At maximal velocity, the mean stride rates were 3.117 strides per second for above average and 2.44 strides per second for below average performers. The relationship between horizontal velocity and stride length was found to be statistically non-significant for both groups. The mean stride lengths were 9.127 feet for above average and 8.428 feet for below average. It was also reported that slower skaters showed a greater tendency to run on their skates than did above average skaters. This was exemplified by the greater knee flexion and greater vertical displacement of the skate from the ice by the slower skaters, during the recovery phase of the skating stride. The mean degrees of flexion at the knee were 95.96 degrees for above average and 84.73 degrees for below average skaters. This difference was found to be statistically significant at the .95 confidence level.

Lariviere (1969) studied the "Relationship Between Skating Velocity and Length of Stride, Angle of Forward Inclination, and Angle of Propulsion," during the first four strides. The results indicated that the fastest skaters, in comparison with the slowest skaters, seemed to lean forward more, abduct their skates more, and take longer strides. An angle of propulsion of about 90 degrees was most effective during the first stride in providing a fast start from a stationary position. This angle decreased to 35 degrees during the fourth stride of the fastest skaters. A significant positive relationship was also found between the velocity obtained at the end of the first four strides and the length of those strides. The fastest group of skaters had a significantly smaller angle of forward inclination than had the slower group at the end of four strides. During the fourth stride, the angle of forward inclination was 49 degrees for the fastest skater and 53 degrees for the slowest skater. After the first four strides, the angle of forward inclination had almost reached the theoretically ideal angle of 45 degrees (Broer, 1966). This referred to the opinion of Marcotte (1963) who stressed that his statements, concerning the forward lean of the body, were essentially theoretical. He advanced that an angle of forward inclination larger than 45 degrees contributed to a loss of time and an increased muscular energy expenditure. A skater should attempt to lean forward at an angle of 45 degrees as soon as he increased his momentum, which allows him to almost reach this theoretical ideal angle of forward inclination without collapsing forward.

Other studies are found in the literature on ice hockey skating but they are not closely related to this scientific investigation. Saint-Denis (1956) determined the fastest method of starting from a stopped position in ice hockey when a skater carried a hockey stick in both hands without controlling a puck. The skaters were asked to use both the skating front start method and the running method (the use of the front tips of the skate blades for propulsion during the first four or five fast strides). He concluded that the running method of starting was the fastest.

Thiffault (1967) compared the time required to skate 20 feet from a stationary starting position by means of four different methods. The methods were called the front start, the side start lead foot, side running start, and the side cross-over. The side start lead foot method of starting was found to be the fastest.

Naud (1974) in his study "A Comparison of Selected Hockey Skating Techniques," compared three methods of initiating forward movement (IFM), and three methods of stopping, reversing direction, and starting (SRS), with professional, college, junior B and bantam players. The results indicated that the thrust and glide method was significantly faster than either the straight-away method or the cross over method in three of the four groups. The thrust and glide method was indeed faster for the professionals but not significantly faster, as it was for the lesser performance groups. The thrust and glide method of starting was faster because it made use of outward rotation of the front leg and the thrusting action of the back leg. As for the methods of stopping, reversing direction, and starting (SRS), the method of stopping with the feet parallel and reversing direction with the use of the thrust and glide start was significantly faster than the other two. It involved stopping with both feet parallel and approximately 12 inches apart and reversing direction by making use of the "thrust and glide" start. Another method involved identical position of the feet when stopping but in reversing direction the skater made use of one "cross over" start. A third method involved stopping with both feet apart in a straight line and parallel to the starting line and reversing direction by using one "cross over" start. The method of starting, reversing direction by making use of a thrust and glide start allowed the skaters to stop quicker as it decreased the drift and upon reversing direction, the skaters were in a mechanically better position to initiate forward movement (90° push of rear leg).

Jones (1970) also compared the skating styles used in ice hockey. He reported that the front method of starting was found to be superior to the side method of starting in relation to speed and acceleration for both the first 30 feet and the total distance of 60 feet.

While scientific research concerning the analysis of various ice skating speeds remains limited, many hockey players and hockey experts expressed their ideas on the topic. Most of them agreed that speed of skating is most important but their description of the skill is very superficial.

Orr (1970) when elaborating on speed of skating believed that "the harder you push, the faster you will go." He advanced that strong legs are essential and affected one's style of skating of long strides or short and choppy strides. Orr also noticed that players tried to attain speed by either bending over more than others or opted to skate in a straight up position.

Percival (1960) believed that some players had "the type of muscles to generate speed." He also claimed that "the slower endurance boys, no matter what they do, will never be able to skate as fast as the speed boys." Percival considered speed to be about 25 percent mental: "the player who consciously drives himself past the natural tendency to take things easy will skate faster than if he makes no such conscious attempt." Players who skated with their body in an erect position were observed to lose their forward drive as well as run on their skates with a high foot lift. Those players who failed to utilize the hip freely seemed to lack drive and speed and worked very hard without any meaningful results. When hockey players lifted their skat blades too high off the ice, it caused a waste of energy and detracted from both speed and balance.

Meeker (1973) referred to power when analysing speed of skating. He considered the correct skating posture an essential factor in developing power. The proper position consisted of a slight crouch with the knees slightly bent, the shoulders over the knees, and the knees over the ball of the foot, and the head kept up. Speed or power could be observed on clean ice from the marks of the thrusting skate blade. "A sharp curve that ended more than 45 degrees from the skater's direction showed close to maximum thrust." A very slight curve in the skate cut indicated low power. Skaters in the latter case have to transfer their weight off the driving leg prematurely to maintain their balance. In order to develop full power, a skater needs to turn his toes outward to assist his skate in biting the ice and giving him the essential drive.

Wild (1971) believed that short strides helped an ice hockey skater attain great speed while long strides helped maintain speed and was less tiring. If a player kept using short strides, he would be fast on the start; but he would be unable to keep up to a skater who changed to a long stride after building up speed.

Walford (1971) supported the theory that the stride should be short and powerful when an increase in speed was needed; a longer and less demanding stride should be used in order to maintain speed.

In summary, the results of scientific research on speeds of forward skating revealed that length of stride may not be accompanied by increases in velocity, even though faster skaters exhibited both high stride rates and longer stride lengths than slower skaters. The tendency of poorer skaters to run on their skates was associated with greater knee flexion and greater vertical displacement of the skate from the ice during the recovery phase of the skating stride. It was also believed that the important factor in speed of skating was to get the blade back on the ice, under the center of gravity, as quickly as possible. When accelerating from a start, faster skaters leaned forward more, abducted their skates more, and took longer strides.

From the beliefs of hockey players and hockey experts, it appeared that correct skating posture, longer strides, stronger legs, outward rotation of the blade beyond the 45 degree angle from the line of direction, freedom of the hip during the thrusting action, and low recovery of the skate blade were the most determinant factors accounting for speed of forward skating. The correct skating posture involved the semi-crouch upper body position, the knees slightly bent, the shoulders over the knees, the knees over the ball of the foot, and the head held up.

This review of literature clearly showed that hockey researchers and hockey experts were not in complete agreement concerning the factors accounting for the various speed of forward skating. Furthermore, only one study by Marino (1974) was very closely related to this study of forward skating at maximal velocity, while studies by Lariviere (1969) and Marcotte (1963) dealt with acceleration in skating.

Chapter 2

METHODS AND PROCEDURES

Selection of Subjects

The 14 male skaters who volunteered to participate in this study initially trained until they performed the speed skating test as naturally, effectively, and consistently as possible along the speed line. This ranged from 4 to 10 trials.

The skaters showed a wide range of skating velocities. The six bantam players were from the same TASA bantam team from Timberlea, Nova Scotia. The two slow university skaters played non-competitive hockey games within the physical education structure, while the three fast university skaters were members of the Varsity Hockey Team. The other three skaters from the professional ranks were competing for the Nova Scotia Voyageurs of the American Hockey League.

Despite the restricted number of subjects involved in this study, their performances did represent a range of skating speeds.

Direct Measurement of Velocity

The apparatus for the measurement of velocity included two sets of photo electric cells, one Dekan timer, one flashing light, and five stacking tables (see Appendix A).

A two-inch wide line constituted the starting line. Two photo electric cells were situated there. The second set of photo electric cells was placed 40 feet away and parallel to the starting line. Both the finish line and the speed line were two inches wide. The speed line was drawn perpendicular to both the start and finish lines. The latter set of photo electric cells stopped the timer and indicated the elapsed time to travel 40 feet along the speed line (see Appendix A).

Direct Linear and Angular Measurements

The linear and angular measurements were obtained on clean ice from the marks of the thrusting skate blades immediately after the second and fourth trial. The measuring apparatus included one large wooden protractor, one metal tape measure, two metal squares, and a nylon string.

The angular measurements consisted of the angle of thrust and the angle of curvature of the right and left strides. The linear measurements included length of the right and left strides along the speed line, width of the right and left strides, length between strides, and width between strides.

Three trained observers served to collect these measurements. The positioning of the measuring apparatus and the reading of the measures were agreed to by each of the three trained observers for each of the 11 variables measured on the ice.

The measurements obtained from the film were recorded by the investigator. The recording of the 19 required points on the digitizer tablet was performed by the investigator who selected the middle score of the three scores recorded for each of the 19 required points.

Cinematographical Methods

The use of two cameras provided lateral and frontal views. The lateral views of the ice hockey skating techniques were filmed via a Locam 16 mm high speed motion picture camera, model 1645 AE; the locam camera rested upon a tripod midway between the first and second sets of photo electric cells at a distance of 49 feet from the filming zone.

A Bolex Model H 16, 16 mm springwound motion picture camera was used to film the frontal perspective of the ice hockey skaters. The Bolex camera was positioned upon a tripod midway between the second set of photo electric cells at a distance of 50 feet from the middle of the filming zone.

The Bolex speed was set at 52 frames per second and equipped with 75 mm lens. The Locam speed was set at 46 frames per second and equipped with 25 mm lens.

Prior to filming, an electric clock divided into hundreds of a second was filmed with both cameras. This acted as a calibration check for both the Locam and Bolex cameras.

Before filming the subjects, a linear scale was placed in the filming zone in both planes of action and filmed for measurement purposes. The scale was held perpendicular to the ice surface and was marked in 12-inch segments.

As the subjects approached the filming zone, a verbal cue was given to start the cameras, thus allowing both cameras to reach the pre-determined speed before the subjects actually entered the filming zone. When the subjects stepped on the starting line, a light was flashed in order to set a synchronizing point for the two different camera views.

Testing Procedures

Each of the selected skaters was requested to perform four trials. The first trial consisted of recording only the velocity. It did not involve filming or angular and linear measurements. On the second trial, velocity, lateral and frontal film perspectives, and linear and angular measurements from the ice were taken. The third trial repeated the procedures of the first trial. The fourth trial repeated the procedures of the second trial.

On each trial, the skater started on a verbal signal and accelerated over an elected distance towards the starting line in order to have attained as close to maximum speed as possible when he crossed the starting line. The skater was asked to skate as fast as possible until he had completely crossed the finish line. Each skater was reminded to skate as straight as possible over the speed line.

The procedure required that each subject be wearing only skates, socks, and gym shorts so that particular body points could be more easily located. Subjects supplied their own skates, socks, and gym shorts.

Indirect Measurement by Cinematography

The developed film was placed in a super sports analyser 800 and the picture projected onto the flat vertical surface on one-millimeter graph paper, which was used as a screen. This particular projector was used because it provided stop action and single frame advancement in addition to forward and backward movement of the film. The graph paper was used to record angular measurements while stop action and single frame advancement provided for the recording of the number of frames.

Angular Measurements

The lateral view provided by the Locam 16 mm camera contributed to the measurement of six angular variables: the angle of extension of the leg to the back, angle of the leg at extension, angle of knee flexion, angle of forward inclination, angle of trunk, and angle of trunk to thigh. The Bolex camera captured the frontal view which served for the measurement of three angular variables: the angle of abduction of the blade, angle of inclination of the lower leg, and angle of abduction of the leg.

The lateral view also provided the recording of the velocity of knee extension.

All angles measured are subject to a small amount of error depending on the position of the limbs relative to the camera.

Frame Measurement

The single frame advancement provided by the super sports analyser 800 provided the recording of three variables from the lateral view of the Locam 16 mm camera: early recovery time, mid-recovery time of the skate blade, and time of knee extension. It also provided the recording of one variable from the frontal view of the Bolex camera, the total recovery time of the skate blade.

The range of knee extension was obtained from the difference between the angle of knee flexion and the angle of the knee at extension.

Digitizing

Each of the 19 required points for the calculation of the center of gravity of the body in various selected frames was obtained from the frontal and lateral views of the film. Every second frame was analyzed, taking into account the variation in speed of the Bolex (52 feet/second) and the Locam (45 feet/second). The films were projected onto a graf pen digitizer. The graf pen digitizer was made up of a graf pen, which upon contact with the digitizer tablet sparked the end. Sharp transient pulses were produced by the pen source; these pulses reached the X and Y microphones on the digitizer tablet. The co-ordinates of the points touched were then recorded automatically in a control unit.

The control unit interpreted information from the sensors indicating the position of the pen on the X and Y axis of the tablet. The co-ordinates were then recorded on MOVEBOD sheets. The program MOVEBOD required the entry of 19 body parts in sequence for each frame analyzed. Since the computer expected a minimum of 19 entries per frame, any deviation from this format would result in an error which could not be detected by the computer.

The MOVEBOD program gave the writer horizontal, vertical, linear displacements, velocities, and acceleration of all body parts and the center of gravity of the body.

Each of the 14 subjects was analyzed via computer program MOVEBOD for their fastest trial from both lateral and frontal views. Eight frames (every second frame) were analyzed for the six fast adult skaters while 10 frames were analyzed for the two slow adult skaters. Ten frames were analyzed for the slow youth skaters while it varied considerably for the fast youth skaters. The fastest youth skater was analyzed over 10 frames; the second fastest youth over 7 frames; and the third fastest youth for 8 frames. This variation was due to the restricted filmed area from the lateral view.

Analysis of Data

The collected data was entered and verified on IBM cards. The importance of variables and combinations of variables in accounting for the variance in velocity were determined using a stepwise multiple regression analysis. The analysis was computed in each of the following groups: total group of 14 skaters, 6 youth skaters, and 8 adult skaters.

This method also provided a correlation matrix for each of the three groups from which the correlations between velocity and each of the 27 variables were analyzed. A significance level of alpha = 0.05 was used. This was decided upon rather by tradition than by any other justification.

The use of the multiple stepwise discriminant analysis provided two important sets of information: 1) two group comparisons at each step of the analysis, and 2) a weighted listing of variables ranked according to their importance for discriminating between groups of fast and slow skaters. Three analyses were computed: between 9 fast skaters (6 adults and 3 youths) and 5 slow skaters (2 adults and 3 youths); between 3 fast youth skaters and 3 slow youth skaters; and between 6 fast adult skaters and 2 slow adult skaters.

Chapter 3

RESULTS

Total Group of 14 Skaters

The correlation matrix of all variables for the total group of 14 skaters revealed that velocity was found to have a significant positive correlation with width of the left stride, range of knee extension, width of the right stride, length of the right stride along the speed line, length of the right stride, and width between strides. A significant negative correlation was found between velocity and angle of knee flexion, total recovery time of the skate blade, mid-recovery time of the skate blade, angle of the trunk, and time of knee extension.

The relationship between width of the left stride and the following three variables: range of knee extension, angle of knee flexion, and total recovery time of the skate blade was found to be significantly related for the group of 14 skaters. These last three variables were also found to be significantly related with angle of abduction of the leg, angle of the trunk, and angle of forward inclination.

Width between strides was found to be significantly related with width of the left stride and range of knee extension. Time of knee extension was found to be significantly related with total recovery time of the skate blade and angle of the trunk. Length of the right stride was found to be significantly related with length of the right stride along the speed line, width of the left stride, width between strides, and angle of curvature of the right stride.

However, the study revealed that velocity was found to be non-significantly related with length of the left stride, length of left stride along the speed line, length between strides, early recovery time of the skate blade, angle of curvature of the left stride, angle of thrust, angle of abduction of the blade, angle of inclination of the lower leg, angle of abduction of the leg, angle of extension of the leg to the back, angle of the leg at extension, angle of forward inclination, and angle of trunk to thigh.

Table 1 indicates the variables which were found to be statistically significant with velocity for the total group of 14 skaters. Table 2 indicates the variables which were found to be statistically non-significant with velocity for the total group of 14 skaters.

Six Youth Skaters

The correlation matrix of all variables for the six youth skaters revealed that velocity was found to have a significant positive correlation with length of the right stride, width of the right stride, width of the left stride, range of knee extension, angle of abduction of the blade, angle of abduction of the leg, and angle of extension of the leg to the back. A significant negative correlation was found between

Table 1. Significant Relationships in the Correlation Matrix of Variables for the Total Group of 14 Skaters

Variable #1	Significant Variables
Velocity	#7 (width of the left stride)
Velocity	#14 (range of knee extension)
Velocity	#23 (angle of knee flexion)
Velocity	#12 (total recovery time of the skate blade)
Velocity	#6 (width of the right stride)
Velocity	#4 (length of the right stride along the speed line)
Velocity	#2 (length of the right stride)
Velocity	#11 (mid-recovery time of the skate blade)
Velocity	#8 (width between strides)
Velocity	#25 (angle of the trunk)
Velocity	#13 (time of the knee extension)

Table 2. Non-Significant Relationships in the Correlation Matrix of Variables for the Total Group of 14 Skaters

Variable #1	Non-Signigicant Variables
Velocity	#3 (length of the left stride)
Velocity	#5 (length of the left stride along the speed line)
Velocity	#9 (length between strides)
Velocity	#10 (early recovery time of the skate blade)
Velocity	#15 (angle of curvature of the right stride)
Velocity	#16 (angle of curvature of the left stride)
Velocity	#17 (angle of thrust)
Velocity	#18 (angle of abduction of the blade)
Velocity	#20 (angle of inclination of the lower leg)
Velocity	#21 (angle of abduction of the leg)
Velocity	#22 (angle of extension of the leg to the back)
Velocity	#24 (angle of the leg at extension)
Velocity	#26 (angle of forward inclination)
Velocity	#27 (angle of the trunk to thigh)

velocity and angle of knee flexion, angle of the trunk, angle of forward inclination, mid-recovery time of the skate blade, total recovery time of the skate blade, and time of knee extension.

However, the study revealed that length of the stride along the speed line and width between strides were found to be statistically non-significant with velocity for the six youth skaters, while these same relationships were found to be statistically significant for the total group of 14 skaters. The relationships between velocity and four other variables were found to be statistically significant for the six youth skaters, while these same relationships were non-significant for the total group of 14 skaters. These four variables were angle of abduction of the blade, angle of abduction of the leg, angle of extension of the leg to the back, and angle of forward inclination.

However, the study revealed that the relationships between velocity and 12 other variables were found to be statistically non-significant for the six youth skaters. These 12 variables were length of the left stride, length of the right stride along the speed line, length of the left stride along the speed line, width between strides, length between strides, early recovery time of the skate blade, angle of curvature of the right stride, angle of curvature of the left stride, angle of thrust, angle of inclination of the lower leg, angle of the leg at extension, and angle of the trunk-thigh.

Table 3 indicates the variables which correlated with velocity for the six youth skaters. Table 4 indicates the variables which did not correlate with velocity for the six youth skaters.

Eight Adult Skaters

The correlation matrix of all variables for the eight adults revealed that velocity was found to have a significant negative correlation with total recovery time of the skate blade, angle of the trunk, angle of knee flexion, and angle of forward inclination. A significant positive correlation was found between velocity and range of knee extension, angle of inclination of the lower leg, width of the left stride, width between strides, and angle of extension of the leg to the back.

However, the study revealed that width of the right stride, length of the right stride along the speed line, length of the right stride, mid-recovery time of the skate blade, and time of knee extension were found to correlate with velocity for the eight adults, while the same correlations were not found for the total group of 14 skaters. The relationships between velocity and three other variables were found to be statistically significant for the eight adult skaters while the same relationships were found to be non-significant for the total group of 14 skaters. These variables were angle of inclination of the lower leg, angle of extension of the leg to the back, and angle of forward inclination.

However, the study revealed that the relationships between velocity and 15 other variables were found to be

Table 3. Significant Relationships in the Correlation Matrix of Variables for the Six Youth Skaters

Variable #1	Significant Variables
Velocity	#12 (total recovery time of the skate blade)
Velocity	#23 (angle of knee flexion)
Velocity	#7 (width of the left stride)
Velocity	#21 (angle of abduction of the leg)
Velocity	#6 (width of the right stride)
Velocity	#13 (time of knee extension)
Velocity	#18 (angle of abduction of the blade)
Velocity	#22 (angle of extension of the leg to the back)
Velocity	#26 (angle of forward inclination)
Velocity	#25 (angle of the trunk)
Velocity	#14 (range of knee extension)
Velocity	#2 (length of the right stride)
Velocity	#11 (mid-recovery time of the skate blade)

Table 4. Non-Significant Relationships in the Correlation Matrix of Variables for the Six Youth Skaters

Variable #1	Non-Significant Variables
Velocity	#3 (length of the left stride)
Velocity	#4 (length of the right stride along the speed line)
Velocity	#5 (length of the left stride along the speed line)
Velocity	#8 (width between strides)
Velocity	#9 (length between strides)
Velocity	#10 (early recovery time of the skate blade)
Velocity	#15 (angle of curvature of the right stride)
Velocity	#16 (angle of curvature of the left stride)
Velocity	#17 (angle of thrust)
Velocity	#20 (angle of inclination of the lower leg)
Velocity	#24 (angle of the leg at extension)
Velocity	#27 (angle of the trunk-thigh)

statistically non-significant for the eight adults. These 15 variables were length of the right stride, length of the left stride, length of the right stride along the speed line, length of the left stride along the speed line, width of the right stride, length between strides, early recovery time of the skate blade, mid-recovery time of the skate blade, time of knee extension, angle of curvature of the right stride, angle of curvature of the left stride, angle of thrust, angle of abduction of the blade, angle of the leg at extension, and angle of the trunk-thigh.

Table 5 indicates the variables which correlated with velocity for the eight adult skaters. Table 6 indicates the variables which did not correlate with velocity for the eight adult skaters.

Multiple R of the Total Group of 14 Skaters

The stepwise multiple regression analysis of the total group of 14 skaters revealed that width of the left stride regressed strongly on velocity, as the dependent variable, with a regression coefficient (R) of .90. In the second step of the analysis, angle of abduction of the skate blade was entered, regressing on velocity with a multiple (R) of .95. This reduced the variance in velocity by a further 8.8 percent to a remaining 9.9 percent. According to Weber and Lamb (1970), the coefficient of determination (R^2) after step 3 indicated that 95.6 percent of the variance in velocity was related to the variance in width of the left stride, angle of abduction of

Table 5. Significant Relationships in the Correlation Matrix of Variables for the Eight Adult Skaters

Variable #1	Significant Variables
Velocity	#12 (total recovery time of the skate blade)
Velocity	#23 (angle of knee flexion)
Velocity	#26 (angle of forward inclination)
Velocity	#14 (range of knee extension)
Velocity	#20 (angle of inclination of the lower leg)
Velocity	#7 (width of the left stride)
Velocity	#8 (width between strides)
Velocity	#25 (angle of the trunk)
Velocity	#22 (angle of extension of the leg to the back)

Table 6. Non-Significant Relationships in the Correlation Matrix of Variables for the Eight Adult Skaters

Variable #1	Non-Significant Variables
Velocity	#2 (length of the right stride)
Velocity	#3 (length of the left stride)
Velocity	#4 (length of the right stride along the speed line)
Velocity	#5 (length of the left stride along the speed line)
Velocity	#6 (width of the right stride)
Velocity	#9 (length between strides)
Velocity	#10 (early recovery time of the skate blade)
Velocity	#11 (mid-recovery time of the skate blade)
Velocity	#13 (time of knee extension)
Velocity	#15 (angle of curvature of the right stride)
Velocity	#16 (angle of curvature of the left stride)
Velocity	#17 (angle of thrust)
Velocity	#18 (angle of abduction of the blade)
Velocity	#24 (angle of the leg at extension)
Velocity	#27 (angle of the trunk-thigh)

the skate blade, and time of knee extension of which 5.5 percent was not related to the variance in velocity. The coefficient of non-determination ($1-R^2$) indicated that 4.4 percent of the velocity was not related to the variance of any of these variables (see Table 7).

Multiple (R) of the Eight Adult Skaters

The stepwise multiple regression analysis for the eight adult skaters revealed that total recovery time of the skate blade regressed strongly on velocity, as the dependent variable, with an (R) of .75. The next variable to be entered, in step 2, was width of the left stride which regressed on velocity by a further 33.3 percent to a remaining 10 percent. The coefficient of determination, after step 3, indicated that 98.7 percent of the variance in velocity was related to the variance in total recovery time of the skate blade, width of the left stride, and width of the right stride of which 8.7 percent was related to the variance in velocity. The coefficient of non-determination ($1-R^2$) revealed that 1.3 percent of the variance in velocity was not related to the variance of any of these three variables (see Table 8).

Multiple (R) of the Six Youth Skaters

The stepwise multiple regression analysis for the six youth skaters revealed that total recovery time of the skate blade regressed strongly on velocity, as the dependent variable, with an (R) of .98. The coefficient of determination

Table 7. Summary of the Stepwise Multiple Regression Analysis of the Total Group of 14 Skaters

Step Number	Variable Entered or Removed	Multiple R	RSQ	Increase in RSQ	F Value to Enter or Remove	Number of Independent Variables Included
1	7	.9016	.8129	.8129	52.1282	1
2	18	.9492	.9010	.0881	9.7887	2
3	13	.9779	.9564	.0554	12.6963	3
4	11	.9860	.9721	.0158	5.0944	4
5	25	.9892	.9785	.0063	2.3550	5
6	21	.9945	.9890	.0105	6.6582	6
7	16	.9976	.9953	.0063	8.0960	7
8	5	.9986	.9971	.0018	3.1937	8
9	15	.9996	.9992	.0020	9.6934	9
10	17	.9999	.9998	.0007	13.2537	10

Table 8. Summary of the Stepwise Multiple Regression Analysis of the Eight Adult Skaters

Step Number	Variable Entered or Removed	Multiple R	RSQ	Increase In RSQ	F Value to Enter or Remove	Number of Independent Variables Included
1	12	.7529	.5669	.5669	7.8530	1
2	7	.9486	.8999	.3330	16.6347	2
3	6	.9933	.9867	.0868	26.0611	3
4	10	.9977	.9953	.0086	5.5360	4
5	14	1.0000	.9999	.0046	149.4804	5
6	2	1.0000	1.0000	.0001	0.0000	6

Table 9. Summary of the Stepwise Multiple Regression Analysis of the Six Youth Skaters

Step Number	Variable Entered or Removed	Multiple R	RSQ	Increase In RSQ	F Value to Enter or Remove	Number of Independent Variables Included
1	12	.9842	.9687	.9867	123.6284	1
2	9	.9992	.9984	.0297	54.8551	2
3	23	.9998	.9996	.0012	8.4462	3
4	22	1.0000	1.0000	.0004	23.9823	4

after step 1, indicated that 98.7 percent of the variance in velocity was related to the variance in total recovery time of the skate blade. This revealed that 1.3 percent of the variance in velocity was not related to the variance in total recovery time of the skate blade (see Table 9).

Discriminant Analysis of Velocity Between Nine Fast Skaters and Five Slow Skaters

The stepwise multiple discriminant analysis, with velocity being removed as a variable, revealed that total recovery time of the skate blade accounted for 74.2 percent of the differentiation between the nine fast skaters (6 adults and 3 youths) and five slow skaters (2 adults and 3 youths) with a significant F-value of 34.44. The angle of inclination of the lower leg accounted for a further 17.7 percent with a significant F-value of 24.05. These two variables accounted for 91.9 percent of the variance between the nine fast skaters and five slow skaters (see Table 10).

Discriminant Analysis of Velocity Between the Three Slow Youth Skaters and Three Fast Youth Skaters

The stepwise multiple discriminant analysis, with velocity being removed as a variable, revealed that width of the right stride accounted for 85.7 percent of the variance between the three fast youth skaters and the three slow youth skaters with a significant F-value of 23.93. The angle of inclination of the lower leg accounted for a further 11.5 percent with a significant F-value of 12.39. These two variables accounted for 97.2 percent of the variance between the three

Table 10. Summary of the Stepwise Multiple Discriminant Analysis Between the Nine Fast Skaters and the Five Slow Skaters

Step Number	Variable Entered or Removed	F Value to Enter or Remove	Number of Variables Included	U-Statistic
1	12	34.4388	1	.2584
2	20	24.0474	2	.0811
3	10	5.7954	3	.0513
4	15	7.0757	4	.0287
5	25	17.1035	5	.0092
6	2	13.1967	6	.0032
7	16	42.6420	7	.0004
8	17	10.1721	8	.0001
9	5	6.6714	9	.0000
10	27	1.6394	10	.0000

fast youth skaters and the three slow youth skaters (see Table 11).

Discriminant Analysis of Velocity Between the Six Fast Adult Skaters and Two Slow Adult Skaters

The stepwise multiple discriminant analysis, with velocity being removed as a variable, revealed that angle of abduction of the leg accounted for 71.2 percent of the variance between the six fast adult skaters and two slow adult skaters, with a significant F-value of 14.84. The total recovery time of the skate blade accounted for a further 25.9 percent with a significant F-value of 45.50. These two variables accounted for 97.1 percent of the differentiation between the six fast adult skaters and the two slow adult skaters (see Table 12).

Biomechanical Analysis

The analysis of movement of the center of gravity of the body of the 14 subjects revealed that subject 2, the second fastest adult skater, recorded horizontal velocity ranging from 32.7 feet/second to a maximum of 35.72 feet/ second during a stride. The slowest skater, subject 14, recorded horizontal velocities ranging from 16.01 feet/second to a maximum of 19.03 feet/second during a stride. These results clearly indicated that the variation from slowest to fastest velocity was not related to average velocity.

It was also observed that the linear and horizontal velocities were nearly identical for each of the skaters. The analysis of the vertical displacement of the center of gravity

Table 11. Summary of the Stepwise Multiple Discriminant Analysis Between Three Fast Youths and Three Youths

Step Number	Variable Entered or Removed	F Value to Enter or Remove	Number of Variables Included	U-Statistic
1	6	23.9279	1	.1432
2	20	12.3878	2	.0274
3	22	2.0559	3	.0138
4	23	10.2161	4	.0012

Table 12. Summary of the Stepwise Multiple Discriminant Analysis Between Six Fast Adults and Two Slow Adults

Step Number	Variable Entered or Removed	F Value To Enter or Remove	Number of Variables Included	U-Statistic
1	21	14.8439	1	.2879
2	12	45.4972	2	.0285
3	20	46.1121	3	.0023
4	26	89.6536	4	.0001
5	9	33.0211	5	.0000
6	27	19.4001	6	.0000

showed no consistancy among all of the skaters. However, some of the professional skaters whose center of gravity rose considerably, recorded some of the fastest times.

From the frontal perspective, the analysis of horizontal changes of the center of gravity, right hip, right knee, and right foot of subject 2, a fast adult skater, compared with subject 7, a slow adult skater, strongly supported width of stride as being a discriminating factor between fast and slow skaters (see Figures 16, 17). The faster skater, as opposed to the slower skater, maintains a greater width between the hip and knee, between knee and foot, and between the hip and foot during the thrusting stride.

The lateral and frontal views provided by the film analysis offered a clear understanding of speed of forward skating. It was obvious that the variation of angles at the knee from one skater to another helped categorize the skaters in terms of their skating speed. The smallest recorded angle at the knee ranged from 95-114 degrees for both the fast adult and youth skaters. The skaters registering the smallest angle at the knee prior to the initial thrusting action of the same leg seemed to be the ones who kept the knee of the recovery leg in a more flexed position prior to returning the skate blade on the ice. This allowed knee and hip extension of the thrusting leg through the maximum power range of 130-155 degrees (Rasch and Burke, 1971).

The slower skaters, on the other hand, tended to drag the recovery leg, thus creating a greater angle at the knee

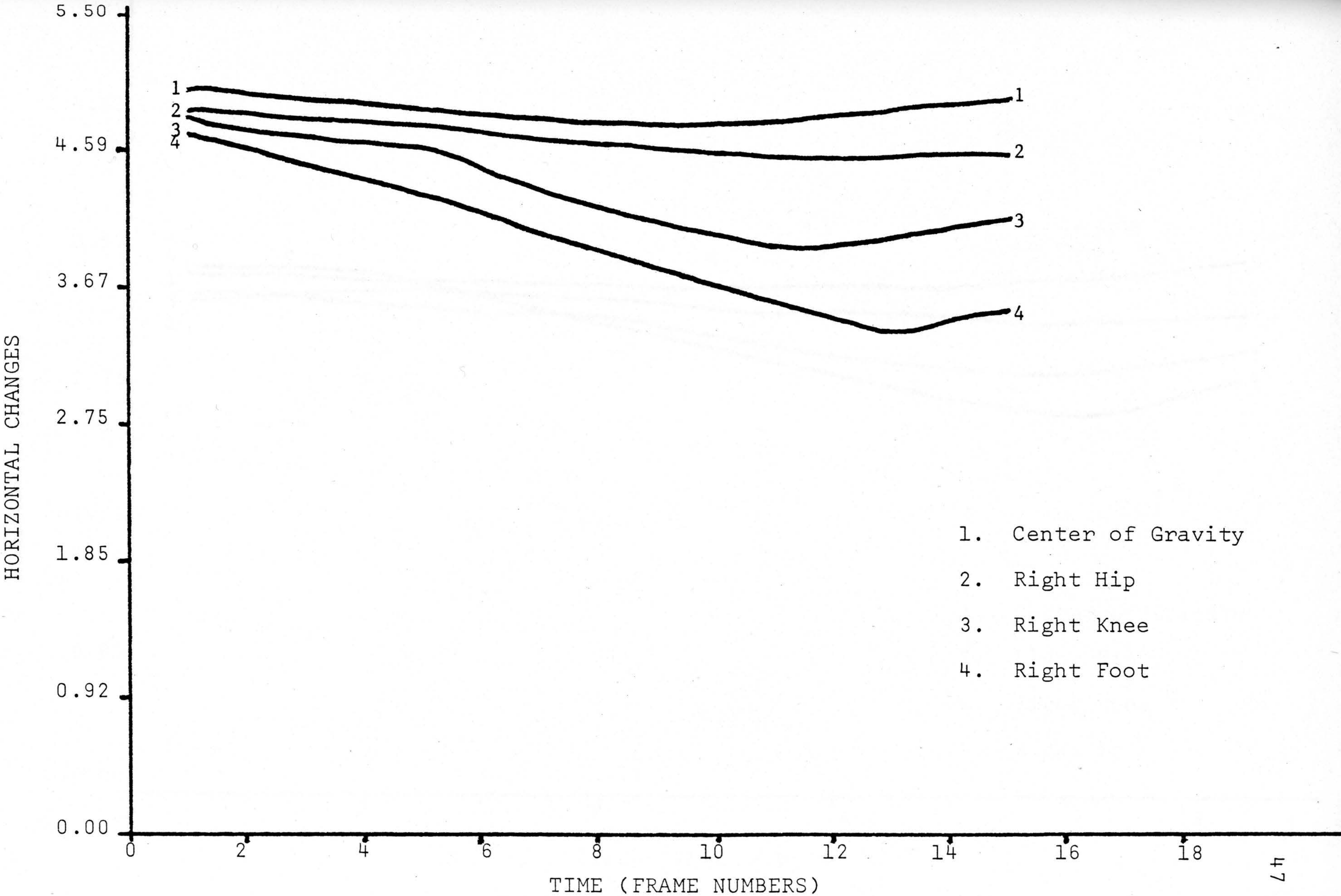


FIGURE 16: Subject 2, A Fast Adult Skater Viewed from a Front Perspective

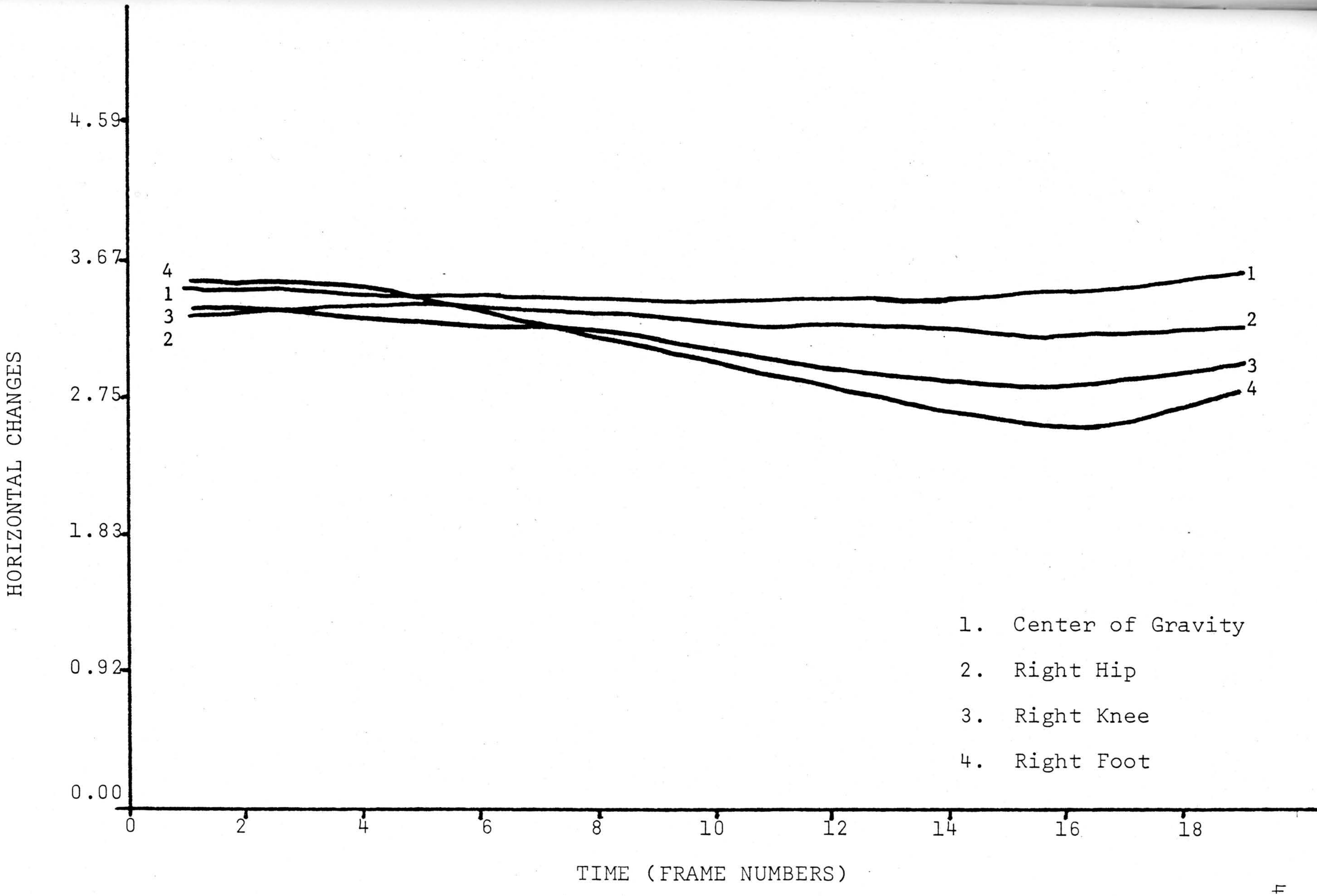


FIGURE 17: Subject 7, A Slow Adult Skater
Viewed from a Front Perspective

during the recovery period. This greater angle at the knee was associated with a more upright position of the upper body on the part of the slower skaters. This occured along with the thrusting knee extending through a small fraction of the maximum power range of 130-155 degrees. The faster skaters maintained an upper body lean ranging from 30-39 degrees from the horizontal as compared to 41-54 degrees for the slower skaters.

The slower skaters, as seen from a frontal view, were also observed recording smaller angles of abduction of the thrusting leg when failing to bend the knee around the favorable range of 95-114 degrees prior to the initiation of the thrusting phase. The smaller the angle at the knee prior to the initial thrusting action, the further sideways the thrusting leg abducted. On the other hand, the slower skaters initiated the thrusting action from a greater angle at the knee. This made them unable to thrust as far sideways as the faster skaters as well as being unable to extend the knee through the maximum angle of power of 130-155 degrees.

The angle of abduction of the leg indicated whether or not a skater maintained a wide stride during the thrusting phase. The width of the right stride for the fast adult skaters ranged from 25.3 to 38.5 inches, while ranging from 18 to 24 inches for the slower adult skaters. The width of the right stride for the faster youth skaters ranged from 23.3 to 27.8 inches, while ranging from 12.5 to 16.5 inches for the slower youth skaters. The width of the left stride for the faster youth skaters ranged from 22.3 to 28 inches while ranging from 12 to 19.3 inches for the slower youth skaters.

These results clearly indicated that the thrusting action is not symmetrical. Depending on whether the skaters were right handed or left handed, one stride was wider than the other. Keeping in mind that the opposite leg to the leading arm was thrusting, wider left strides were recorded when the left leg thrusted harder than the right leg. Similarly, wider right strides were recorded since the right leg thrusted harder than the left leg. This occured along with one stride being longer than the other for all but two instances. When the left leg thrusted harder than the right leg, the right stride was longer than the left stride. When the right leg thrusted harder than the left leg, the left stride was longer than the right stride.

Another observation was that faster skaters directed the thrusting force downward, sideways, and backwards as opposed to the slower skaters who directed the force mostly downward. Four factors occured along with the downward, sideways, and backward force applied by the faster skaters. These four factors were a small angle at the knee ranging from 95-114 degrees prior to the initial thrusting action, a greater width between strides, a greater angle of inclination of the lower leg, and finally a setting of the inside edge of the skate blade without which no backward force could be applied.

The angle of the knee prior to the initial thrusting action indicated whether or not a skater extended his knee through the angle of maximum power which enabled him to apply the force necessary to maintain or increase his speed. The width between strides indicated whether or not a skater applied any downward and lateral force prior to returning the recovery skate blade on the ice. The angle of inclination of the lower leg indicated whether or not a skater was in a position conducive to applying a downward, backward, and lateral force. The setting of the inside edge of the skate blade indicated whether or not a skater dug into the ice, as opposed to gliding onto the ice surface, which is an essential position of the skate blade in order to apply any downward, backward, and lateral force.

Another observation revealed that the total recovery time of the skate blade decreased as the angle at the knee decreased during the recovery period and specifically at the time of contact with the ice. The smaller the angle at the knee was, the quicker was the setting of the inside edge of the skate blade which occured along with a quicker initiation of application of the downward, backward, and lateral force. The slower skaters, however, recorded greater angles at the knee at the time of contact with the ice. This led to a delayed initiation of application of the downward force.

The total recovery time of the skate blade for both the fast adult and youth skaters ranged from 0.33 to 0.41 seconds as compared to 0.46 to 0.50 seconds for the slow adult and youth skaters.

Chapter 4

GENERAL DISCUSSION

Analysis of the data gathered in this study demonstrated that faster skaters took longer right strides, took wider strides, abducted the leg more, used greater width between strides, returned the skate back on the ice under the center of gravity more quickly, set the inside edge of the skate blade more quickly, extended the thrusting knee more quickly, extended the thrusting knee through a wider range of motion, flexed the thrusting knee more prior to the initial thrusting action, and leaned forward more with the lower and upper part of the body.

The mean length of right strides was 104.93 inches for the faster skaters compared with 97.30 inches for the slower skaters (see Appendix C). The significant positive relationship between velocity and right strides only was contrary to the findings of Lariviere (1969) and Marino (1974). Lariviere reported that faster skaters took longer strides while Marino reported that the mean stride lengths were greater for the faster skaters than for the slower skaters, but that the relationship between velocity and stride length was found to be statistically non-significant.

The statistically non-significant relationships between velocity and abduction of the skate blade, in this thesis, did not correspond to the findings reported by Lariviere (1969) and Marcotte (1963). These authors indicated that faster skaters abduct their skates more and lean forward more with the lower part of the body. The results of this thesis revealed that angle of abduction of the skate blade significantly accounted for the variance in velocity of the youth skaters only. The mean angle of abduction of the skate blade was 48.33 degrees for the fast youth skaters compared with 35.33 for the slow youth skaters (see Appendix B).

The significant negative relationship between velocity and angle of forward inclination, in this thesis, was supported by Lariviere (1969) and Marcotte (1963). The mean angle of forward inclination was 57 degrees for the fast skaters compared with 65.33 for the slow skaters (see Appendix U).

The significant negative relationship between velocity and mid-recovery time of the skate blade as well as between velocity and total recovery time of the skate blade corresponded to the findings obtained by Marino (1974) who reported a significant positive relationship between stride rate and horizontal velocity. Marino (1974) found that the important factor in skating was to bring the skate back on the ice, under the center of gravity, as quickly as possible in order to provide for a quicker initiation of the following stride. The mean mid-recovery time of the skate was 0.26 seconds for the fast skaters as compared to 0.29 seconds for the slow skaters. The mean total recovery time of the skate blade was

0.37 seconds for the fast skaters compared with 0.48 seconds for the slow skaters.

The results of this study indicated that the opinions of hockey experts were correct in assuming that forward lean of the lower and upper part of the body (Meeker 1973; Percival 1960), angle of knee flexion (Meeker 1973), angle of abduction of the leg (Percival 1960), and mid-recovery time of the skate blade (Meeker 1973) were most important factors characterizing the fastest skaters.

The mean angle of the trunk was 38.67 degrees for the fast skaters compared with 49.20 degrees for the slower skaters. The mean angle of knee flexion was 106.11 degrees for the fast skaters compared with 123.60 degrees for the slower skaters. The mean width between strides was 21.21 inches for the fast skaters compared with 17.76 inches for the slow skaters.

The belief expressed by Meeker (1973) concerning the angle of abduction of the blade was contrary to the findings of this study. Meeker (1973) maintained that an angle of abduction of the skate blade greater than 45 degrees indicated close to maximum thrust while a small angle of abduction of the skate blade indicated low power. The results of this thesis revealed that there was a statistically non-significant relationship between angle of abduction of the skate blade and velocity. This seems to be due to slower adult skaters who recorded angles of abduction of the skate blade as large as the fast adult skaters. There was, however, a statistically significant relationship between velocity and angle of abduction of the skate blade for the youth skaters only. The mean angle of abduction of the skate blade was 48.33 degrees for the fast youth skaters compared with 35.33 degrees for the slow youth skaters.

The results obtained from the stepwise multiple regression analysis indicated that width of the left stride was the most important variable as it accounted for 81.3 percent of the variance in velocity for this group of 14 skaters. The width of a stride, which can easily be measured on the ice, gives an indication of whether or not a skater flexed his knees prior to thrusting, abducted and everted the skate blade during thrusting, and leaned forward with the lower and upper part of the body in order to direct the thrusting action as far as possible to the side and to the back. By maintaining a wide stride, the skater maintained a wide stance, and as a result kept the skate blade on the ice for a longer period of time as opposed to lifting the skate blades off the ice prematurely due to a long gliding stride. Such action of the skate blade provided for a quicker total recovery time of the skate blade which corresponded to returning the skate blade back on the ice quickly for the setting of the inside edge of the skate prior to the subsequent stride.

The double combination of width of stride and angle of abduction of the skate blade accounted for 90.1 percent of the variance in velocity for the total group of 14 skaters. The angle of abduction of the skate blade gave an indication of whether or not a skater abducted the skate blade, which was associated with wide strides and large angle of abduction of the leg.

The triple combination of width of stride, angle of abduction of the skate blade, and time of knee extension accounted for 95.6 percent of the variance in velocity for the total group of 14 skaters. Time of knee extension occured along with a greater forward lean of the upper part of the body.

The multiple stepwise discriminant analysis for the total group of 14 skaters indicated that total recovery time of the skate blade was the most discriminating variable as it accounted for 74.2 percent of differentiation in velocity between the nine fast skaters and the five slow skaters. Total recovery time of the skate blade gave an indication of whether or not a skater flexed the knees prior to thrusting so as to go through a large range of knee extension within a short time, leaned forward with the upper and lower part of the body in order to obtain wider strides, accentuated abduction of the leg, and greater extension of the leg to the back.

Angle of inclination of the lower leg was selected as the second most discriminating variable as it accounted for a further 17.7 percent of the differentiation in velocity between the nine fast skaters and the five slow skaters. Angle of inclination of the lower leg gave an indication of whether or not a skater took a proper position to allow the thrusting leg to abduct as much as possible.

The total recovery time of the skate blade was recorded as the most important variable accounting for the variance in velocity for both the youth skaters and adult skaters. The total recovery time of the skate blade accounted for 98.4 percent of the variance in velocity and probably accounted for the width of the left stride as indicated by the significant negative relationship (R) of -.93 between these two variables for the analysis of the six youth skaters. The analysis of the eight adult skaters revealed that width of the left stride accounted for only 19.6 percent of the variance in velocity, which was explained by some slow adult skaters taking as wide a stride as some of the fast adult skaters. This was due to width of the left stride being possibly dependent upon maturation level.

The most discriminating variable to account for the differentiation in velocity between the three fast youth skaters and the three slow youth skaters was width of the right stride, which accounted for 85.8 percent.

The angle of abduction of the leg was the most discriminating variable between the six fast adult skaters and the two slow adult skaters, as it accounted for 71.2 percent of the differentiation in velocity.

Contrary to what was expected, total recovery time of the skate blade was not the most discriminating variable between the fast and slow youth skaters as well as between the fast and slow adult skaters. Total recovery time of the skate blade seems to have been accounted for by width of the right stride as indicated by the significant relationship (R) of

-.76 between the two variables for the discriminant analysis between the fast and slow skaters.

Unlike sprinting speed where a runner needs to apply force directly backwards in order to attain horizontal velocity, the important factor in speed of forward skating seemed to be the ability to apply force on the ice downwards, sideways, and backwards in order to attain horizontal velocity. A wide stride indicated that a skater thrusted while a narrow stride indicated that a skater glided throughout most of the strides. The mean width of the left strides for the nine fast skaters was 21.21 inches compared with 17.76 inches for the five slow skaters. The mean width of the right strides for the nine fast skaters was 29.21 inches compared with 20.46 inches for the five slow skaters.

Another important factor in speed of forward skating seemed to be the elapsed time between the lift-off of one skate blade and the setting of the edges of the same skate blade on the ice prior to tis initial thrusting action. The significantly greater extension of the thrusting leg to the back as well as the significantly greater forward lean of the upper and lower part of the body, by the faster skaters, indicated that upon lifting the skate blade off the ice the knee *of the recovery leg was bent and remained so when contacting* the ice, which accelerated the setting of the inside edge of the same skate blade prior to initiating the subsequent stride. The mean total recovery time of the skate blade of the nine fast skaters was 0.30 seconds compared to 0.36 seconds for the five slow skaters.

Chapter 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The purpose of this study was to conduct a biomechanical analysis of hockey players skating at top speed in a direct line in order to discover some factors which might account for any observed differences in speeds of forward skating.

The analysis of correlations, for the group of 14 skaters, between velocity and each of the 26 other variables indicated that the faster skaters seemed to take wider strides, take longer right strides, use a greater width between strides, lean forward more with the upper part of the body, flex the thrusting knee more prior to the initial thrusting action, extend the thrusting knee more quickly, apply force through a wider range of knee extension, return the skate blade on the ice under the center of gravity more quickly, and set the inside edge of the skate blade more quickly on the ice.

Another method, the stepwise multiple regression analysis, indicated that width of stride was the most important factor to account for the variance in velocity among the group of 14 skaters. The combination of width of stride and angle of eversion of the blade was most important as it accounted for 90.1 percent of the variance in velocity among the group of 14 skaters.

Other analyses were also computed via the stepwise multiple discriminant analysis. This method revealed that total recovery time of the skate blade (elapsed time to set the inside edge of the skate blade after recovery) was the most discriminating factor between the 9 fast skaters and 5 slow skaters as it accounted for 74.2 percent of the differentiation. Angle of inclination of the lower leg prior to the initial thrusting action was found to be another important discriminating factor between the 9 fast skaters and 5 slow skaters as it accounted for a further 17.7 percent of the differentiation.

The same methods were used to analyze the youth and adults separately. The results indicated that total recovery time of the skate blade (elapsed time from lift-off of the skate blade to initial setting of the inside edge of the skate blade) was the most important factor in accounting for the variance in velocity between slow and fast youth skaters and between slow and fast adult skaters.

The variance between the fast and slow youths was mostly accounted for by width of stride while angle of abduction of the leg was found to be the most discriminating factor between the fast and slow adults.

Conclusions

The results of this study indicated that within the limitations of this thesis, the following statements can be made:

1. As velocity of forward skating increases, width of stride increases.

2. As velocity of forward skating increases, the elapsed time, between the lift-off of one skate blade and the setting of edges of the same skate blade prior to its initial thrusting action, decreases.

3. As velocity of forward skating increases, the elapsed time, from the beginning to the end of knee extension, decreases.

4. As velocity of forward skating increases, the angle of knee flexion, prior to the initial thrusting action, decreases.

5. As velocity of forward skating increases, the angle of the trunk (forward lean of the upper part of the body), decreases.

6. As velocity of forward skating increases, the length of the right stride increases.

7. As velocity of forward skating increases, the width between strides increases.

8. As velocity of forward skating increases, the elapsed time, between the lift-off of one skate blade and the return on the ice of the same skate blade under the center of gravity, decreases.

9. As velocity of forward skating increases, the angle of abduction of the leg increases.

10. As velocity of forward skating increases, the angle of forward inclination increases.

11. The variation from the slowest to the fastest velocity was not related to average velocity.

12. The linear and horizontal velocities were nearly identical for each of the skaters.

13. The vertical displacement of the center of gravity showed no consistancy among all of the skaters. However, some of the professional skaters who rose considerably recorded some of the fastest times.

14. The faster skaters as opposed to the slower skaters maintained a greater width between the hip and the knee, between the knee and the foot, and between the hip and the foot during the thrusting action.

15. The faster skaters recorded smaller angles at the knee than the slower skaters both during the recovery period and prior to the initial thrusting action.

16. The variations between the width and length of the right and left strides indicated that the thrusting action was asymetrical.

Coaches will undoubtedly prefer to be informed how they could devise a specific and progressive training program to improve one's speed of forward skating. The following statements will guide the coaches in attaining the desired objectives.

1. 91.9 percent of the variance in velocity of forward skating, discriminating between fast skaters and slow skaters, was accounted for by two important factors: total recovery time of the skate blade (74.1 percent) and angle of

inclination of the lower leg (17.7 percent).

2. 97.2 percent of the variance in velocity of forward skating, discriminating between fast youth skaters and slow youth skaters, was accounted for by two important factors: width of stride (85.68 percent) and angle of inclination of the lower leg (11.53 percent).

3. 97.2 percent of the variance in velocity of forward skating, discriminating between fast adult skaters and slow adult skaters, was accounted for by two important factors: angle of abduction of the leg (71.2 percent) and total recovery time of the skate blade (25.9 percent).

4. When trying to predict speed within a group of skaters, 95.6 percent of the variance in velocity was accounted for by width of a stride (81.3 percent), angle of abduction of the blade (8.8 percent), and time of knee extension (5.5 percent).

5. When trying to predict speed within a group of youth skaters, 96.9 percent of the variance in velocity was accounted for by total recovery time of the skate blade.

6. When trying to predict speed within a group of adult skaters, 98.7 percent of the variance in velocity was accounted for by three important factors: total recovery time of the skate blade (56.7 percent), width of left stride (33.3 percent), and width of the right stride (8.7 percent).

Recommendations

The results of this study have indicated that speed of forward skating may be programmed. There are observable and measurable variables or skills which account for the various velocities. If these skills are improved, velocity, in turn, can also be improved.

A similar study could be repeated involving:

1. More subject of varied chronological age levels.

2. More measurements of body limbs and their lengths, sizes, reaction, and movement times.

3. More measurements of strength in relation to the legs.

4. More accurate measurements of angles through the use of three dimensional film and elgons.

BIBLIOGRAPHY

Broer, Marion. Efficiency of Human Movement. Second Edition. Philadelphia: W.B. Saunders Company, 1966.

Dixon, W. J. (ed.) BMD: Biomedical Computer Programs. Second Edition. Berkeley: University of California Press, 1970.

Jones, Brian, E. Comparison of the Ice Skating Starting Styles used in Ice Hockey, M.P.E., 1969.

Lariviere, G. "Relationships Between Skating Velocity and Length of Stride, Angle of Forward Inclination, and Angle of Propulsion," Master's Thesis, Oklahoma State University, 1969.

Marcotte, Gaston. "Technique du Coup de Patin," (mimeographed). Ecole de Formation de L'Association Canadienne de Hockey Amateur, 1963.

Marino, G. W. "A Comparative Analysis of Selected Mechanical Aspects of the Ice Skating Stride," Master's Thesis, University of Illinois, 1974.

Meeker, Howie. Howie Meeker's Hockey Basics. Scarborough: Prentice-Hall of Canada Ltd., 1973.

Naud, Ronald, L. "A Comparison of Selected Hockey Skating Techniques," Master's Thesis, Dalhousie University, 1974.

Orr, B. Orr on Ice. Toronto: Prentice-Hall, Inc., 1970.

Percival, Lloyd. The Hockey Handbook. Revised Edition. New York: A. S. Barnes and Company, Inc., 1972.

Rasch, Philip, G. and Roger K. Burke. Kinesiology and Applied Anatomy. Fourth Edition. Philadelphia: Lea and Febiger, 1971.

St-Denis, Claude. "A Study to Determine the Fastest Method of Starting from a Stopped Position in Ice Hockey," Unpublished Master's Thesis, Springfield College, 1956.

Thiffault, Charles. "Etude Comparative de Differents Departs au Hockey avec le Controle de la Rondelle," 35^{e} Congres Annuel de L'Association Canadienne Francaise pour L'Avancement des Sciences, 1967.

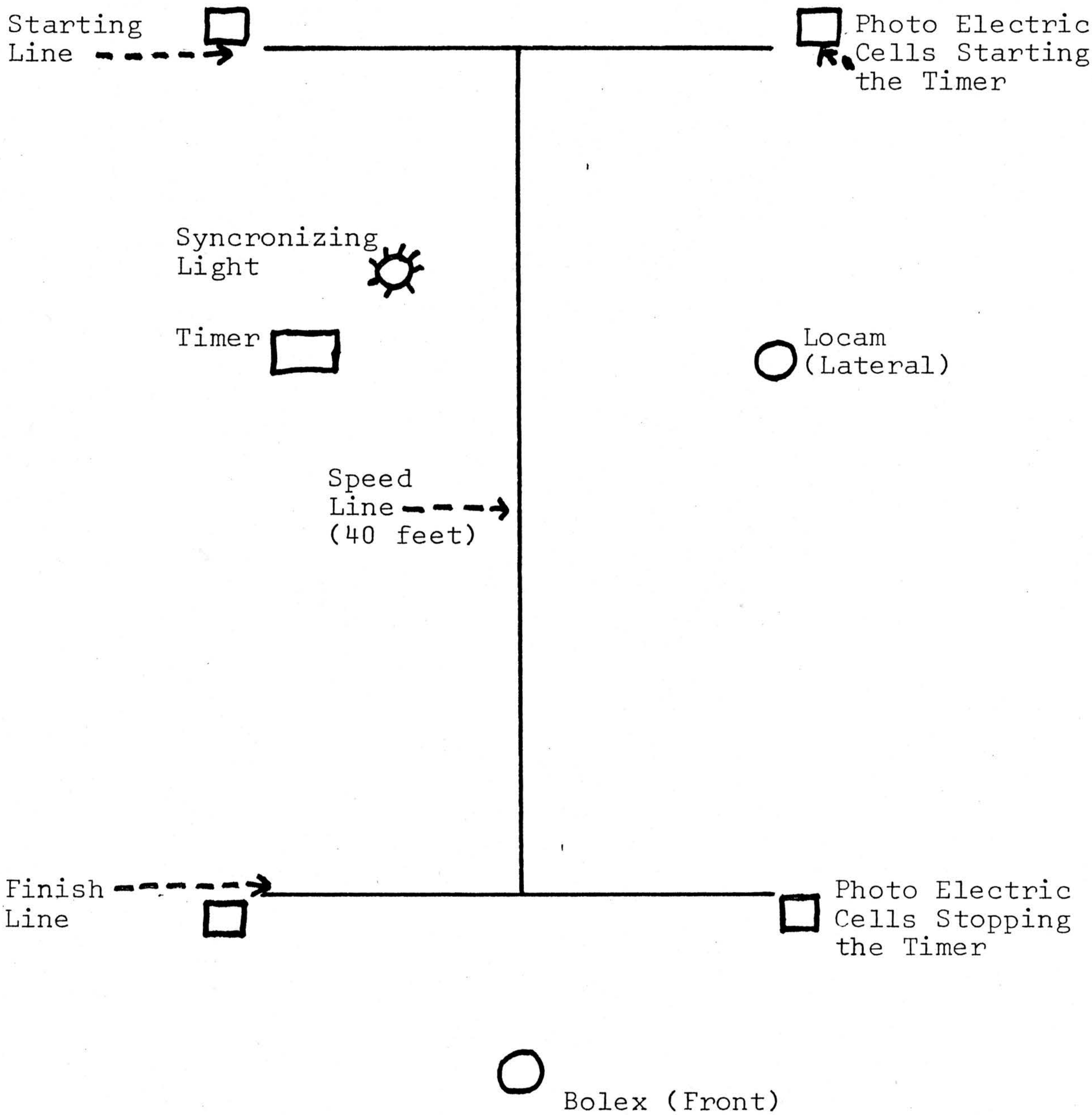
Walford, Gerald, A. Ice Hockey-An Illustrated Guide for Coaches. New York: Ronald Press, Co., 1971.

Weber, J. C. and D. R. Lamb. Statistics and Research in Physical Education. The C. V. Mosby Company: St. Louis, 1970.

Wild, John. Power Skating: The Key to Better Hockey. Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1971.

Appendix A

EXPERIMENTAL SETTING



Appendix B

SUBJECTS

Number	Name	Category
1	OJA, Mickey	Adult
2	CAMERON, Eric	Adult
3	NAUD, Ron	Adult
4	SCRUTTON, Ted	Adult
5	HUBICK, Greg	Adult
6	WILSON, Rick	Adult
7	HOLT, Larry	Adult
8	BEER, Bob	Adult
9	SCOTT, Craig	Youth
10	LEBLANC, Ed	Youth
11	TILLEY, Paul	Youth
12	ROODE, Carson	Youth
13	CIRTWELL, Kevin	Youth
14	ROODE, Roger	Youth

Appendix C

VELOCITY OF SUBJECTS (FEET/SECOND)

Subject	Velocity
1	35.1
2	33.6
3	33.6
4	33.1
5	32.3
6	30.8
7	27.4
8	27.4
9	27.4
10	27.2
11	25.5
12	21.6
13	20.6
14	18.1
Mean	28.12
Standard Deviation	5.31

Appendix D

LENGTH OF STRIDES (INCHES)

Subject	Length of Right Stride	Length of Left Stride	Length of Right Stride Along Speed Line	Length of Left Stride Along Speed Line
1	107.5	100.3	103.1	94.8
2	124	132	119.8	126
3	144	110.5	140.5	107.3
4	144.5	93.3	141.8	91
5	80.5	96	75.5	92
6	120.5	138.5	113	133.5
7	58.5	54.5	54.5	51.3
8	122	100	107.5	94.5
9	89	83.3	78	79
10	117.5	110.5	113	106
11	78	80	74.3	76.8
12	91	90	88.5	84
13	68	81.5	65.5	79.5
14	78.5	115	76	115
Mean	106.21	102.21	100.29	98.14
Standard Deviation	25.20	17.68	24.62	17.44

Appendix E

WIDTH OF STRIDES (INCHES)

Subject	Width of Right Stride	Width of Left Stride
1	29.5	29.5
2	28	36.5
3	25.3	33.8
4	20	28.5
5	25.8	24
6	38.5	31.3
7	18	17.3
8	24	26
9	23.3	26
10	27.8	28
11	23.5	22.3
12	12.5	19.3
13	16.5	19
14	16.5	12
Mean	23.94	26.09
Standard Deviation	6.43	6.56

Appendix F

WIDTH BETWEEN STRIDES (INCHES)

Subject	Width Between Strides
1	22
2	26.5
3	25.5
4	29
5	23
6	27.8
7	21.3
8	19.5
9	5.3
10	17.3
11	14.5
12	14.5
13	19.5
14	15.8
Mean	19.98
Standard Deviation	6.38

Appendix G

LENGTH BETWEEN STRIDES (INCHES)

Subject	Length Between Strides
1	25.5
2	-4.5
3	10
4	7.0
5	6
6	-6.8
7	42.3
8	2
9	16.8
10	-4.3
11	12
12	13.8
13	17.3
14	12
Mean	7.77
Standard Deviation	9.38

Appendix H

EARLY RECOVERY TIME OF THE SKATE BLADE (SECONDS)

Subject	Early Recovery Time of the Skate Blade=
1	0.20
2	0.22
3	0.26
4	0.20
5	0.20
6	0.20
7	0.24
8	0.22
9	0.20
10	0.22
11	0.24
12	0.22
13	0.30
14	0.22
Mean	10.14
Standard Deviation	1.41

Appendix I

MID-RECOVERY TIME OF THE SKATE BLADE (SECONDS)

Subject	Mid-Recovery Time of the Skate Blade
1	0.24
2	0.24
3	0.30
4	0.22
5	0.24
6	0.26
7	0.28
8	0.26
9	0.26
10	0.26
11	0.28
12	0.28
13	0.35
14	0.28
Mean	12.29
Standard Deviation	1.49

Appendix J

TOTAL RECOVERY TIME OF THE SKATE BLADE (SECONDS)

Subject	Total Recovery Time of the Skate Blade
1	0.35
2	0.41
3	0.39
4	0.39
5	0.33
6	0.39
7	0.46
8	0.46
9	0.33
10	0.37
11	0.37
12	0.46
13	0.48
14	0.54
Mean	18.79
Standard Deviation	2.89

Appendix K

TIME OF KNEE EXTENSION (SECONDS)

Subject	Time of Knee Extension
1	0.28
2	0.39
3	0.30
4	0.30
5	0.28
6	0.28
7	0.22
8	0.28
9	0.30
10	0.33
11	0.24
12	0.37
13	0.37
14	0.48
Mean	14.70
Standard Deviation	2.83

Appendix L

RANGE OF KNEE EXTENSION (DEGREES)

Subject	Range of Knee Extension
1	73
2	77
3	51
4	66
5	63
6	62
7	36
8	54
9	49
10	54
11	65
12	45
13	51
14	34
Mean	57.43
Standard Deviation	11.05

Appendix M

ANGLE OF CURVATURE OF STRIDES (DEGREES)

Subject	Angle of Curvature of Right Stride	Angle of Curvature of Left Stride
1	175	176
2	168	173
3	168	176
4	167	170
5	179	170
6	175	172
7	170	179
8	173	164
9	168	170
10	169	175
11	174	178
12	168	166
13	179	179
14	172	176
Mean	171.79	173.14
Standard Deviation	4.14	4.69

Appendix N

ANGLE OF THRUST (DEGREES)

Subject	Angle of Thrust
1	34
2	28
3	21
4	32.5
5	27
6	33
7	39
8	25
9	24
10	16
11	26
12	29
13	27
14	23
Mean	27.50
Standard Deviation	5.91

Appendix O

ANGLE OF ABDUCTION OF THE BLADE (DEGREES)

Subject	Angle of Abduction of the Blade
1	41
2	44
3	43
4	37
5	29
6	55
7	46
8	45
9	42
10	59
11	44
12	44
13	40
14	22
Mean	42.21
Standard Deviation	9.18

Appendix P

ANGLE OF INCLINATION OF THE LOWER LEG (DEGREES)

Subject	Angle of Inclination of the Lower Leg
1	11
2	21
3	26
4	18
5	8
6	14
7	7
8	6
9	10
10	21
11	14
12	8
13	13
14	14
Mean	13.64
Standard Deviation	5.99

Appendix Q

ANGLE OF ABDUCTION
OF THE LEG (DEGREES)

Subject	Angle of Abduction of the Leg
1	32
2	40
3	32
4	35
5	27
6	38
7	20
8	21
9	34
10	38
11	30
12	30
13	28
14	20
Mean	30.36
Standard Deviation	6.62

Appendix R

ANGLE OF EXTENSION OF THE LEG TO THE BACK (DEGREES)

Subject	Angle of Extension of the Leg to the Back
1	39
2	31
3	30
4	35
5	35
6	26
7	33
8	27
9	37
10	41
11	42
12	25
13	22
14	31
Mean	32.50
Standard Deviation	6.05

Appendix S

ANGLE OF KNEE FLEXION
(DEGREES)

Subject	Angle of Knee Flexion
1	102
2	95
3	114
4	109
5	109
6	101
7	126
8	121
9	107
10	109
11	109
12	118
13	123
14	130
Mean	112.36
Standard Deviation	10.12

Appendix T

ANGLE OF THE LEG AT EXTENSION

Subject	Angle of the Leg at Extension
1	175
2	172
3	165
4	175
5	172
6	163
7	162
8	175
9	156
10	163
11	174
12	163
13	174
14	164
Mean	168.07
Standard Deviation	6.39

Appendix U

ANGLE OF THE TRUNK (DEGREES)

Subject	Angle of the Trunk
1	39
2	36
3	39
4	37
5	37
6	37
7	41
8	49
9	35
10	48
11	30
12	54
13	48
14	54
Mean	42.43
Standard Deviation	7.49

Appendix V

ANGLE OF FORWARD INCLINATION (DEGREES)

Subject	Angle of Forward Inclination
1	47
2	53
3	58
4	65
5	64
6	61
7	66
8	62
9	53
10	59
11	59
12	61
13	72
14	63
Mean	60.21
Standard Deviation	6.25

Appendix W

ANGLE OF TRUNK TO THIGH (DEGREES)

Subject	Angle of Trunk to Thigh
1	172
2	162
3	162
4	152
5	162
6	155
7	155
8	162
9	163
10	169
11	150
12	173
13	156
14	171
Mean	161.71
Standard Deviation	7.49