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RELATIONSHIPS BETWEEN THE VELOCITY OF THE ICE HOCKEY WRIST SHOT AND SELECTED HUMAN FACTORS

by

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ABSTRACT

The main purpuse of this study was to investigate the relationships between the velocity of the ice hockey wrist shot and selected human factors in order to be able to predict the velocity of the wrist shot. A second objective was to identify the modifiable human factors most highly related with puck velocity in order to guide further research investigating the causal factors of a high speed wrist shot.

Thirty-five subjects were selected from junior, intermediate, collegiate, senior and professional leagues to take part in the study. Their ages ranged from seventeen to twenty-nine.

Forty-eight strength, flexibility, muscle ratio, and anthropometric variables were measured in the Buchanan Fitness Centre at U.B.C. Puck velocity was measured by the use of a radar gun at the Thunderbird arena. Each subject shot a minimum of five shots and the top three scores were averaged to give the puck velocity score. With this data, Stepwise Regression and All Possible Subsets Regression techniques were used to find the best possible regression equation for predicting puck velocity.

The product-moment correlations of puck velocity with each variable were tested for significance at the .05 level. The following correlations were significant: arm adduction at the shoulder of the lower arm, forearm supination of the upper arm, wrist strength in extension of the upper arm, wrist strength in flexion of the lower arm, and diagonal arm strength of the lower arm.

The best linear regression equation found for predicting puck

velocity was:

	Variable group
Y(puck velocity) = 73.0946 + X_1(arm girth upper arm)(.7544)	A
+ X_2(wrist flexibility upper arm)(.1374)	F
+ X_3(forearm rotation upper arm)(-.1779)	F
+ X_4(trunk rotation)(-.0574)	F
+ X_5(trunk flexion)(.1645)	S
+ X_6(arm abduction upper arm)(-1.1586)	S
+ X_7(arm adduction lower arm)(.8949)	S
+ X_8(diagonal motion upper arm)(-.2990)	S
+ X_9(forearm supination upper arm)(1.7023)	S
+ X_{10}(flexion/extension elbow lower arm)(-7.5737)	R

Where: A is anthropometric, F is flexibility, S is strength, R is Ratio. This equation had a multiple R value of .813 and a standard error of estimate of 4.52.

Several transformations were performed on the data in an attempt to reduce the amount of uncertainty in the prediction equation. It was found that cubing the strength variables led to a new regression equation which accounted for more of the uncertainty and used fewer variables. The best regression equation using transformed data was:

Y(puck velocity) = 103.1292 + X_1(stick length)(.3405)	
+ X_2(shoulder rotation lower arm)(.0626)	F
+ X_3(trunk rotation)(-.0972)	F
+ X_4(hip extension glide leg)(-.2334)	S
+ X_5(elbow flexion upper arm)(-.1918)	S
+ X_6(arm adduction lower arm)^3(.0001)	S^3
+ X_7(forearm supination upper arm)^3(.0116)	S^3
+ X_8(wrist extension upper arm)^3(.0001)	S^3
+ X_9(elbow flexion upper arm)^3(.0003)	S^3

This equation had a multiple R of .871 and a standard error of estimate of 3.74. The transformed data equation reduced the uncertainty by 1.0% with one fewer variable being required.

It is recommended that the variables with a significant correlation with puck velocity and the variables in the untransformed data equation be investigated further by implementing them into a training program for hockey players. In this way it might be empirically verified that these factors are the causes of a fast shot.

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Chapter 1

INTRODUCTION

The official game of ice hockey started in North America in the early 1900's, and was characterized by skilled stickhandling and passing. However, over the years the emphasis of the game gradually changed from stickhandling and passing to shooting. The development of the slapshot in the late fifties and early sixties led to goals being scored with greater frequency from distances further away than before. With an increasing emphasis on faster shots the high velocity wrist shot became more and more prominent.

The wrist shot has a major advantage over the slapshot in that it requires a shorter backswing and can be executed in a significantly shorter time period. Alexander, Haddow, and Schultz (1963) found that although the slapshot is capable of producing a higher puck velocity, it is not, on the average, as accurate as the wrist shot. Thus it is important that players develop a high speed wrist shot as well as a slapshot. Hockey stars such as Phil Esposito and Mike Bossy are two splendid examples of players who have developed a highly effective high speed wrist shot.

In recent years articles by well known hockey players have been written explaining how to perform a wrist shot and, although most of these athletes explain how to perform a wrist shot, little is said about what human characteristics are important to develop in order to execute the shot well. Successful players Phil Esposito

(1975), Rod Gilbert (1972), and Ken Hodge (1967) maintain that the way of improving one's shot velocity and accuracy is by hours of practise. In the early stages of one's development as a hockey player, it is probable that routine practise plays a significant role in the improvement of one's shot, but it seems reasonable to conjecture that, later, specific exercises undertaken in conjunction with disciplined practise can produce a faster shot.

A question often raised when discussing shooting pertains to why one person is able to shoot the puck faster than another. Indeed this is a central concern of coaches, sports scientists, players, and others interested in developing superior performance in hockey players. In an attempt to resolve this problem one may begin by looking at what human factors are required to produce a high velocity wrist shot. Brown (1980) suggests that when analyzing a motor skill such as the wrist shot the human factors can be broken down into five basic categories: genetic makeup, body type, psychomotor abilities, physical characteristics, and technical execution of the skill. These categories consist of either modifiable or inherent factors. One might initially hypothesize that inherent growth factors such as size may be limiting factors in obtaining high puck velocity. However upon investigation this does not seem to be true. The Russian coach Tarasov (1973) states that a player doesn't have to be abnormally strong to produce a hard shot. Subjectively one observes that some of the smaller lighter players are among the hardest shooters, examples being: Danny Gare 5'9" 175 lbs, Guy Lafleur 6'0" 180 lbs, and Bobby Schmautz 5'9" 176 lbs. It appears that body size and possible inherent body characteristics such as somatotype may not be as important as one might suppose.

Many authors have attempted to isolate the key factors of a high velocity wrist shot. Hull (1967) attributed puck speed to arm and wrist strength. He also claims that much of the speed with which a puck moves is a combination of the technical perfection of the mechanics of the shot and the shooter's strength. Tarasov (1973) believes that it results from the proper technique of using the thumb of the upper hand and the strength of the lower hand on the shaft to lock the blade while executing the shot. He also maintains that shifting the weight of the supporting leg at the proper instant is a crucial element in determining the puck's velocity. Hodge (1967) states that timing, coordination and strength are the key factors. Chambers (1979) states that the speed and the power of the wrist shot depend on the strength in the arms, shoulders and wrists, along with coordination of the shooting movement and upper body rotation.

The beliefs presented by these athletes and coaches are not based on empirical data but rather on subjective opinions. However, these thoughts should not be discounted because they are subjective in nature but research should be conducted in an attempt to substantiate these beliefs.

Research in the mechanics of shooting has just begun, and there is no concensus as to what the most important factors are in a high speed wrist shot. It is hoped that this study will shed further light on this subject.

Statement of the Problem

The aim of this study is to investigate the relationships between the velocity of the ice hockey wrist shot and selected human factors.

Subproblems

The main problem can be broken down into the following subproblems.

1. To investigate and select the human factors with the highest linear relationships with puck velocity.

2. To identify the modifiable human factors most highly related linearly to the puck velocity of the wrist shot.

3. To find the best possible regression equation for predicting puck velocity.

Definition of Terms

Wrist shot (Sweep Shot): A shot in ice hockey that is characterized by a sweeping motion of the blade of the stick on the ice and a weight transfer from one leg to the other. The puck remains in contact from the beginning of the execution of the shot to the point of release.

Upper Arm and Hand: Refers to the limb in contact with the top of the shaft of the stick.

Lower Arm and Hand: Refers to the limb in contact with the middle of the shaft of the stick.

<u>Drive Leg and Foot</u>: Refers to the leg and foot that lie on the same side of the midline as the lower arm. It is characterized by extension of the knee during the execution of the wrist shot.

<u>Glide Leg and Foot</u>: Refers to the leg and foot that lie to the same side of the midline as the upper arm. It is characterized by flexion of the knee during execution of the wrist shot.

Delimitations

Relationships between puck velocity and human factors can only be applied when speaking of players who have developed a pattern of execution consistent with those required in this study. These relationships will have no bearing on players who are in the developmental stages of shooting or below the age of seventeen. The results of this study are delimited to players who participate at the junior, university, senior, intermediate and professional levels.

Assumption and Limitations

It is assumed that the subject will use his game style while executing the shot and that he will not alter his shooting pattern throughout the test. One tester will be solely concerned with observing the pattern demonstrated and will watch to be certain the pattern remains consistent throughout the test.

It is also assumed that what the subject does prior to the testing sessions will not affect the results. The subjects will be instructed to avoid strenuous exercise prior to testing.

The subject will be required to provide his own stick for the study. Kingston (1980) states that stick flex, height, weight, curve and lie may limit the validity of the findings. However, requiring the subjects to use sticks to which they are not accustomed would likely upset the shooting motion. Thus having the subjects use their own stick seems to be the best solution. The sample may be biased in that only volunteer subjects directly available to the researcher will be used. There is no evidence to suggest that this bias will be large.

Significance of the Study

Whether the individual is an athlete or a coach, there is a need to know the human factors that are important in achieving a high speed wrist shot. It is hoped that this study will provide information beyond that given by most hockey books, and that it will also give a good basis for further research.

By using the regression equation developed in this study one should be able to predict the velocity of a person's wrist shot. The relationships of the selected human factors to puck velocity cannot be looked at in terms of causality but only in degree of linearity. One can hypothesize that the factors that have significant relationships with puck velocity may indicate aspects to be concentrated on during on-and off-ice training periods. Using the framework laid by this study one could investigate the causes of a faster shot by analyzing a training program incorporating the factors proven to be related to puck velocity in this research. Thus in this proposed future study one could speak of the "causes" of a faster shot rather than just the characteristics related to a fast shot.

Chapter 2

REVIEW OF LITERATURE

This chapter presents a general review of the literature which has a bearing on factors which may be involved in the execution of an effective ice hockey wrist shot. Books, journals, research papers, and expert opinion (from personal contact) form the basis of literature reviewed in this chapter.

The content of this chapter is divided into six main categories: shooting technique, off-ice training, biomechanical characteristics, physiological characteristics, other sports and authorities census.

Shooting Technique

Many articles have been written on the "proper technique" to be used in the execution of the wrist shot, and, overall, most authorities agree on what are the important technical characteristics of the shot. However, there is a disagreement as to the relative importance of these characteristics. Hayward (1978), Johnston (1976), Jones (1979), MacDonald (1978), and Patrick and Monahan (1957) all list the following as important ingredients of a good shot:

Initial phase- At the start of the shot the puck is well back behind the drive leg, the wrists are cocked and the weight is on the drive leg; the puck should be towards the heel of the blade.

Transfer phase- The puck is swept forward. At the same time there is a transfer of weight from the drive leg to the glide leg. As the stick comes across the midline of the body the wrists uncock.

Follow through phase- The weight now becomes directly over the glide leg, and the stick follows through until it points to the target, completing the shot.

These authors differ somewhat as to what they believe are the most important aspects of each phase, but they all agree that these components comprise an effective technique. Phase 1 and 3 are primarily style and form of execution and are easy to monitor. Phase 2 is more concerned with the power of the legs and the strength and flexibility of the wrists and arms. This phase is of major concern to the development of the test variables in this study.

Being more or less in agreement on technique, the authorities are unanimous in stating that the technique must be practised over and over again. Professional hockey players Esposito (1975), Hull (1967), and Hodge (1967) all credit hours of practise with improving their shots. Hull (p.126) states that "no one whether in the N.H.L. or the Kiwanis Atom League gets enough practise shooting". Robb (1972), a motor learning researcher, concurs that many hours of practise are necessary before a skilled movement is executed smoothly and efficiently. She suggests that there are three phases of learning: the plan formation phase, wherein the learner must formulate an executive plan and understand the sequential organization of the skill, the practise phase, in which the learner must practise in order to fix the performance sequence in the human system, and the autonomous phase, wherein the learner is now able to perform the total executive program almost without conscious effort. This study deals only with subjects who are in the third phase of learning.

Off-Ice Training

In recent years off-ice training and practise has become more popular with many coaches; e.g., Tremble (1978) maintains that off-ice practise is valuable in conditioning the athletes and maximizing the use of ice time. He states that all shots can be practised off the ice. The literature on this form of training is related to the present investigation, in that the advocates of off-ice training invariably speculate on what factors produce a good fast shot. For example, in Sports Talk magazine (1978) it is recommended that four off-ice exercises should be considered beneficial to shooting. Forward and reverse wrist curls are recommended as exercises to develop the wrist flexors and extensors both of which are important to the wrist shot. In the second exercise, the wrist roll, the arms are extended straight out from the body and grasp a short stick. Attached to the stick is a rope with weight attached to it. The player winds the cord around the stick lifting the weight towards the stick. This strengthens the wrist flexors and extensors as well as some of the shoulder and forearm muscles. The third exercise consists of rotating a small weight in the hand in circles. The fourth exercise involves a method of "muscle fighting" or eccentric contractions. One hand pushes against the other in front of the chest and the hands move back and forth across the body. This exercise works the triceps, biceps and pectoral muscles of the body. The author of the article felt that the exercises would help a shooter develop the strength needed to execute an effective wrist shot.

Biomechanical Characteristics Related to Shooting

Physiological Characteristics

Halliwell, Gropel and Ward (1977) performed a kinematic analysis of the snap shot using professional hockey players as subjects. Their research concentrated on the motion of the hands required to skillfully execute the stationary snap shot. Seven professional hockey players were filmed while executing the snap shot, with linear hand displacement and shooting accuracy being recorded for each subject. They found that linear hand displacement for the upper hand was similar for both the high and low snap shot. The same was found to be true for the lower hand. The movement patterns for the upper and lower hands were parallel although certain spatial and temporal differences were evident. For both the high and the low snap shot the upper hand started from a position behind the puck and moved toward the target. However, just prior to impact the upper hand reversed direction and moved away from the target back towards the body. Throughout the shot the lower hand moves toward the target. From these observations they inferred that, in both the high and low snap shot, when the upper hand was producing a pulling force away from the target, the lower hand was executing a pushing force towards the target. In this case the shaft acts as a first class lever with the lower hand acting as a fulcrum. One concludes from this that both arms are instrumental in force application.

Although the snap shot and the wrist shot differ slightly in execution, it is reasonable to assume that this same pattern takes place in the wrist shot. The wrist shot differs from the snap shot in that there is a longer sweeping motion and a distinct transfer of weight from one side of the body to the other. The shots are similar in that they both require a similar cocking and uncocking of the wrists, although in the snap shot this tends to be more dynamic in nature.

MacGillivary and Watson (1964) performed a kinesiological analysis of the skating wrist shot. Through the use of film analysis they identified the muscles responsible for the primary movements of action for each of the three phases of movement of the shot. They listed the movements of each body segment and the muscles responsible for their action. No indication of the relative importance of the various movements or muscle groups was given. From their mechanical analysis they came up with six main points:

1. The mass should be moving in the direction of the shot.

2. Additional force is given by the torque transmitted from the feet on the ice, through the rotation of the thighs at the hips and the rotation of the trunk around the spine and finally through the shoulders, arms and wrists.

3. The sum of the forces involved is increased by delaying arm and shoulder muscle movements.

4. The individual should drive through the puck so as to lessen the possible decrease in energy and momentum due to premature diminution of force.

5. The subject should follow through towards the target.

6. The mechanical advantage is increased when the lower hand moves down the shaft of the stick.

All of these points relate directly to the proper technique mentioned earlier. Points 2, 3, and 4 also involve human factors such as muscle balance and strength, and body flexibility. The other points primarily deal with learned style and form.

Stick Characteristics

Kingston (1980) maintains that the interaction of stick characteristics (i.e., weight, height, and flex) with technique and arm strength are important factors that should be considered when discussing puck velocity.

Perhaps golf is the most obvious other sport in which a "stick" is used, with the presence of considerable flex. In looking at the effect of shaft flex in the golf swing, Daish (1972) found that the characteristics of the shaft do not affect the drive to any appreciable extent. He suggested that this was due to the short time of contact between the club head and the ball.

Since the hockey wrist shot has a longer contact period then the golf swing, the shaft plays a more important role in the wrist shot and could conceivably have an effect on puck speed. Based on these principles the well known sports manufacturer C.C.M. developed a method of determining the most effective stick flex for a player based on his wrist strength. Unfortunately the concept was not publicly supported and is no longer marketed.

Jensen and Schultz (1970) explain that flex is a temporarily stored counterforce. If a surface or implement used in a performance has elasticity, then an applied force produces bend or compression which represents stored energy. This stored energy depends on the amount of disfigurement of the object combined with its ability to spring back. This disfigurement of the shaft occurs in the wrist shot and results in stored energy which is, in turn, converted into kinetic energy of the puck.

It is well known from Physics that the mass of the implement striking an object will affect the velocity of that object. Daish (1972) found that in the golf swing increasing the club mass to infinity would increase the ball velocity by at most one seventh. He deduced the club mass M, the ball mass m, and the velocity v are related by the formula

$$v = \frac{kM}{M + m}$$

for some constant k. In the limit as $M \to \infty$, v becomes $v_\infty = k$. Since the average golf club is about seven times as heavy as the ball, $v = \frac{7km}{7m+m} = \frac{7k}{8}$. Hence $\frac{v_\infty}{v} = \frac{8}{7}$, and the velocity of the ball can be increased by at most $\frac{1}{7}$. In hockey the puck and stick weight average 0.15 kg and .69 kg respectively. Hence $\frac{v_\infty}{v} = \frac{k}{\frac{0.69k}{0.84}} = \frac{0.84}{0.69} = 1.22$.

Thus one might increase the puck velocity in the wrist shot by at most 22%, if the muscles could manage to sweep an infinitely heavy stick. Doubling the stick weight results in a ratio $\frac{v_\infty}{v} = 1.11$. Unfortunately doubling the weight of the stick would require the subject to be porportionally stronger in order to produce the same stick motion and velocity and this is not easily achieved.

Thus far the research cited indicates that technique, stick characteristics and biomechanical principles of the body are integral components of a good wrist shot.

Physiological Characteristics Related to Shooting

This section deals with the anthropometric and physiological characteristics of a hockey player, and discusses how they may relate to the velocity of the wrist shot.

Somatotypes

Three somatotypes analyses have been performed on U.B.C. hockey teams in the last twenty years. Selder (1964), found that all the players he tested were in the dominant mesomorph category. Ennos (1976) repeated the analysis on the 1976 team and found that all but one subject were in the dominant mesomorph category. Comparing the 1964 and 1976 teams he found that there was no significant difference in somatotypes between the two teams. On the other hand Ennos found that the 1976 team was significantly taller and heavier then the 1964 team. He also concluded that body size but not body structure had changed in the selection process of ice hockey players in the past twelve years. Moyls and Nobbs (1979) repeated the procedure on the 1979 hockey team. Grouping the players according to the position played, they found that defensemen were significantly heavier and and higher in endomorphic ratings than the forwards. Again no significant differences in somatotype ratings were found between the three teams. The somatotypes of successful hockey players does not appear to have changed over the fifteen year period, 1964-79, but size has, especially weight.

These three studies indicate that successful hockey players are in a highly selective somatotype category. Success in the game of hockey requires a dominant mesomorphic somatotype. Skill in shooting is of course one small part of the competent hockey player's arsenal. At this point there is little evidence that shooting skill is related to a specific somatotype. All good shooters seem to be in the dominant mesomorph category (in spite of considerable physical variation). But this is probably due to the fact that they are good hockey players, rather than specifically good shooters.

Strength

Several investigators have attempted to isolate selected strength of arm movements affecting puck velocity in the wrist shot. Alexander, Drake, Reichenbach, and Haddow (1964) investigated the effect of isometric strength development on the shot velocity of varsity ice hockey players. Eighteen members of the University of Alberta varsity hockey team were used in this study, with nine of these subjects used as a control group. Four of the remaining nine were analyzed on film to determine the arm movements thought to be important in shooting. From this analysis, the subjects to be tested were placed on a program consisting of eight isometric exercises specifically designed to develop these arm movements. The exercises for the upper arm were designed to increase strength for arm adduction at shoulder, arm adduction at shoulder in hyperextension, wrist supination and wrist extension. The lower arm exercises were designed to increase strength in forearm extension, arm flexion at shoulder, wrist pronation and wrist flexion. During the training period, which lasted for five weeks, all subjects also participated in regular daily practises. The investigators found that the speed of shooting in both the skating slap and wrist shots for the experimental group improved significantly

($p < .05$) as a result of the training program. For the experimental group, the skating wrist shot mean increased from 65.5 M.P.H. to 70.8 M.P.H. while the control group improved from 67.5 M.P.H. to 69.4 M.P.H. For the skating slap shot the experimental group mean improved from 71.1 M.P.H. to 75.3 M.P.H. while the contol group improved from 70.6 M.P.H. to 70.7 M.P.H.

Reed, Cotton, Hansen, and Gauthier (1979) investigated upper body strength and handedness shooting characteristics of junior and professional hockey players. Seventy-nine juniors and forty-three professionals were classified into left- and right- groups. These two groups were in turn broken down into left and right shots giving a total of four groups. Left and right grip strength, shoulder strength in horizontal abduction and forearm strength in pronation were measured on each subject. In measuring grip strength, the results indicated a trend towards greater right than left scores in all subgroups. This trend was more pronounced for professionals than it was for the juniors. The horizontal abduction showed a similar trend in that the means were higher on the right side than on the left, for all groups. However, only the professional group demonstrated significant right strength dominance. One infers from this study that both sides of the body should be tested.

Moyls (1979) investigated the effect of dominant hand placement on accuracy and velocity of the standing snap shot. Subjects from the University of British Columbia varsity hockey team were classified by dominant hand and shooting characteristics. Shooting accuracy, velocity, and left and right grip strength were measured on each subject. Placement of the strongest hand in either of the two positions did not result in significant differences in either accuracy or velocity. Furthermore, the analysis showed no significant difference between the group with the dominant hand placed on the shaft of the stick and the group with the dominant hand placed on the top position on the stick as far as accuracy and velocity were concerned. Hand position had a correlation of -.013 with accuracy and a correlation of .268 with puck velocity.

Muscle Balance

The ability of the agonist and antagonist muscles to work together in opposition is an important component of human movement. In order to generate a force, prime movers act without interference from antagonistic muscle groups. The efficiency and smoothness of the movement will depend, to a large measure, on the strength, balance and flexibility of agonist-antagonist (and synergistic) pairs about joints. Jensen and Schultz (1970) state that an inadequate range of motion in certain joints may restrict one's ability to perform. Inflexibility acts as a resistance or brake to both speed and strength of movement. One's ability to reduce resistance by relaxing the antagonistic muscles is a key factor in the speed of the movement. This concept of muscle balance appears to be an important factor to be considered in a movement such as the wrist shot. Jensen and Schultz maintain that the overdevelopment of one set of muscles can result in a person becoming musclebound. This decreases the speed and force of the movement by upsetting the agonist-antagonistic balance essential to a fluid smooth movement.

Jesse (1977) emphasizes the importance of minimizing muscular imbalance through adequate testing and properly designed conditioning programs. An exact balance of muscles cannot be obtained because of their differences in anatomical size and length. However, he states that participation in some specific sports can actually aggravate the situation, resulting in increased muscular imbalance. He cites two studies in the Soviet Union which claim to have proven conclusively that participation in competitive sport creates muscular imbalance in the body. Jesse adds that many conditioning programs devised by coaches also add to muscle imbalance. He points out that the goal of training and conditioning, at least from the standpoint of injury prevention, should reduce the ratio of imbalance to as small a differential as possible. Flexibility is difficult to aquire in a joint when there is a great disparity in the ratio of strength between the muscles on both sides of the joint. Constantly overstretched muscles on one side of a joint, caused by an imbalance created by stronger muscles on the opposite side, result in weakness and loss of power in the stretched muscles. A weak atrophic muscle is easily fatigued and is exposed to loss of elasticity sooner than a strong non-fatigued muscle. A tired muscle looses some of its ability to relax. But these antagonistic muscles must relax completely while the prime mover muscles move the joint if optimum speed and coordination are to be obtained. Jesse strongly maintains that an evaluation of muscle balance is required when analyzing the characteristics of skilled movement and injury prevention.

Important to any skilled movement is the efficient summation of forces by muscles or muscle groups. Jensen and Schultz (1970) maintain that few performances result from the upper extremities alone, and in almost all cases these movements must be closely coordinated and assisted by the movements in the neck, trunk, and lower extremities.

In the ice hockey wrist shot the proper sequential summation of muscle groups is vital to the success of the shot. Coaches King (1980), Kingston (1980) and Watt (1980) maintain that optimum synchronization and summation of the forces in the shot will increase the velocity of the wrist shot and may offset the effect of lack of strength. The force must be transferred from the contact with the ice through the legs to the body, arms and stick. Without a proper summation of forces the shooter will attain little effective power in his shot.

Eye Reflexes

Specific to the hockey wrist shot is the importance of eye movement. Johnston (1976) feels that the head should lift to look at the target during the execution of the shot to ensure accuracy of the shot. On the other hand, Brown (1980) maintains that if the eyes lift during the execution of the shot there is a change in the organization of the muscles due to eye and neck reflexes affecting extensor muscles. Consequently, by keeping the eyes fixed, one avoids interupting the organization of the muscle sequence in the shot.

Research by Gardiner (1969) indicates that there are two main reflexes occurring when the head moves. The first originates in the labyrinthine receptors located in the inner ear. The second is located in the neck. In connection with these reflexes Gardiner points out that the head exerts important influences upon positions of movement of the trunk and limbs. The neck reflexes ensure that the body follows the head movements. Reflexes generated by the labyrinthine receptors ensure that the centre of gravity of the body falls over the base of support. Gardiner speculates that simple labyrinthine and neck reflexes are concerned at all times in the coordination of limb movements and total body patterns. She cites work by Litmer which has shown that neck reflexes act more efficiently upon the upper limbs while labyrinthine reflexes have more impact on the lower limbs. Positions and movement of the head may be used to reinforce contractions of the arm muscles by involving tonic neck reflexes. Various positions of the head favor specific movements of the trunk and limbs. Fixing the head by focussing the eyes on a point stabilizes the gravitational effect on the labyrinthine receptors. The neck reflexes can make any necessary adjustments of the body to keep it aligned with a correctly positioned head. Gardiner also notes that many motor patterns require learning to inhibit the responses. In summary, the work of Gardiner shows that both in learning to shoot and in the execution of a good shot, positioning of the head can play a significant role.

Other Sports

Research done on other activities and sports related to this topic is minimal. Of particular interest, however, is Wiren's (1968) investigation of the human factors influencing the golf drive for distance. Various strength, flexibility, anthropometric and distance tests were performed on fifty-one golfers. This data was entered into a stepwise regression program for predicting drive distance. Eighteen physical variables entered the equation as contributing predictors. Wiren then also performed a film analysis on a few of the golfers. From the film analysis he developed a second regression equation with four variables entering into the equation. He then combined the four variables from the film analysis with the eight best physical predictors to give an overall regression equation. This overall equation had a multiple correlation coefficient of .953. He concluded that these models were reasonably accurate tools for predicting the distance of a golf drive. The variables having the highest correlation with drive distance were speed of downswing .789, length of backswing .719, clubhead speed prior to impact .680, handicap .612, right wrist palmar flexion strength .586, age .522, wrist cock retention (delayed hit) .523, thigh girth .494, right ankle plantar flexion strength .491, and left shoulder horizontal extension strength .484. Although the golf swing is different from the wrist shot in execution several of the principles such as summation of forces and body flexibility are similar. Thus Wiren's work can help in the understanding of the problems faced in this study.

Authorities Census

Table 2.1 represents a summary of the characteristics various authorities feel are important in the execution of the wrist shot. The authority's name is listed in the category which he feels is the most important factor in the execution of the high speed wrist shot. Some names fall in more than one column; in these cases they feel that more than one major factor is contributing to the shot.

There is a remarkable similarity in the authorities' responses. It appears that the coordination of the movement (ideal summation of forces) is thought to be about as important as muscular strength. King (1980) states "after analyzing many good shooters that on occaision I have observed shooters who generate great velocity yet don't appear to have great physical strength. I believe this is because the synchronization of the mechanics are refined and exact". Watt (1980) and Kingston (1980) concur that coordination of movement can offset lack of strength. It appears that ideally, coordination and strength will together produce the best results.

Table 2.1. Census of Authorities

Strength	Coordination (muscle summation)	Flexibility
Bobby Hull* (arms, wrists)		
Ken Hodge*	Ken Hodge*	
Dave Chambers* (arms, wrists) shoulders	Dave Chambers*	Dave Chambers*
Clare Drake	Clare Drake	
George Kingston (arms)	George Kingston	
Marshall Johnston*	Marshall Johnston*	
Tom Watt (forearms, wrists)	Tom Watt	
Dave King (forearms, trunk)	Dave King	
	Anatoli Tarasov*	
Howie Wenger (elbows, knees) shoulders, hips		
Bob Hindmarch (legs)	Bob Hindmarch	

*- Indicates information found in authority's book or article. Other information is based on personal contact.

Summary

The literature reviewed in this chapter indicates that many hours of practising the proper technique are necessary if one is going to be able to shoot the puck at a high velocity. If optimum results are to occur then the exact technique is essential.

Strength is known to play a role in determining the velocity of the wrist shot, but the exact nature of this role and the muscle groups involved has not been determined. It is thought that muscular balance and optimum synchronization of muscle forces are vital components related to a high speed shot. By lifting the head during the execution of the shot, the synchronization of muscle forces is altered. It is still unknown whether this effect is important to the outcome of the shot in terms of puck velocity.

Little research has been done in the area of flexibility and the role it plays in executing a high velocity wrist shot. At the present time its effects remain unknown.

Chapter 3

PROCEDURES

This chapter reviews the testing procedures used in measuring the human factors thought to be important in predicting the velocity of the wrist shot. Of primary interest are the rationales for variable selection, variable measurement methods, research design, and the statistical techniques selected for the analysis of the data. The detailed step-by-step procedures for measuring the test variables are found in Appendix A.

Sample

The sample was made up of thirty-five active male hockey players drawn from five ability levels of hockey. These levels were: junior, intermediate, senior, university, and professional. The subjects varied in age from seventeen to twenty-nine. It may be noted that there is an overlap in calibre at all five levels. Some of the subjects have participated in four of the five levels within a time span of three years.

Criteria for selection were that the subject was currently participating in organized hockey at one of these five levels, and that he had the ability to execute a well-developed wrist shot. The features looked for in determining whether a player had a well developed wrist shot were the following; (i) sweeping motion of the stick through the shot; (ii) weight transfer when puck passes midline of body (right handed shot—from right leg to left leg); (iii) extended follow through; (iv) and weight ending up directly over supporting leg. Initially a list was drawn up of sixty-five players who met the required criteria. From this list, players were contacted until a sample of thirty-five players had agreed to participate in the study. It was hoped that by meeting the criteria the sample would be consistent with regard to method of execution, but fairly broad in range in shooting ability.

Design

This descriptive field study was based on a multiple correlation design and utilized Forward Stepwise Regression and All Possible Subsets Regression techniques in analyzing the data.

Selection of Variables

A major portion of this study deals with the selection of the independent variables to be measured. When analyzing a motor skill there are several conventional approaches available. The characteristics which can be analyzed fall naturally into two categories: modifiable and non-modifiable. It has been the intent of this study to look at characteristics that are subject to modifications. This automatically eliminated such characteristics as genetic traits and body somatotypes, since neither of these can be changed to any great extent. Therefore this study concentrated on analyzing the wrist shot through an investigation of physical characteristics; this appears to be the simplest means of analyzing primarily modifiable characteristics such as strength, flexibility and muscle balance yet also incorporates some non-modifiable characteristics in the area of anthropometry.

Having decided on the general components of the motor skill to be analyzed, the next task was to select the specific physical variables to be investigated. Several letters were written to authorities in the sport of hockey. They were asked to list the specific muscle groups, joints and body dimensions that they deemed to be most important in terms of strength, flexibility and composition in determining or restricting the puck velocity achieved in the execution of the wrist shot.

It may be noted that several of the authorities specified the optimum summation of forces as an important element in determining puck velocity. No attempt was made in this study to try to alter the coordination of the shooting motion other than to ensure the execution was consistent with that already specified. The optimum summation of forces was not determined in this study.

The test battery was selected on the basis of the responses received, related literature, and the author's subjective opinion. The physical variables chosen can be grouped into four categories:

1. Anthropometric Measures
2. Flexibility
3. Muscular Strength
4. Muscular Balance

Table 3.1 lists the independent variables used in this study.

It may be noted that the anthropometric variables were investigative in nature. Very little information was found in related literature that predicted what relationship these anthropometric variables would have with a motor skill of this nature.

Table 3.1. Independent Variables Selected for Testing[1]

Group	Variable	Abbreviation
Anthropometric Variables	Age	AGE
	Height	HT
	Weight	WT
	Arm Length Upper Arm	UARM L
	Arm Length Lower Arm	LARM L
	Arm Length/Stick Length	ARM/STI
	Wrist Girth Upper Arm	UWRISTG
	Wrist Girth Lower Arm	LWRISTG
	Forearm Girth Upper Arm	UFORARMG
	Forearm Girth Lower Arm	LFORARMG
	Arm Girth Upper Arm	UARM G
	Arm Girth Lower Arm	LARM G
	Hand Dominance	HAND
Flexibility Variables	Wrist Flexion Extension Upper Arm	UWRISTFX
	Wrist Flexion Extension Lower Arm	LWRISTFX
	Shoulder Rotation Upper Arm	USHROT
	Shoulder Rotation Lower Arm	LSHROT
	Forearm Rotation Upper Arm	UFORROT
	Forearm Rotation Lower Arm	LFORROT
	Trunk Rotation	TRUNKROT
Strength Variables	Trunk Flexion	TRUNKFLE
	Trunk Extension	TRUNKEXT
	Hip Flexion Glide Leg	GLHIPFLE
	Hip Extension Glide Leg	GLHIPEXT
	Hip Flexion Drive Leg	DRHIPFLE
	Hip Extension Drive Leg	DRHIPEXT
	Arm Abduction at Shoulder Upper Arm	USHABD
	Arm Adduction at Shoulder Lower Arm	LSHADD
	Diagonal Motion Upper Arm	UARMDIAG
	Diagonal Motion Lower Arm	LARMDIAG
	Forearm Supination Upper Arm	UFORSUP
	Forearm Pronation Lower Arm	LFORPRO
	Wrist Extension Upper Arm	UWRISTST
	Wrist Flexion Lower Arm	LWRISTST
	Elbow Flexion Upper Arm	UELBFLEX
	Elbow Extension Upper Arm	UELBEXT
	Elbow Flexion Lower Arm	LELBFLEX
Muscle Ratio Variables	Flexion/Extension Glide Hip	F/E GHIP
	Flexion/Extension Drive Hip	F/E DHIP
	Flexion/Extension Trunk	T F/E
	Drive/Glide Leg Flexion	D/G FLEX
	Drive/Glide Leg Extension	D/G EXT
	Flexion/Extension Elbow Upper Arm	U F/E EL
	Flexion/Extension Elbow Lower Arm	L F/E EL
	Upper/Lower Elbow Flexion	U/L F EL
	Upper/Lower Elbow Extension	U/L E EL
Stick Variable	Stick Length	STICK L

1. Upper and Lower Arm refer to the limb that grasps the stick in the upper and lower shaft positions (see upper and lower arm definitions, p.4).

The relaxed arm girths were selected because they are primarily a measure of bone development; the flexed forearm girths because they are predominantly a measure of muscle development; and the wrist girths because they are a combination of bone and muscular tendinous tissue. These measurements appear to cover the bone and muscle development of the arm.

Stick length was the only characteristic of the stick to be measured. It was believed that the relationship of the arm to stick length was important when considering the mechanical advantage in the execution of the wrist shot. MacGillivary and Watson (1964) showed that by lowering the bottom hand on the shaft, one increases the mechanical advantage in the shot by decreasing the length of the resistance arm and increasing the length of the force arm. The resistance arm is the distance from the lower hand on the stick to the puck. The force arm is from the top hand of the stick to the lower hand. Thus by changing the position of the lower hand one can alter the mechanical advantage. On the other hand, this process of lowering the bottom hand on the stick does decrease the speed advantage of the stick. The ratio of arm length to stick length affects the lower hand position.

The muscular strength variables were selected by analyzing the shooting motion and choosing those elements of the motion deemed most important by the authorities consulted. An attempt was made to include variables which covered the major areas of the body, such as arms, legs and trunk; however, a more concentrated emphasis was placed on the arms.

The flexibility variables were selected for similar reasons, again with the most concentrated area being the arms and shoulders.

The muscular balance ratios were selected on the basis of considerations presented by Jesse (1977). This section was coordinated with the strength variables already selected in order that extra strength variables need not to be measured. In addition, it was felt that the strength variables selected for shooting would be the most important to consider in muscular balance.

Instruments and their Reliability

K15 Radar Gun

A K15 radar gun (Digitar K15 doppler A-06-000011 M.P.H. IND. Inc.) was used to measure the velocity of the puck. The transmitter frequency of the gun has a maximum error rate of .05% and the speed of the radio waves is within .001% of the speed of light. The K15 radar gun has an internal calibration system which indicates whether the gun needs adjustment. If the gun requires calibration this system specifies the exact measures to be calibrated to. Problems occur when the radar gun is not positioned directly behind the flight of the object. In this case the problem is solved by placing the tester directly behind the net. The signal is broad enough to give accurate results for this situation.

There are two types of interference that can influence the speeds recorded. The first type is a low frequency source (e.g., neon lights) in the testing vicinity. This source is not additive in nature and, as long as the subject's puck velocity is greater than the source reading, the puck velocity will be displayed on the gun. The subjects are capable of shooting the puck at speeds much faster than this source interference. The second type of interference is additive in nature and is found in the presence of ultra sound. This is a more serious problem in that the system will add this constant interference to the velocity of the puck. If the source of the interference is established, the true puck velocity can be obtained. In this study it was found that the first type of interference was present but did not interfere with the results obtained in any way. No calibration was required throughout the tests.

Cybex II

All the strength tests were measured on the Cybex II isokinetic exerciser. The machine was calibrated before being used and at the end of the study. No major adjustments were required as the Cybex machine has been found to hold calibration for periods much longer than that required in this study.

Leighton Flexometer

All the flexibility tests were measured by the use of a flexometer developed by Leighton (1966). The flexometer consists of a weighted 360 degree dial and a weighted pointer mounted in a case. The dial and pointer rotate independently of each other and are responsive to the gravitational pull of the earth. The instrument will record any angle of movement as long as it is positioned 20 degrees off the horizontal. The instrument requires no calibration and is as reliable as the tester; however extensive practise with the instrument is required for valid results to be obtained. The investigator has used this instrument in two studies and has obtained reliable results when measuring in the pilot study.

Tape

All the girth variables were measured with a cloth tape. The tape was checked three times for accuracy. It was found that the tape had not stretched throughout the course of the testing but had stretched by three millimeters over thirty centimeters prior to use.

Testing Procedures

The testing procedures used were those recommended by the manufacturers and researchers who developed the testing equipment. A detailed description of these testing procedures is found in Appendix A.

For consistency, only one investigator and one aide were used throughout the course of the testing. All the measurements were performed by the investigator.

Each subject was required to read and sign a consent form, outlining the testing and timing requirements , prior to any involvement in the study. The testing was broken down into two sessions. The first session took place at the University of British Columbia Thunderbird Arena where stick length and puck velocity were measured. The second session took place at the University of British Columbia Buchanan Fitness Center. All strength, flexibility and anthropometric measures were tested there. The order of testing was the same for each subject; anthropometric measures first, flexibility measures second and strength measures last.

Shooting Velocity

The procedures used to measure puck velocity followed the principles outlined in Corbett's (1980) paper on Radar Systems. Five pucks were weighed and frozen prior to testing. The subject was positioned on the blueline directly in front of the goal. The tester was situated directly behind the goal with the K15 radar gun aimed at the puck. The subject was instructed to shoot the puck as hard as possible at the middle of the net. He was allowed as many warm up shots as he wanted. Each subject shot a minimum of five test shots. Any shots that missed the net were not included as test shots. If the subject's fourth or fifth shot exceeded by 3 K.P.H. or more the speed of the fastest shot in his first three attempts, he continued to shoot until he had two consecutive shots after his fastest shot within the 3 K.P.H. limit. The fastest three shots were averaged to give the subject's shooting score. The subject's sequence of head motions was also recorded. No subject required more than nine shots.

Anthropometric Measures

Girths. Girth measurement procedures are outlined in the MOGAP (1976) paper in Appendix A. Each girth was measured and recorded twice. If these measurements differed by more than 10% a third measurement was taken. The closest two scores were averaged to give the test score.

Height, Weight and Arm Lengths. Height and arm length were measured by the use of a stadiometer. Each arm length was measured twice. When the difference between the two scores was more than 10% a third measurement was taken. The closest two were averaged to give the arm length score.

Weight was measured on a balance beam scale. The subject was weighed wearing shorts only.

Flexibility Measures

Each subject had a brief ten-motion warmup similar to the flexibility measures being tested (see Appendix B). The flexometer was then strapped to the subject and two test trials were recorded for each movement. The largest value obtained was recorded as the test score.

Muscular Strength Measures

Eighteen strength tests were administered to the subject. Each test consisted of two trials for each test. Before the actual test one practise trial was given at about half the maximum force in order to allow the subject to become accustomed to the resistance given by the Cybex machine. The Cybex was set at a maximum arm speed of 30 degrees per second, for all but one of the tests. The trunk extension test was executed as an isometric contraction rather than isokinetic as was the case in the other tests. The lever arm length was recorded for each exercise. The printout from the machine gave the torque applied through the full range of motion. By dividing the maximum torque applied by the lever arm length one obtains the maximum force applied by the subject. The procedures for each exercise follow those specified in the Cybex II manual (1978).

Muscle Balance

The muscular balance ratios were calculated for three muscle groups in the body. These were obtained by dividing the force in flexion by the force in extension around a body joint. The ratio of hip flexion/hip extension was calculated for both legs. The drive leg was compared to the glide leg for both flexion and extension. The lower arm was similarly compared to the upper arm. Similar comparisons were made for elbow flexion and extension, in both arms. Trunk flexion/trunk extension was also calculated. The calculated ratios were used to analyze the balance of muscle forces of the hip, trunk, and elbow joints and to compare the right to the left limb in flexion and extension.

Analysis of Data

There were two major objectives in analyzing the data: first, to find the human characteristics most important in predicting puck velocity; and second, to find the best overall regression equation for predicting puck velocity.

Multiple regression techniques provide a natural and effective tool for achieving these objectives. In the first instance Stepwise Regression was the technique chosen, but the All Possible Subsets technique was required to verify the cutoff point for variables entering the regression equation. Programs BMD:P2R (Stepwise Regression) and BMD:P9R (All Possible Subsets Regression) were run to identify the best regression equation. (BMD P Series Manual, 1980)

Stepwise Regression starts with no variables in the regression equation and enters first the variable that has the highest correlation with the dependent variable. It then proceeds to enter the variable having the highest partial correlation with the dependent variable. The partial correlation suppresses the effect of the variable already entered into the equation. The program proceeds in this step-by- step fashion.

A significance level must be specified prior to the running of the program. The significance level was set by an F-to-enter value of .500. Any variable that had a partial correlation with the dependent variable that gave a F value of .500 or greater, would enter the equation. Those with an F value of less than .500 would be removed from the equation. Using such a low F-to-enter value resulted in many variables entering the equation; however, by monitoring the standard error of estimate, the best regression equation could be selected. The best possible prediction equation occurs when the standard error of estimate is at a minimum.

As a check and aide in finding the best regression equation, the BMD:P9R All Possible Subsets Regression program was also run. This program starts with a single variable and gives the ten best individual variables for predicting puck velocity. It then proceeds to give the ten best two variable equations and continues on in this fashion; at each step another variable is added. Next the adjusted R squared criterion was applied to give the best regression equation. The adjusted R squared value takes into account the number of independent variables entering the equation and the sample size. The regression equation with the largest adjusted R squared value is selected as the best.

The results from these two programs gave the overall best regression equation. This procedure was carried out first on the raw data and then later on transformed data. The data was transformed in an attempt to produce a better regression equation utilizing the variables that did not appear to be related to puck velocity in a linear fashion. The following transformations were applied to the variables: x^2, x^3, log x, and $\sqrt{x}$. Running the two regression programs again, another best regression equation was calculated.

The two equations were compared in terms of predicting ability of puck velocity and are discussed in chapter 4.

Chapter 4

RESULTS AND DISCUSSION

In this chapter the data are examined statistically and an optimal regression equation is established. The Stepwise Program and the All Possible Subsets Regression Program are analyzed and discussed with regard to selecting the best possible regression equation. The contribution of each group of variables to the regression equation is analyzed in terms of predictive ability and multiple correlation values. Various transformations are then applied to the data, and the effect of this process on the regression equation is observed. Specifically, the equations for the transformed data are compared with that for the untransformed data relative to bias and predictive ability.

Results: Multiple Regression Using Raw Scores

Descriptive Statistics

Table 4.1 gives the mean and standard deviation for each variable. Puck velocity had a fairly broad range of scores with a minimum speed of 75.7 K.P.H. and a maximum speed of 105.7 K.P.H. The mean value was 86.6 K.P.H., with a standard deviation of 6.5 K.P.H. In general, the sample turned out to be very homogeneous for the anthropometric variables. Comparing the coefficients of Variation, one can see that the flexibility measures are slightly more variable then the anthropometric measures, and the strength measures tend to be

Table 4.1. Descriptive Statistics for All Variables[1.]

Group	Variable No.	Variable Name	Mean	Standard Deviation	Coefficient of Variation
Anthropometric Variables	1	AGE	22.571	2.465	0.109
	2	HT	180.860	4.811	0.027
	3	WT	80.880	5.900	0.073
	5	UARM L	79.431	3.246	0.041
	6	LARM L	79.231	3.114	0.039
	7	ARN/STI	0.607	0.024	0.040
	8	UWRISTG	18.283	0.766	0.042
	9	LWRISTG	18.230	0.783	0.043
	10	UFORARMG	29.368	1.419	0.048
	11	LFORARMG	29.237	1.220	0.042
	12	UARM G	32.605	2.012	0.062
	13	LARM G	33.160	1.883	0.057
Flexibility Variables	15	UWRISTFX	158.114	15.221	0.096
	16	LWRISTFX	156.543	14.745	0.094
	17	USHROT	196.228	18.900	0.096
	18	LSHROT	197.114	19.282	0.098
	19	UFORROT	192.314	21.678	0.113
	20	LFORROT	186.514	21.493	0.115
	21	TRUNKROT	160.486	25.988	0.162
Strength Variables	22	TRUNKFLE	91.714	15.315	0.167
	23	TRUNKEXT	111.428	19.850	0.178
	24	GLHIPFLE	50.023	9.585	0.192
	25	GLHIPEXT	73.117	14.595	0.200
	26	DRHIPFLE	49.011	9.600	0.196
	27	DRHIPEXT	73.134	13.910	0.190
	28	USHABD	25.100	4.053	0.161
	29	LSHADD	35.688	7.204	0.202
	30	UARMDIAG	34.563	8.749	0.253
	31	LARMDIAG	31.223	9.346	0.299
	32	UFORSUP	7.694	1.720	0.223
	33	LFORPRO	8.489	2.118	0.249
	34	UWRISTST	31.277	8.903	0.285
	35	LWRISST	48.403	11.313	0.234
	36	UELBFLEX	41.674	7.988	0.192
	37	UELBEXT	33.274	7.853	0.236
	38	LELBFLEX	42.954	7.785	0.181
	39	LELBEXT	32.640	6.723	0.206
Muscle Ratio Variables	40	F/E GHIP	0.695	0.126	0.182
	41	F/E DHIP	0.680	0.121	0.179
	42	T F/E	0.849	0.209	0.246
	43	D/G FLEX	0.980	0.064	0.066
	44	D/G EXT	1.005	0.089	0.089
	45	U F/E EL	1.282	0.231	0.180
	46	L F/E EL	1.340	0.228	0.170
	47	U/L F EL	0.976	0.118	0.121
	48	U/L E EL	0.948	0.209	0.221
Stick Variable	4	STICK L	130.800	5.417	0.041
Dependent Variable	14	PUCKVEL	86.560	6.525	0.075

1. See Page for a description of the variables and code identification

the most variable of all. The muscle ratio group is really heteroskedastic in that the values of the coefficient of Variation range from .066 for flexion of the drive leg over glide leg to .246 for flexion over extension for the trunk. On the whole, however, one can conclude from this table that the sample was fairly homogeneous.

The product-moment correlation matrix is presented in Appendix C. Table 4.2 shows the correlations of puck velocity with the dependent variables. The shoulder adduction motion for the lower arm had the highest correlation with puck velocity, yielding a value of .451. The next highest correlation was with the forearm supination strength measure for the upper arm; this had a correlation of .431. These two variables had the highest linear relationships with puck velocity. For thirty-five degrees of freedom a correlation coefficient of .325 is required for the relationship to be significant at the .05 level. The five variables which qualified under this criteria, were; arm adduction at the shoulder of the lower arm (.451), forearm supination of the upper arm (.431), wrist strength in extension of upper arm (.418), diagonal arm strength of lower arm (.378) and wrist strength in flexion of lower arm (.344). It is interesting to note that all of these variables are measures of arm strength. No other variables were significant at the .05 level.

Stepwise and All Possible Subsets Regression Analysis

The P:2R (Stepwise Regression) and P:9R (All Possible Subsets Regression) programs were run on the data. The procedures are described in Chapter 3. Table 4.3 shows the order of variables entering the equation and the F-value, Multiple R^2, and the increase in R^2 after each step for the Stepwise Regression program. Table 4.4 shows the order of

Table 4.2. Product-Moment Correlation Table of Test Variables and Puck Velocity

	PUCKVEL
AGE	.0293
HT	.0189
WT	.2094
STICK L	.0318
UARM L	-.0435
LARM L	.0386
ARM/STI	-.0380
UWRISTG	.2509
LWRISTG	.3047
UFORARMG	.2603
LFORARMG	.2755
UARM G	.3210
LARM G	.3128
UWRISTFX	.0189
LWRISTFX	-.1984
USHROT	.1453
LSHROT	.0599
UFORROT	-.2207
LFORROT	-.2587
TRUNKROT	-.0424
TRUNKFLE	.1920
TRUNKEXT	.1432
GLHIPFLE	.1530
GLHIPEXT	.2874
DRHIPFLE	.1951
DRHIPEXT	.3110
USHABD	.3041
LSHADD	.4511
UARMDIAG	.2000
LARMDIAG	.3778
UFORSUP	.4311
LFORPRO	.1212
UWRISTST	.4176
LWRISTST	.3437
UELBFLEX	.1807
UELBEXT	.1064
LELBFLEX	.1972
LELBEXT	.2359
F/E GHIP	-.1380
F/E DHIP	-.1391
T F/E	.0046
D/G FLEX	.0923
D/G EXT	.0928
U F/E EL	.0516
L F/E EL	-.0993
U/L F EL	.0302
U/L E EL	-.2873

Table 4.3. Order of Entering of Variables Using Stepwise Program

No. of Variables	Variable Entered	Variable Removed	R Squared	Increase in R Squared	F-To-Enter	F-To Remove
1	LSHADD		.2035	.2035	8.431	
2	UFORROT		.2910	.0875	3.948	
3	USHROT		.3656	.0746	3.648	
4	UWRISTFX		.4148	.0492	2.524	
5	L F/E EL		.4519	.0371	1.961	
6	UARM G		.4781	.0262	1.408	
7	USHABD		.5114	.0333	1.840	
8	UFORSUP		.5373	.0258	1.452	
9	UARMDIAG		.5807	.0434	2.589	
8		USHROT	.5780	-.0027		0.160
9	TRUNKFLE		.6278	.0497	3.340	
10*	TRUNKROT		.6613	.0335	2.377	
11	WT		.6787	.0174	1.247	
12	LWRISTST		.6924	.0136	0.976	
13	F/E GHIP		.7101	.0177	1.283	
14	LFORROT		.7200	.0099	0.708	
15	STICK L		.7342	.0142	1.012	
16	LFORARMG		.7463	.0122	0.863	
15		UARM G	.7461	-.0002		0.013
16	UFORARMG		.7654	.0192	1.476	
15		F/E GHIP	.7594	-.0059		0.455
16	LSHROT		.7720	.0126	0.993	
17	USHROT		.7878	.0158	1.263	
18	F/E GHIP		.8010	.0132	1.060	
19	D/G EXT		.8095	.0085	0.673	
20	LFORPRO		.8250	.0155	1.242	
21	LELBFLEX		.8417	.0166	1.367	
20		LFORROT	.8411	-.0005		0.045
19		STICK L	.8371	-.0041		0.357
20	LARMDIAG		.8687	.0316	3.375	
21	F/E DHIP		.9040	.0352	4.770	
22	UELBFLEX		.9122	.0083	1.130	
23	DRHIPFLE		.9258	.0135	2.003	
24	GLHIPEXT		.9416	.0158	2.708	
25	HT		.9489	.0073	1.292	
24		F/E GHIP	.9487	-.0002		0.044
25	LFORROT		.9521	.0034	0.639	
26	AGE		.9584	.0063	1.216	

* Cutoff of variables entering in selection of best equation

variables entering using the All Possible Subsets Regression program. The suggested best equation is identified by this program and is noted in Table 4.4 with an asterisk. One can see from these tables that it is possible to account for virtually all the variance by letting all the variables enter. After the 38th step in the Stepwise solution the Multiple R has a value of .9790, indicating that 96% of the information required to predict puck velocity is known. With a small sample size it is possible to account for virtually all the variance when the subjects to number of variables ratio is small. With thirty-five subjects and twenty-six variables entered in the equation at the 38th step, the subjects to number of variables ratio is relatively small. Thus it is necessary to limit the number of variables entering the equation. The determination of a cutoff point for variables entering the equation is usually based on monitoring the standard error of estimate. As variables start to enter the equation the standard error should decrease. However, as the subject to variable ratio gets smaller the standard error should reach a minimum and eventually start to increase. With this data, however, the standard error of estimate never did achieve a minimum (see Figure 1). Thus alternate criteria were required for the selection of the best equation. It was decided to plot the number of variables against each of (i) the standard error of estimate, (ii) the adjusted R squared, and (iii) the multiple R. The adjusted R squared value considers the number of variables in the equation and the sample size. The BMD P Series Manual (1977,p.424) gives the formula used to calculate this value. Ideally, the best regression equation results when the value reaches a maximum; however, with this data, the adjusted R squared never

Table 4.4. Order of Entering of Variables Using All Possible Subsets Program

No. of Variables	Variable Entered	Variable Replaced	R Squared	Adjusted R Squared
1	LSHADD		.2035	.1793
2	UFORROT		.2909	.2466
3	USHROT		.3656	.3042
4	UWRISTFX		.4148	.3368
5	L F/E EL		.4519	.3574
6	UARM G		.4781	.3663
7	USHABD		.5114	.3848
8	UFORSUP		.5373	.3949
9	UARMDIAG		.5807	.4298
10	TRUNKFLE		.6278	.4727
11	TRUNKROT		.6621	.5004
12	WT		.6787	.5035
13	STICK L	WT	.7057	.5235
	LFORARMG			
14	LSHROT	UARM G	.7290	.5393
	LWRISTST			
15	WT	STICK L	.7468	.5469
	UARM G	LFORARMG		
	F/E GHIP			
16	STICK L	WT	.7682	.5622
	LFORARMG	UARM G		
	DRHIPFLE			
17	LWRISTG		.7773	.5546
18*	UARM G	UWRISTFX	.8331	.6454
	UWRISTST	USHABD		
	D/G EXT	F/E GHIP		
	U F/E EL			
19	USHABD		.8384	.6337
20	F/E GHIP		.8451	.6238

* Selected as best equation by adjusted R Squared criteria of program

reaches a maximum. Considering all three graphs, Figures 1,2 and 3, it seems natural to stop variables from entering the equation when the absolute values of the slopes begin to reach a minimum.

Analyzing Figures 1,2 and 3 for the stepwise program, the point at which all three graphs level off occurs at the 12th step. This yields an equation with ten variables, and is the best regression equation according to the cutoff criterion. The cutoff of variables is noted by a dashed line on the three graphs. The equation cut at this point accounts for 66% of the variance. By running both Stepwise and All Possible Subsets Regression programs it was possible to see if both programs entered the variables in the same order. Comparing the two programs for the first ten variables (Tables 4.3 and 4.4) one finds only one discrepancy. The Stepwise program enters the flexibility measure trunk rotation while the All Possible Subsets program enters the flexibility measure shoulder rotation of the upper arm. Since the Stepwise program had a higher multiple R value it was selected. Thus the best regression equation for predicting puck velocity is:

$$
\begin{aligned}
Y(\text{puck velocity}) = {} & X_1(\text{arm girth of upper arm})(.7544) \\
& + X_2(\text{wrist flexibility upper arm})(.1374) \\
& + X_3(\text{forearm rotation upper arm})(-.1779) \\
& + X_4(\text{trunk rotation})(-.0574) \\
& + X_5(\text{trunk flexion})(.1645) \\
& + X_6(\text{arm abduction upper arm})(-1.1586) \\
& + X_7(\text{arm adduction lower arm})(.8949) \\
& + X_8(\text{diagonal motion upper arm})(-.2990) \\
& + X_9(\text{forearm supination upper})(1.7023) \\
& + X_{10}(\text{flexion/ext. elbow lower})(-7.5737) \\
& + 73.0946.
\end{aligned}
$$

This equation has a multiple R value of .813 and a standard error of estimate of 4.52. Therefore the equation can account for 66% of the

Figure 1. Standard Error of Estimate Versus Number of Variables

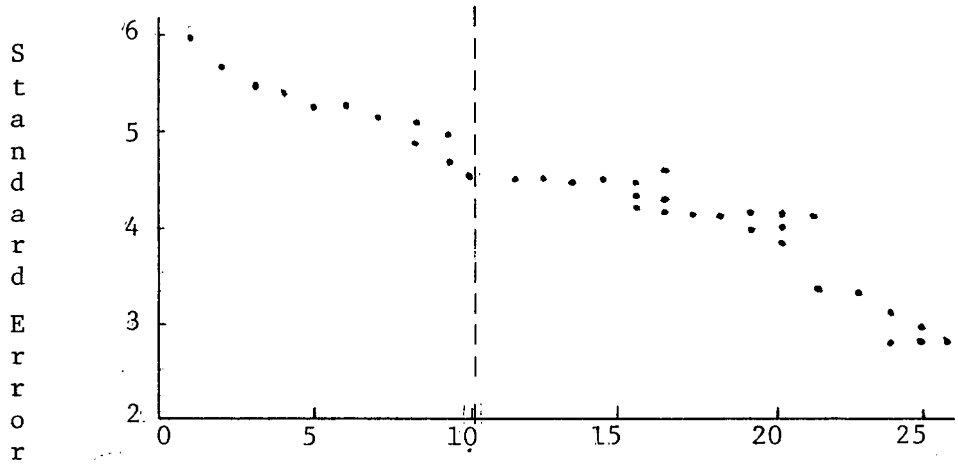


Figure 2. Adjusted R Squared Versus Number of Variables

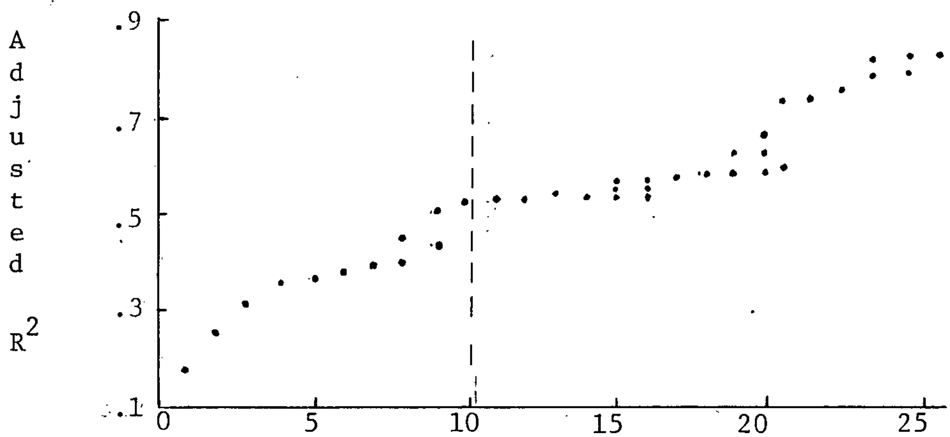
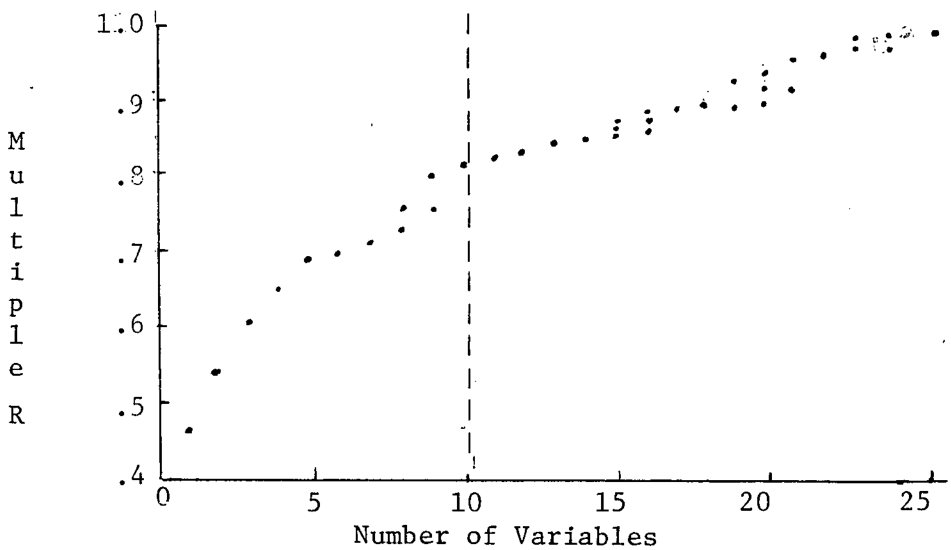


Figure 3. Multiple R Versus Number of Variables



variability and gives a prediction accuracy of ± 9.0 K.P.H. 95% of the time.

Discussion: Multiple Regression Using Raw Scores

Anthropometric Variables

Table 4.5 shows the order of entering of the Anthropometric variables.

Table 4.5. Anthropometric Variables Order of Entering

Step No.	Variable	F-to-Enter
6	Arm Girth Upper Arm	1.4076
13*	Weight	1.2471
18*	Forearm Girth Lower Arm	0.8632
35*	Height	1.2919
38*	Age	1.2162

No other anthropometric variables had a F-to-Enter of greater than .500

*- Variable did not enter best regression equation.

In general, the six girth measures had very poor linear relationships with puck velocity. Arm girth, the anthropometric variable with the highest zero order correlation with puck velocity (.321), was the only anthropometric variable to enter the best regression equation. The relaxed arm girths primarily measure bone development while the forearm and wrist girths (both flexed) measure a combination of muscle and bone. One would expect the flexed forearm girths to be more highly correlated with the strength variables than the relaxed arm girths. This was the case. Since upper arm girth had a relatively large correlation with puck velocity, and was not particularly well correlated with the strength variables, it seems reasonable for it to play a somewhat independent role and hence enter the equation. The two arm length measures were essentially uncorrelated with puck velocity and thus did not enter the equation. Body weight had a correlation of .2000 with puck velocity; it would have been the next variable entered had the equation not been cutoff at ten variables. It appears that the increase in weight of hockey players in the past fifteen years (Ennos 1976) is not strongly linearly related to the increase in puck velocity in shooting. Height did not turn out to be an important variable in this analysis. Ennos (1976), Moyls and Nobbs (1979), and Selder (1964) found that the body types of collegiate hockey players were similar, and that players at the college level have been increasingly heavier in recent years. However, one can only conclude from this study that height and weight are not as important in predicting puck velocity as one might be inclined to assume, looking at their studies.

Flexibility Variables

Table 4.6 shows the order of entering of the flexibility variables

Table 4.6. Flexibility Variables Order of Entering

Step no.	Variable	F-to-Enter
2	Forearm Rotation Upper Arm	3.9482
3**	Shoulder Rotation Upper Arm	3.6476
4	Wrist Flexion Extension Upper Arm	2.5239
12	Trunk Rotation	2.3773
16**	Forearm Rotation Lower Arm	0.7076
22*	Shoulder Rotation Lower Arm	0.9928

No other flexibility variables had an F-to-Enter of greater than.5000.

*- Variable not in best regression equation.

**- Variable entered, was removed and entered again. Not in best regression equation.

Chambers (1979) was the only authority to mention that a flexibility measure is important in predicting puck velocity (he stated that trunk rotation played an important role in shooting). In this study, three out of the ten variables entering the equation were flexibility measures. Trunk rotation, forearm rotation and wrist flexibility of the upper arm all proved to be important in predicting puck velocity. It should be noted that the upper and lower forearm rotation correlated fairly highly with each other (r=.599). Thus forearm rotation of the lower arm is probably an important variable, but because of it's correlation with the upper arm (which entered first), it did not enter the best equation. It appears that the importance of flexibility in shooting may be more important then has generally been thought. However, one observes that trunk rotation and upper forearm rotation have negative correlations (r's of -.0424 and -.2207 respectively). One can attempt to explain this by the fact that most of the strength variables are negatively correlated with the flexibility variables. Thus the higher the flexibility score the lower the strength score. Shoulder flexibility does not appear to follow this pattern and is correlated positively with most of the strength variables and puck velocity.

Strength Variables

Table 4.7 shows the order of entering of the strength variables

Table 4.7. Strength Variables Order of Entering

Step no.	Variable	F-to-Enter
1	Arm Adduction at Shoulder Lower Arm	8.4308
7	Arm Abduction at Shoulder Upper Arm	1.8402
8	Forearm Supination Upper Arm	1.4520
9	Diagonal Motion Upper Arm	2.5894
11	Trunk Flexion	3.3401
14*	Wrist Strength Lower Arm	0.9760
26*	Forearm Pronation Lower Arm	1.2419
27*	Elbow Flexion Lower Arm	1.3748
30*	Diagonal Motion Lower Arm	3.3748
32*	Elbow Flexion Upper Arm	1.1296
33*	Hip Flexion Drive Leg	2.0032
34*	Hip Extension Glide Leg	2.7083

No other strength variables had a F-to-Enter value of greater than .5000.

*- Variable not in best regression equation.

In line with the predictions made by the authorities recorded in the census in chapter 2, the strength measures did have the greatest impact on the regression equation. The following strength measures: trunk flexion, arm adduction at the shoulder of the lower arm, arm abduction at the shoulder of the upper arm, diagonal motion of the upper arm, and forearm supination of the upper arm all did enter the best regression equation. Alexander, Drake, Reichenback (1964) investigated eight exercises, including arm adduction and wrist supination of upper arm, and found that an isometric exercise program consisting of these eight exercises significantly increased the velocity of the skating wrist and slap shots. It is interesting to note that two of their exercises (arm adduction and wrist pronation of the upper arm) were variables which entered the best regression equation.

Arm adduction at the shoulder of the lower arm was the best individual predictor of puck velocity, accounting for 20% of the uncertainty by itself. Wrist strength was not an important variable in terms of predicting puck velocity. Several of the authorities suggested that wrist strength was an important variable to consider when analyzing the causes of a fast shot. Moyls (1979) found little or no relationship between puck velocity and grip strength. It appears that forearm supination and pronation may play a more important role than wrist flexion, extension or grip strength.

Muscle Ratio Variables

Table 4.8 shows the order of entering of the muscle ratio variables.

Table 4.8. Muscle Ratio Variables Order of Entering

Step no.	Variable	F-to-Enter
5	Flexion/Extension Elbow Lower Arm	1.9609
15*	Flexion/Extension Hip Glide Leg	1.2832
25*	Drive/Glide Leg Hip Extension	0.6732
31*	Flexion/Extension Hip Drive Leg	4.7701

No other muscle ratio variables had a F-to-Enter value of greater than .5000.

*-Variable not in best regression equation.

As indicated in Chapter 2, Jesse (1977) felt that an analysis of muscle ratios may be more significant than an analysis of individual strengths. In this study, only one muscle ratio entered the equation: the ratio of elbow flexion to extension of the lower arm proved to be important in predicting puck velocity. It was the fifth variable to enter the equation, and it had a negative coefficient. The mean for this score was 1.34. The negative coefficient suggests that it may be more efficient if the ratio is closer to 1.00. Thus by having the extensor and flexor muscles balanced the motion would be more efficient for the reasons suggested by Jensen and Schultz (1970) in Chapter 2. Therefore the extensor muscles in the arm should be strengthened to increase the efficiency of the motion. However one can only speculate as to the effect on shot velocity at this time. Further study in this area is needed. Several of these ratios enter the equation after the cutoff. Although flexion/extension of the hip for the glide leg had a fairly large F-to-Enter value when it entered the equation, this value did not become large enough to enter until after the 15th step. This was due to the high intercorrelations of some of the variables. However, it appears that some of the uncertainty is not accounted for in the other variables and thus it entered at the 15th step.

Head Sequence Variable

Head sequence was not entered into the analysis because every subject used the same sequence. All the subjects started with the head down looking at the puck. The head was lifted after the execution of the shot was completed. Since none of the subjects varied from this sequence, one does not have to be be as concerned with the eye reflex effects on the shot as originally was thought. Since the pattern was consistent throughout the test it is assumed that the neck and labyrinthine reflexes outlined by Gardiner (1969), were consistent also.

Results: Multiple Regression Using Nonlinear Transformations

From the initial computer runs it appeared that several of the variables were not related to puck velocity in a linear fashion. Transformations of the data were used in an attempt to produce a better prediction equation, possibly incorporating variables which were not linearly related. The following transformations were applied to the variables: x^2, x^3, log x, and $\sqrt{x}$. As a result of these procedures only the strength variables showed an increase in their correlation coefficient with puck velocity, and that occurred when the cubic function was used. For every strength measure, the correlation with puck velocity increased when the data was transformed by a cubic function. It is of some interest that none of the anthropometric or flexibility variables improved when transformed by any of these functions. Table 4.9 shows the correlation values of the transformed variables with puck velocity.

With the initial 48 variables, and the cubed strength variables now in the data storage, the Stepwise and All Possible Subsets Regression programs were rerun. Table 4.10 shows the order in which the variables entered in the Stepwise procedure. Table 4.11 shows the All Possible Subsets entering order. After ten steps the transformed run has (in both procedures) a multiple R of .889, 8% better than the untransformed regression of the better (Stepwise) procedure at the same point. The cutoff point was determined by the same procedure as was used previously on the untransformed data. Figures 4, 5, and 6 show the number of

Table 4.9. Product-Moment Correlation Table of Cubed Strength Variables and Puck Velocity

	PUCKVEL
$TRUNKFLE^3$	.2334
$TRUNKEXT^3$	.1934
$GLHIPFLE^3$	.2165
$GLHIPEXT^3$	.3929
$DRHIPFLE^3$	.2840
$DRHIPEXT^3$	.3888
$USHABD^3$	.3922
$LSHADD^3$	.4727
$UARMDIAG^3$	.2492
$LARMDIAG^3$	.4409
$UFORSUP^3$	.4938
$LFORPRO^3$	.1555
$UWRISTST^3$	.4439
$LWRISTST^3$	.3727
$UELBFLEX^3$	.2815
$UELBEXT^3$	.1401
$LELBFLEX^3$	.3299
$LELBEXT^3$	.3000

Table 4.10. Order of Entering of Variables Using Stepwise Program for Transformed Data

No. of Variables	Variable Entered	Variable Removed	R Squared	Increase in R Squared	F-To-Enter	F-To-Remove
1	$UFORSUP^3$		.2438	.2438	10.640	
2	$LSHADD^3$		.3302	.0864	4.126	
3	UELBFLEX		.4156	.0855	4.533	
4	$UELBFLEX^3$		.5690	.1534	10.676	
5	$UWRISTST^3$		.6036	.0345	2.526	
6	STICK L		.6463	.0427	3.383	
7	TRUNKROT		.6807	.0344	2.907	
8	GLHIPEXT		.7353	.0546	5.364	
9*	LSHROT		.7588	.0235	2.433	
10	$TRUNKFLE^3$		.7739	.0152	1.612	
11	USHABD		.7838	.0098	1.047	
12	AGE		.7960	.0122	1.313	
13	L F/E EL		.8140	.0181	2.040	
14	WT		.8283	.0143	1.667	
15	HT		.8692	.0408	5.930	
16	LSHADD		.8899	.0208	3.393	
17	UWRISTG		.9042	.0143	2.533	
18	$LARMDIAG^3$		.9207	.0165	3.332	
17		$TRUNKFLE^3$	.9174	-.0033		.6708
18	LWRISTG		.9309	.0135	3.117	
19	$GLHIPEXT^3$		.9420	.0111	2.876	
20	USHROT		.9490	.0071	1.937	
21	UARM G		.9530	.0039	1.171	
22	LWRISTFX		.9570	.0040	1.212	

* Cutoff of variables entering in selection of best equation

Table 4.11. Order of Entering of Variables Using All Possible Subsets Program for Transformed Data

No. of Variables	Variable Entered	Variable Replaced	R Squared	Adjusted R Squared
1	UFORSUP^3		.2438	.2209
2	LSHADD^3		.3302	.2883
3	UELBFLEX		.4156	.3591
4	UELBFLEX^3		.5690	.5115
5	UWRISTST^3		.6035	.5352
6	STICK L		.6463	.5705
7	TRUNKROT		.6807	.5979
8	GLHIPEXT		.7353	.6538
9	LSHROT		.7587	.6719
10	TRUNKFLE^3		.7739	.6797
11	USHABD		.7838	.6804
12	AGE		.7959	.6846
13	L F/E EL		.8140	.6989
14	WT		.8283	.7081
15	HT		.8691	.7658
16	LSHADD		.8899	.7920
17	UWRISTG GLHIPEXT^3	GLHIPEXT	.9167	.8334
18	LARMDIAG^3		.9370	.8661
19	USHROT		.9434	.8717
20	GLHIPEXT		.9490	.8762
21	UARM G		.9529	.8769
22*	LWRISTFX		.9570	.8781

* Selected as best equation by adjusted R Squared criteria of program

variables versus the standard error of estimate, adjusted R squared, and multiple R respectively. The cutoff point was nine variables. Moreover the first nine variables to enter the Subsets procedure were exactly the same as the first nine for the Stepwise.

The best regression equation for the transformed variables is:

$$
\begin{aligned}
Y(\text{puck velocity}) = {} & X_1(\text{stick length})(.3405) \\
& + X_2(\text{shoulder rotation lower arm})(.0626) \\
& + X_3(\text{trunk rotation})(-.0972) \\
& + X_4(\text{hip extension glide leg})(-.2334) \\
& + X_5(\text{elbow flexion upper arm})(-1.9188) \\
& + X_6(\text{arm adduction lower arm})^3(.0001) \\
& + X_7(\text{forearm supination upper arm})^3(.0116) \\
& + X_8(\text{wrist extension upper arm})^3(.0001) \\
& + X_9(\text{elbow flexion upper arm})^3(.0003) \\
& + 103.1292.
\end{aligned}
$$

This equation has a multiple R of .871 and a standard error of estimate of 3.74.

Discussion: Nonlinear Versus Linear Equations

On examining the transformed regression equation one sees that four transformed variables (cubed strength) entered the equation. One concludes that the cubic function fitted these variables better than the linear function since the cubed strength variables tended to have higher correlations with puck velocity than the linear variables. In other words, mathematically the cubic curve function fitted the relationship better than the linear function. In terms of improving one's shot this phenomenon remains unexplained.

Two linear strength variables entered this equation. Neither of these entered the untransformed regression equation. One observes

Figure 4. Standard Error of Estimate Versus Number of Variables for Transformed Data

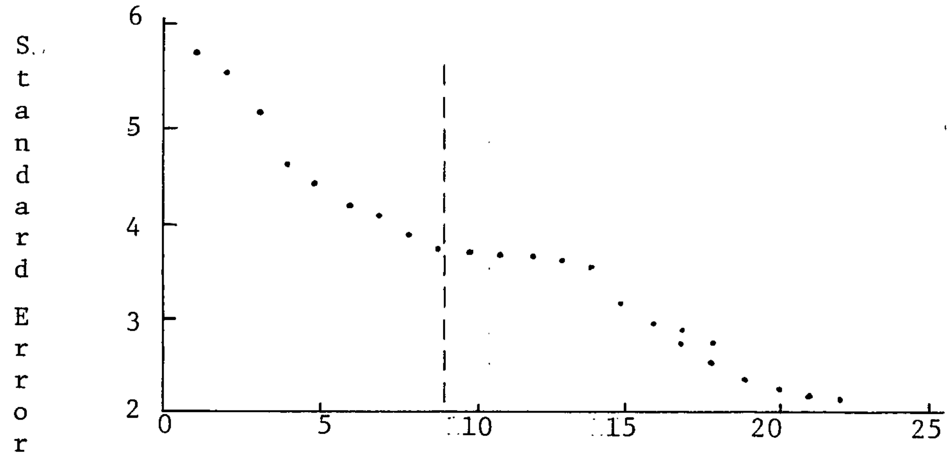


Figure 5. Adjusted R Squared Versus Number of Variables for Transformed Data

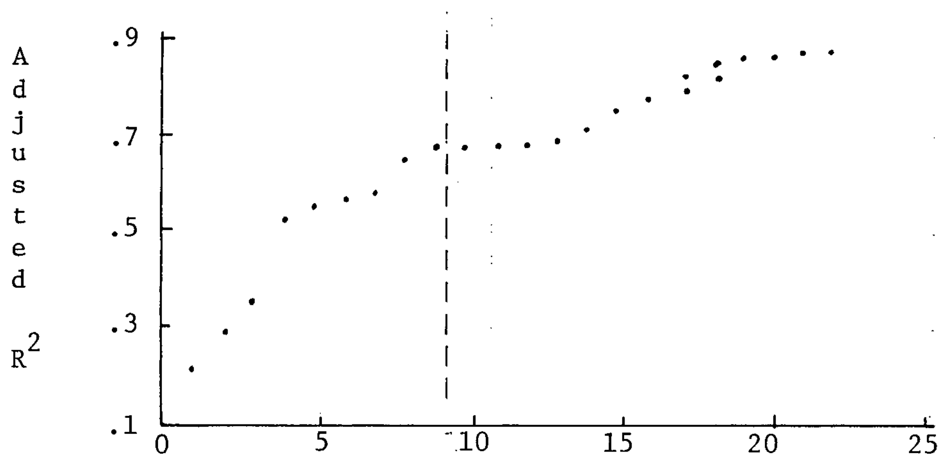
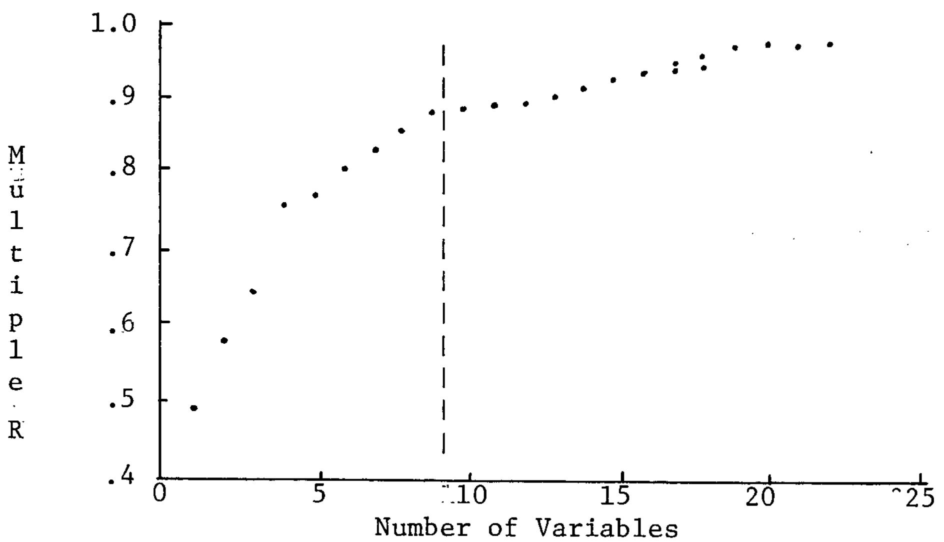


Figure 6. Multiple R Versus Number of Variables for Transformed Data



further that two flexibility variables entered this equation. Stick length was the remaining variable to enter this equation. Trunk rotation was the only untransformed variable to enter both equations.

Using the regression equation without the transformations, each subject's puck velocity was predicted, and the residuals between the observed and predicted were calculated. Table 4.12 shows the observed, predicted and 95% confidence intervals. From this table one can see that all the subject's predicted scores fell within the 95% confidence limits for each observation.

The same procedure was carried out on the equation derived from the transformed data. Table 4.13 shows the results for this equation. Again, all the residuals were within the 95% confidence intervals for each observation.

Since the confidence intervals are fairly small one can conclude that both regression equations are fairly good predictors of puck velocity. A comparison of the two equations seems to show that the inclusion of the cubic strength function improves the equation. It has a higher multiple R value by .06 and employs one less variable in the equation. The standard error of estimate is also lower. Inspection of the confidence intervals for the two equations, indicates that the confidence intervals are smaller for the transformed equation.

By sorting the data into ascending order of puck velocity and plotting the residuals of the subjects in that order, one can check the bias of the equations. Figure 7 shows that the regression equation tends to estimate too high for the lower scores and too low for the higher scores. This is a kind of an averaging effect, tending to draw

Table 4.12. Observed and Predicted Scores with 95% Confidence Intervals

Subject	Observed	Residual	Predicted	95% Confidence Intervals Mean Plus-Minus	Observation Plus-Minus
7	75.7	-2.519	78.219	5.621	10.89
19	76.7	-5.485	82.185	4.705	10.45
5	78.0	-6.012	84.012	5.370	10.76
15	78.0	-0.772	78.772	4.891	10.53
12	79.3	-6.023	85.323	3.900	10.11
25	80.0	-1.206	81.206	4.906	10.54
18	80.0	0.630	79.370	5.332	10.75
35	81.0	-9.644	90.644	4.862	10.52
31	81.3	-2.258	83.558	4.374	10.30
10	83.0	-0.103	83.103	5.360	10.76
34	83.0	-2.259	85.259	6.407	11.32
23	83.3	-1.325	84.625	4.107	10.19
22	83.7	3.353	80.347	4.860	10.52
14	84.3	1.864	82.436	3.708	10.04
11	84.7	-1.030	85.730	5.158	10.66
8	85.0	5.362	79.638	4.607	10.40
32	85.3	-0.599	85.899	4.111	10.19
27	86.0	-3.130	89.130	4.961	10.57
2	86.3	5.797	80.503	5.807	10.99
3	86.3	-5.086	91.386	4.518	10.37
16	87.7	5.111	82.589	5.043	10.60
4	88.3	1.817	86.483	3.475	9.55
33	88.7	-1.386	90.086	6.356	11.29
6	89.0	-2.461	91.461	6.163	11.18
21	89.7	2.229	87.471	5.909	11.04
20	90.0	2.989	87.011	4.190	10.23
17	90.3	4.517	85.783	7.442	11.93
26	92.0	-1.912	93.912	4.985	10.58
30	92.3	2.823	89.477	5.727	10.95
1	93.7	4.006	89.694	5.394	10.78
9	93.7	-1.812	95.512	5.178	10.67
13	94.7	2.985	91.715	6.200	11.20
29	96.3	2.947	93.353	5.465	10.81
24	97.3	3.133	94.167	5.537	10.85
28	105.0	4.562	99,538	6.050	11.12

Table 4.13. Observed and Predicted Scores with 95% Confidence Intervals for Transformed Data

Subject	Observed	Residual	Predicted	95% Confidence Intervals	
				Mean Plus-Minus	Observation Plus-Minus
7	75.7	-4.240	79.940	3.175	8.327
19	76.7	-4.768	81.468	3.793	8.582
5	78.0	3.964	74.054	4.433	8.883
15	78.0	0.158	77.842	4.438	8.886
12	79.3	-3.789	83.089	3.801	8.585
25	80.0	-2.754	82.754	2.763	8.179
18	80.0	-3.644	83.644	2.014	7.957
35	81.0	-5.842	86.842	2.910	8.230
31	81.3	-0.594	81.894	4.030	8.689
10	83.0	-1.476	84.476	2.561	8.113
34	83.0	-3.227	86.227	5.400	9.403
23	83.3	0.258	83.042	3.026	8.271
22	83.7	-3.470	87.170	4.151	8.746
14	84.3	3.525	80.775	4.513	8.923
11	84.7	1.841	82.859	3.230	8.348
8	85.0	0.548	84.452	2.384	8.059
32	85.3	-1.852	87.152	3.744	8.560
27	86.0	-0.690	86.690	5.538	9.483
2	86.3	-0.653	86.953	4.115	8.729
3	86.3	-1.568	87.868	4.186	8.763
16	87.7	-0.297	87.997	2.863	8.213
4	88.3	-0.448	88.748	4.041	8.694
33	88.7	2.065	86.635	3.545	8.475
6	89.0	-0.579	89.579	4.191	8.765
21	89.7	5.401	84.299	4.553	8.944
20	90.0	0.866	89.134	3.963	8.658
17	90.3	6.407	83.893	4.585	8.960
26	92.0	2.669	89.331	3.121	8.306
30	92.3	-0.316	92.616	4.800	9.072
1	93.7	5.152	88.548	4.336	8.835
9	93.7	-3.777	97.477	5.083	9.225
13	94.7	5.893	88.807	4.748	9.044
29	96.3	3.940	92.360	4.338	8.836
24	97.3	1.237	96.063	5.243	9.314
28	105.0	0.078	104.920	6.468	10.050

the scores towards the mean. The corresponding Figure 8, for the equation using strength transformations, displays the same bias although the residuals are on the average smaller. Thus one can conclude that both equations are slightly biased and tend to have an averaging effect on the scores.

Both the transformed data and untransformed data equations are useful but for different reasons. From the practical standpoint the untransformed data equation is more useful to the coach or player who is trying to find the causes of a fast shot. From a scientific approach, one may want to predict puck velocity more accurately and with fewer variables- thus the transformed data equation would be more useful.

Finally, one must conclude that the two regression equations calculated are fairly good predictors of puck velocity. One could obtain better prediction equations by letting more variables enter these equations. The aim of this investigation, however, is to present prediction equations which are not too cumbersome and awkward to use, and yet are still adequate predictors. Some accuracy of prediction is lost but usefullness is enhanced. Also, for further investigation of the causes of a faster shot, the reduced equations present the variables most likely to be important. The best possible prediction equation, selected by a maximum adjusted R squared criterion for the All Possible Subsets run resulted when twenty-two variables had entered the equation using the transformed data. This was too large for practical use and thus was discarded for the smaller equations.

Figure 7. Residuals Plotted in Order of Shot Velocity from Lowest to Highest

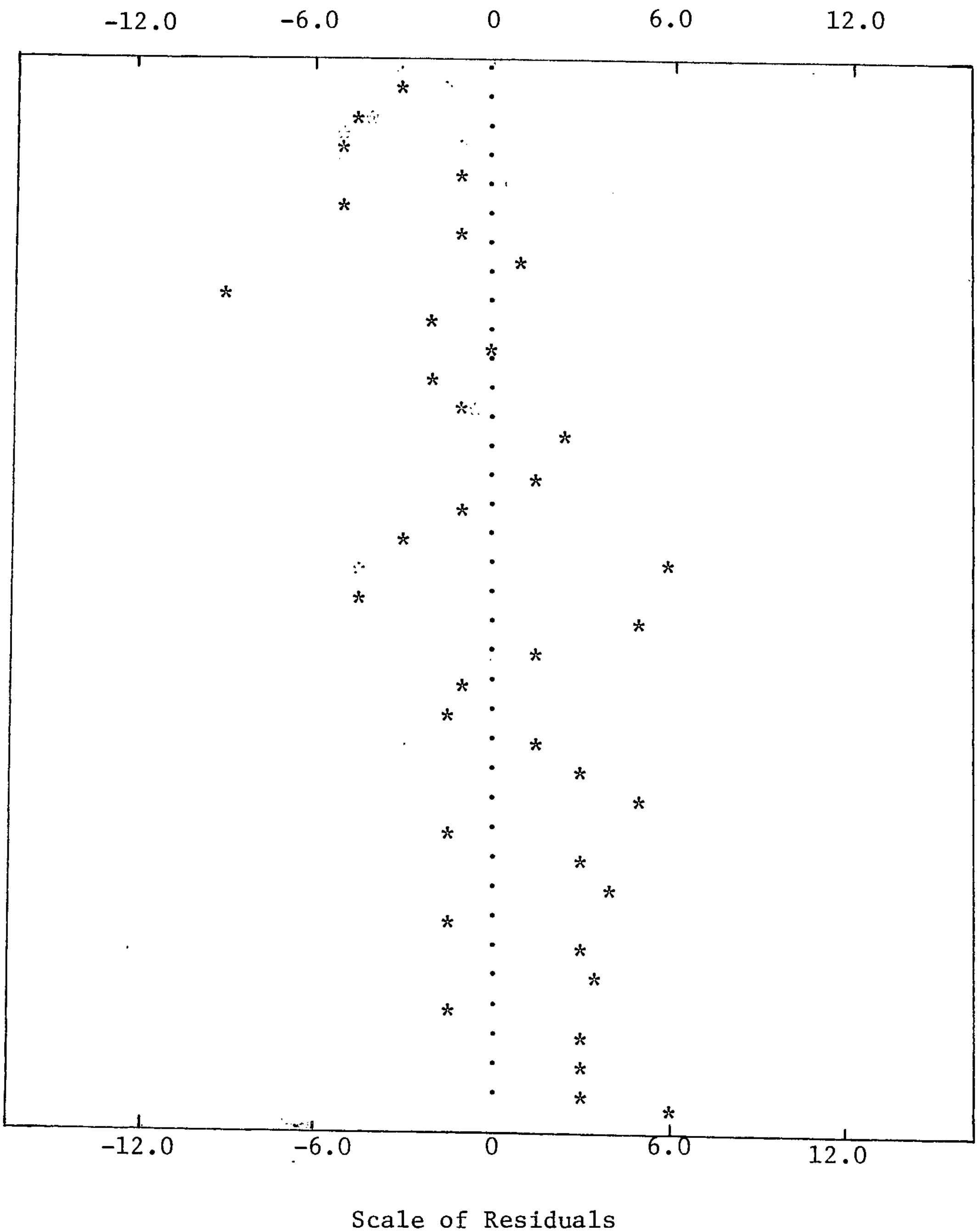
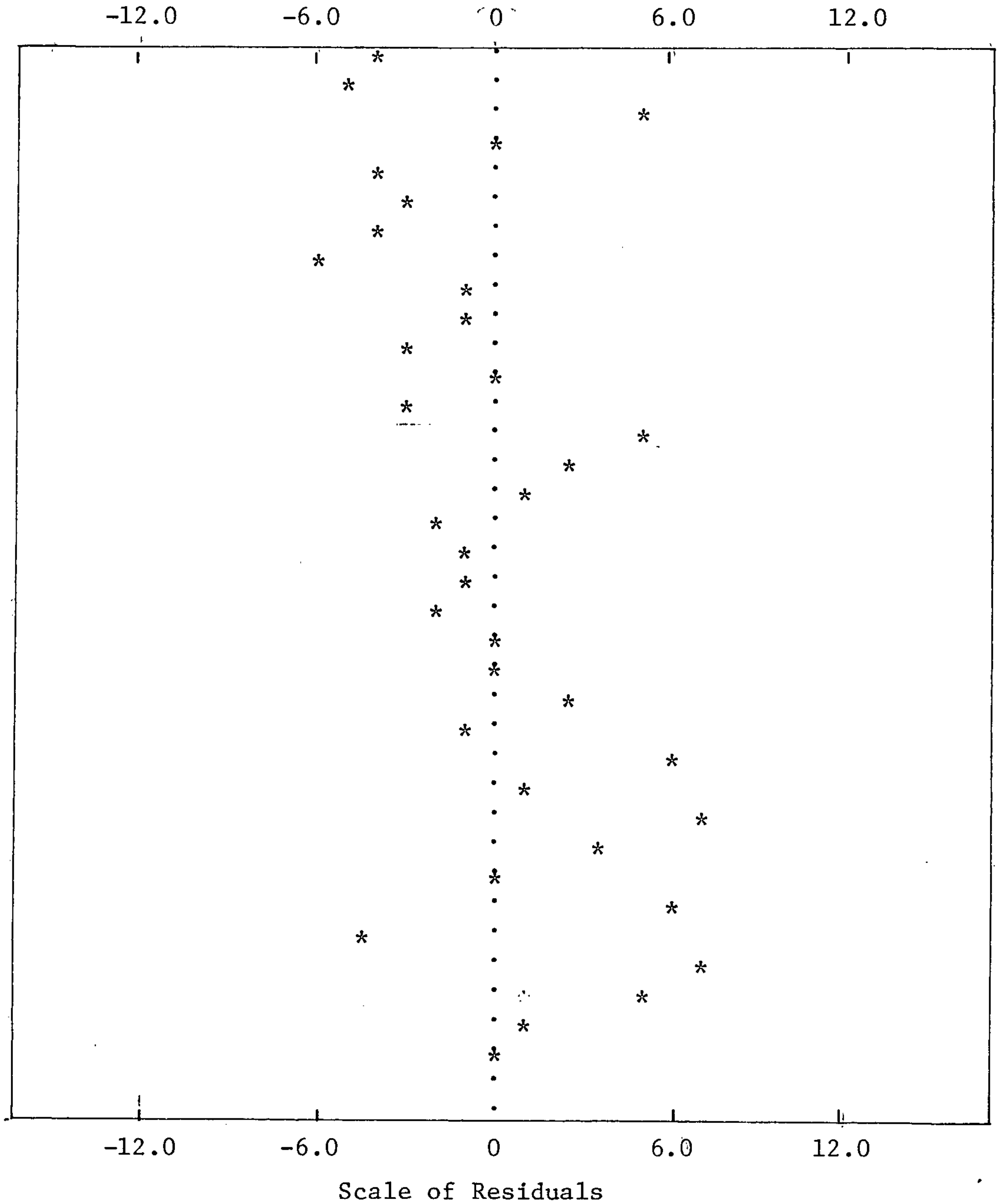


Figure 8 . Residuals Plotted in Order of Shot Velocity from Lowest to Highest for Transformed Data



Chapter 5

SUMMARY AND CONCLUSIONS

Summary

The main purpose of this study was to investigate the relationships between the velocity of the ice hockey wrist shot and selected human factors in order that one can predict the velocity of the wrist shot. A second objective was to identify the modifiable human factors most highly related (linearly) with puck velocity in order to guide further research investigating the causal factors of a high velocity shot.

Thirty-five volunteer hockey players of varying ability were measured on forty-eight variables. With these measures, multiple regression techniques were used to analyze and develop a best regression equation. It was found that as a group, the strength variables: arm adduction at the shoulder of the lower arm, trunk flexion, arm abduction at the shoulder of the upper arm, diagonal motion of the upper arm, and forearm rotation, had the most impact on the equation. Three flexibility variables, one anthropometric variable and one muscle ratio variable were the other variables to enter the equation. The equation accounted for 66.1% of the variance.

The single most important variable in terms of predicting puck velocity turned out to be arm adduction at the shoulder of the lower arm; it accounted for 20% of the variablity. It was found that by cubing the strength variables one could increase the multiple R by

.06, using one less variable. Thus with the transformed data, puck velocity can be predicted more accurately with fewer variables.

Both equations have fairly small ninety-five percent confidence intervals. The equation for the transformed data produced confidence intervals which were slightly smaller than those for the untransformed data. Both equations tended to be slightly biased, having an averaging effect on the scores: the high scores tended to be underestimated and the low scores tended to be overestimated.

The best regression equation using the untransformed data was

$$Y(\text{puck velocity}) = X_1(\text{UARM G})(.7544) + X_2(\text{UWRISTFX})(.1374) + X_3(\text{UFORROT})(-.1779) + X_4(\text{TRUNKROT})(-.0574) + X_5(\text{TRUNKFLE})(.1645) + X_6(\text{USHABD})(-1.1586) + X_7(\text{LSHADD})(.8949) + X_8(\text{UARMDIAG})(-.2990) + X_9(\text{UFORSUP})(1.7023) + X_{10}(\text{L F/E EL})(-7.5737) + 73.0946.$$

This equation has a multiple R value of .813 and a standard error of estimate of 4.52.

The best equation using transformed data was

$$Y(\text{puck velocity}) = X_1(\text{STICK L})(.3405) + X_2(\text{LSHROT})(.0626) + X_3(\text{TRUNKROT})(-.0972) + X_4(\text{UELBFLEX})(-1.9188) + X_5(\text{GLHIPEXT})(-.2334) + X_6(\text{LSHADD})^3(.0001) + X_7(\text{UFORSUP})^3(.0116) + X_8(\text{UWRISTST})^3(.0001) + X_9(\text{UELBFLEX})^3(.0003) + 103.1292.$$

This equation has a multiple R of .871 and a standard error of estimate of 3.74.

By using either of these equations the puck velocity in the wrist shot can be predicted fairly well for any subject having skills consistent with those used in this study.

At this point nothing can be said about the causes of a faster shot, but the groundwork has been laid for further investigation of potential causal variables.

Conclusions

1) Using either transformed or untransformed data equations it is possible to predict puck velocity fairly accurately.

2) The strength variables, as a group, play the most important role in predicting puck velocity.

3) Arm adduction at the shoulder of the lower arm is the best single variable for predicting puck velocity.

4) The flexibility of a shooter may play a more important role in terms of puck velocity than considered by most authorities.

5) The variables entering into the untransformed data equation may be suspected of playing a vital role in the causes of a hard shot.

6) Using the transformed data, the ability to predict puck velocity is improved and fewer variables are required.

Recommendations for Further Study

1) Further research should be conducted to investigate the causes of a faster shot by implementing the variables in the untransformed data equation into a training program and monitoring the effects that this program has on shot velocity.

REFERENCES

Alexander, J.F., Haddow, J.B., & Schultz, G.A. Comparison of the Ice Hockey Wrist and Slap Shot for Speed and Accuracy. Research Quarterly, 1963,34,259-266.

Alexander, J.F., Drake, C.J., Reichenbach, P.J., & Haddow, J.B. Effect of Strength Development on Speed of Shooting of Varsity Ice Hockey Players. Research Quarterly, 1964,35,101-106.

BMDP Biomedical Computer Programs P-Series. Berkely:University California Press, 1977.

Brown, S. Personal Communication. 1980.

Chambers, D. Complete Hockey Instruction. Markam:LR, 1979.

Corbett, R. Radar Systems: An Introductory Brief on their Theory, Use and Practical Applications. Unpublished paper for graduate course, University of British Columbia, 1979.

Daish, C.B. Ball Games. London:English Universities Press, 1972.

Ennos, W. A Comparison of Somatotype Information on the University of B.C. Varsity Ice Hockey Teams. Unpublished paper for graduate course, University of British Columbia.

Esposito, P., & Esposito, T. We Can Teach You to Play Better Hockey. New York:Hawthorn, 1975.

Five Exercises to Help You Develop Shooting Power. Sports Talk, 1978,7.

Gardiner, E.B. Proprioceptive Reflexes and their Participation in Motor Skills. Quest, 1969,12,1-25.

Gilbert, R., & Park, B. Playing Hockey the Professional Way. Montreal: Holt-Rinehart-Winston, 1973.

Halliwell, W.R., Groppel, J.L., & Ward, T. A Kinematic Analysis of the Snap Shot in Ice Hockey as Executed by Professional Hockey Players. Unpublished paper, Movement Science Program, Florida State Univ. 1978.

Hayward, B. Shooting. Sports Talk, 1978,7,2-3.

Hindmarch, R.G. Personal Communication.

Hodge, K., & Awrey, D. Power Hockey. New York:Atheneum, 1967.

Howe, G. Here's Howe. Toronto:Copp Clark, 1963

Hull, R.M. Hockey is My Game. Don Mills:Longman's, 1967.

Jensen, C., & Schultz, G. Applied Kinesiology. New York:McGraw-Hill, 1970.

Jesse, J. Hidden Causes of Injury, Prevention, and Correction for Running Athletes and Joggers. Pasadena:Athletic Press, 1977.

Johnston, M. He Shoots, He Scores. Young Athlete, 1976,3,46-47

Jones, R.E. Shoot. Hockey, 1979,5,40-41.

King, D. Personal Communication. 1980.

Kingston, G. Personal Communication. 1980.

Leighton, J.R. The Leighton Flexometer and Flexibility Test. Journal of the Association for Physical and Mental Rehabilitation, 1966,20, 86-93.

MacDonald, D. The Art of Shooting. Hockey Today, 1978-79,13-15.

MacGillivary, W., & Watson, R. A Kinesiological Analysis of the Skating Wrist Shot in Ice Hockey. Unpublished paper for graduate course, University of Alberta, 1964.

Mahovalich, F. Ice Hockey: How to Play Hockey and Enjoy It. London: Pelham, 1965.

Montreal Olympic Games Anthropometrical Project: Anthropometric Instruments and Measurements. Unpublished paper, San Diego State University, 1976.

Moyls, P.W. The Effect of Dominant Hand Placement on Accuracy and Velocity of the Standing Snap Shot. Unpublished paper for graduate course, University of British Columbia, 1979.

Moyls, P.W., & Nobbs, L.A. A Comparison Study: Somatotypes of the University of B.C. Varsity Ice Hockey Teams (1964,1976,1979), Physical Education Graduate Students (1979) and Other Groups. Unpublished paper for graduate course, University of British Columbia, 1980.

Patrick, L., & Monahan, L. Lets Play Hockey. Toronto:MacMillan, 1957.

Reed, A.T., Cotton, C., Hansen, H., & Gauthier, R. Upper Body Strength and Handedness Shooting Characteristics of Junior and Professional Hockey Players. Paper presented at International Congress of Sports Sciences, Edmonton, Alberta, July, 1979.

Robb, M.D. The Dynamics of Skill Aquisition. Englewood Cliffs:Prentice-Hall, 1972.

Selder, D. Anthropometric, Cardiovascular and Motor Performance of University Ice Hockey Players. Unpublished paper, Masters thesis, University of British Columbia, 1964.

Tarasov, A., & Persson, V. Tarasov's Hockey Technique. Montreal:Holt-Rinehart-Winston, 1973.

Tremble, R. Off-Ice Hockey Drills. Athletic Journal, 1978,59,42.

Watt, T. Personal Communication. 1980.

Wiren, G. Human Factors Influencing the Golf Drive for Distance. Ph.D. Dissertation, University of Oregon, 1968.

Appendix A

VARIABLE TESTING PROCEDURES

Appendix A

VARIABLE TESTING PROCEDURES

Anthropometric Procedures

Height
Instrument- Stadiometer
Position- Standing Position, barefoot, heels together and arms hanging naturally by the sides. Subject looks straight ahead. Horizontal line of sight from orbitale to traglion. (Frankfurt plane)
Measurement- Subject instructed to take deep breath and stand as tall as possible. Stadiometer lowered to vertex of head. Reading taken, subject relaxes.

Body Weight
Instrument- Balance beam scale
Measurement- Standing position, barefoot, minimal clothing. Reading taken, subject relaxes.

Arm Length
Instrument- Stadiometer
Position- Standing position, heels together, arms at side, palms facing back.
Measurement- Stadiometer lowered to acromiale. Reading taken, subject relaxes. Subject leans away but holds foot position as stadiometer lowered. Standing position resumed, stadiometer raised to index finger height, reading taken subject relaxes.

Instrument- tape (for all girths)

Arm Girth
Measurement- Arm extended and relaxed hanging loosely at the side, tape placed midway between the acromion process and the elbow joint. Maximum girth is recorded.

Forearm Girth
Measurement- Elbow extended, forearm supinated and fingers extended. Maximum girth of the forearm is recorded.

Wrist Girth
Measurement- Elbow flexed to 90 degrees, forearm supinated and fingers extended. Minimum girth distal to styloid process is recorded.

Stick Length

Measurement- Measured from heel of blade to top of stick.

Flexibility Procedures

Instrument- Leighton flexometer

Wrist Flexion and Extension

Starting position- Sitting position in standard armchair, back straight, forearm resting on chair arm, fist doubled and extended beyond end of chair arm, palm of hand to be measured turned up. Instrument fastened to thumb-side of fist. (common chair and table of suitable height may be substituted for armchair)
Movement- Count (1) fist moved upward and backward in an arc as far as possible, dial locked (2), fist moved forward, downward and backward in an arc as far as possible, pointer locked (3), subject relaxes, reading taken.
Caution- Forearm may not be raised from chair during movement.

Radial-Ulnar Supination and Pronation

Starting position- Sitting position in standard armchair, back straight, forearms resting on chair arms, fist doubled and extended beyond end of chair arm, wrist of arm to be measured held straight. Strap is grasped in hand, fastening instrument to front of fist. (common chair and table of suitable height may be substituted for armchair)
Movement- Count (1) thumbside of the fist turned outward and downward as far as possible, dial locked, (2) thumb-side of fist turned upward, downward and inward as far as possible, pointer locked, (3) subject relaxes, reading taken.
Caution- Body and forearm must remain stationary, except for specified movement. No leaning of the body may be permitted.

Shoulder Rotation

Starting position- Standing position at projecting corner of wall, arm to be measured extended sideward and bent to right angle at elbow, shoulder extended just beyond projecting corner, opposite arm at side of body, back to wall, shoulder blades, buttocks and heels touching wall. Instrument fastened to side of forearm.
Movement- Count (1) forearm moved downward and backward in an arc as far as possible, dial locked, (2) forearm moved forward, upward and backward in an arc as far as possible, pointer locked (3) subject relaxes, reading taken.
Caution- Upper arm being measured must be held directly sideward and parallel with the floor during movement. Heels, buttocks, and shoulders must touch wall at all times.

Trunk Rotation

Starting position- Supine position on bench, legs together, knees raised above hips, lower legs parallel to bench and body. Assistant holds subjects shoulders. Instrument fastened to middle rear of upper legs, strap going around both legs.
Movement- Count (1) knees lowered to the left as far as possible, dial locked, (2) knees brought back to starting position and lowered to the right as far as possible, pointer locked, (3) subject relaxes,

reading taken.
Caution- Subjects shoulders must not be permitted to rise from bench during movement. Knees must be moved directly sidewards at the height of the hips, not above or below.

Strength Procedures

Instrument- Cybex II

Trunk Flexion
Attachments- Small half T with pad
Setting- 30 degrees per second
Scale- 180 foot pounds
Starting position- Supine position parallel to arm of cybex. Arms at side, legs secured at ankles and superior to knees. Joint of cybex arm lines up with hip joint. Pad placed on chest at lowest point on sternum.
Movement- Subject flexes at waist and drives chest upward and forward as far as possible.
Caution- Legs must not lift off table.

Trunk Extension
Attachments- Small half T with pad
Setting- 0 degrees per second
Scale- 180 or 360 foot pounds
Starting position- Lying supine on stomach parallel to arm of cybex, arms at side, head facing forward. Pad placed on 5th, 6th and 7th cervical vertibrae. Joint of cybex lines up with hip joint.
Movement- Subject tries to flex backward and upward as hard as possible.

Hip Flexion
Attachments- Large half T with pad.
Setting- 30 degrees per second
Scale- 180 or 360 foot pounds
Starting positon- Supine position with pad secured 5 inches above the maleolus, parallel to arm of cybex, arms at side. Joint of cybex lines up with hip joint.
Movement- Subject flexes leg up towards ceiling.
Caution- Leg must remain straight.

Hip Extension
Attachments- Large half T with pad
Setting- 30 degrees per second
Scale- 180 or 360 foot pounds
Starting position- Lying position on stomach, parallel to arm of cybex, legs hanging over table at hips, free leg touching floor. Joint of cybex lines up with hip joint. Pad strapped to calf 5 inches above maleolus.
Movement- Subject extends leg towards ceiling.
Caution- Leg must remain straight.

Shoulder Abduction and Adduction

Attachments- Large or small half T, U attachment at joint.
Setting- 30 degrees per second
Scale- 180 foot pounds
Starting position- Lying on side facing cybex. Joint of cybex lines up with shoulder joint. Subject grasps handle at side with palms facing body with upper arm for arm abduction. Lower arm grasps handle above the head with palm facing up for arm adduction.
Movement- For arm abduction, upper arm moves from side to above head. For arm adduction, lower arm moves from above the head down to the side.
Caution- Arm must not bend during the movement.

Shoulder Diagonal Motion

Attachments- Large half T, U attachment at joint.
Setting- 30 degrees per second, cybex tilted 30 degrees.
Scale- 180 foot pounds
Starting position- Table angled 60 degrees to cybex. Supine position, joint of cybex directly above shoulder joint. Upper arm grasps handle at side. Lower arm grasps handle above head.
Movement- Upper arm moves from side across body up above head. Lower arm moves from above head down across body to side. Same grips as used in shoulder adduction and abduction.
Caution- Arm must remain straight throughout motion.

Forearm Supination and Pronation

Attachments- Large U at joint
Setting- 30 degrees per second
Scale- 30 foot pounds
Starting position- Sitting position facing the arm of cybex, arm held to bench by other arm.
Movement- Lower arm rotated from palms up position to palms down position. Upper arm rotated from palms down position to palms up position.
Caution- Arm must stay in contact with bench.

Wrist Flexion and Extension

Attachments- Small half T with hand grip, U attachment at joint.
Setting- 30 degrees per second
Scale- 30 foot pounds
Starting position- Sitting position parallel to arm of cybex, arm on bench held down by other arm.
Movement- Lower arm grips palms up and flexes towards ceiling. Upper arm grips palms down and extends to ceiling.
Caution- Arm must stay in contact with bench.

Elbow Flexion and Extension

Attachments- Small half T with hand grip
Setting- 30 degrees per second
Scale- 180 foot pounds
Starting position- Supine position parallel to arm of cybex, arms at sides, joint of cybex lines up with elbow joint.
Movement- Flexion movement starts at side and flexes upward to

shoulder. Extension movement starts in full flexion at shoulder and extends down towards bench.
Caution- Forearm and wrist must be straight throughout motion.

Appendix B

FLEXIBILITY WARMUP

Appendix B

FLEXIBILITY WARMUP

The warmup consisted of four simple exercises designed to simulate the motions required in the flexibility tests.

Wrist Flexion and Extension
Starting position- Standing position, arms at sides, elbows flexed to 90 degrees in front of the body, hands clenched.
Movement- Wrists extended up towards ceiling and then down towards floor. Repeated ten times.

Wrist Supination and Pronation
Starting position- Same as wrist flexion and extension.
Movement- Palms rotated from palms down to palms up and back. Repeated ten times.

Shoulder Rotation
Starting position- Standing position, arms out to side, elbows bent to 90 degrees, hands pointed to ceiling.
Movement- Keeping upper arms parallel to floor, shoulder rotates so hands are now pointing to floor. Repeated ten times.

Trunk Rotation
Starting position- Standing position, hands on hips.
Movement- Subject rotates at waist to left and then to right. Repeated ten times.

Appendix C

PRODUCT-MOMENT CORRELATION MATRIX

Product-Moment Correlation Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	1.000																						
2	0.192	1.000																					
3	0.113	0.435	1.000																				
4	0.097	0.493	0.217	1.000																			
5	0.134	0.788	0.306	0.568	1.000																		
6	0.119	0.787	0.270	0.475	0.961	1.000																	
7	0.042	0.273	0.036	-0.520	0.386	0.486	1.000																
8	-0.276	0.060	0.424	-0.049	0.127	0.107	0.142	1.000															
9	-0.131	0.219	0.473	0.048	0.281	0.284	0.215	0.921	1.000														
10	0.104	-0.021	0.620	-0.086	-0.122	-0.109	-0.037	0.451	0.516	1.000													
11	0.115	-0.034	0.575	-0.184	-0.151	-0.120	0.048	0.437	0.512	0.925	1.000												
12	0.159	-0.103	0.564	-0.132	-0.162	-0.195	-0.061	0.400	0.381	0.799	0.741	1.000											
13	0.170	-0.120	0.528	-0.135	-0.213	-0.222	-0.110	0.408	0.391	0.830	0.793	0.958	1.000										
14	0.029	0.019	0.209	0.032	-0.043	0.039	-0.038	0.251	0.305	0.260	0.275	0.321	0.313	1.000									
15	0.123	0.134	-0.099	0.093	0.086	0.126	0.080	0.177	0.269	-0.055	0.002	-0.258	-0.258	0.019	1.000								
16	0.211	0.180	-0.347	0.139	0.231	0.273	0.146	-0.171	-0.021	-0.179	-0.232	-0.341	-0.286	-0.198	0.463	1.000							
17	0.075	0.355	0.027	0.123	0.323	0.362	0.236	0.200	0.299	0.085	-0.062	-0.124	-0.120	0.145	0.269	0.380	1.000						
18	0.075	0.324	-0.051	0.175	0.331	0.330	0.155	0.209	0.308	-0.046	-0.130	-0.231	-0.233	0.060	0.233	0.382	0.820	1.000					
19	0.154	0.276	-0.019	0.070	0.345	0.341	0.274	0.105	0.213	-0.021	0.055	-0.205	-0.188	-0.221	0.414	0.435	0.408	0.587	1.000				
20	-0.042	0.218	0.109	0.313	0.266	0.246	-0.066	0.036	0.143	-0.062	-0.065	-0.258	-0.275	-0.259	0.415	0.369	0.272	0.318	0.599	1.000			
21	0.065	0.266	-0.137	-0.034	0.167	0.191	0.245	0.060	0.172	-0.069	-0.023	-0.204	-0.251	-0.042	0.084	0.256	0.249	0.335	0.292	0.193	1.000		
22	-0.227	-0.030	0.118	-0.176	-0.090	-0.098	0.105	0.269	0.346	0.232	0.324	0.155	0.111	0.192	0.002	-0.100	0.128	0.157	0.277	0.253	0.400	1.000	
23	0.077	0.023	0.197	0.201	0.116	0.112	-0.114	0.097	0.152	0.240	0.167	0.114	0.133	0.143	0.070	0.082	0.335	0.371	0.054	0.277	-0.156	0.030	1.000
24	0.073	-0.055	0.330	0.045	-0.117	-0.108	-0.173	0.291	0.303	0.393	0.378	0.219	0.295	0.153	0.074	0.029	0.099	0.159	0.116	0.192	-0.011	0.385	0.554
25	-0.142	0.014	0.445	0.041	0.054	0.062	-0.026	0.339	0.323	0.472	0.433	0.371	0.367	0.287	-0.150	-0.312	0.201	0.249	0.149	0.126	-0.124	0.402	0.601
26	-0.098	-0.182	0.268	0.010	-0.184	-0.178	-0.197	0.277	0.260	0.363	0.346	0.193	0.234	0.195	-0.001	-0.144	0.090	0.167	0.053	0.159	0.006	0.465	0.548
27	-0.096	0.059	0.509	0.075	0.103	0.109	-0.011	0.351	0.331	0.484	0.393	0.469	0.441	0.311	-0.075	-0.311	0.173	0.107	0.003	0.067	-0.211	0.219	0.512
28	-0.218	-0.149	0.445	-0.272	-0.190	-0.154	0.081	0.478	0.468	0.569	0.611	0.469	0.468	0.304	-0.170	-0.368	-0.069	-0.024	0.010	-0.110	0.064	0.538	0.271
29	-0.041	-0.009	0.261	-0.144	-0.044	0.046	0.108	0.324	0.389	0.327	0.424	0.248	0.270	0.451	-0.159	-0.311	0.037	0.154	0.158	-0.118	0.319	0.461	0.173
30	0.119	0.058	0.595	-0.062	0.095	0.084	0.109	0.327	0.331	0.509	0.542	0.508	0.498	0.200	-0.336	-0.458	-0.173	-0.146	-0.062	-0.083	0.051	0.322	0.148
31	-0.099	-0.003	0.378	-0.019	0.057	0.069	0.059	0.458	0.456	0.457	0.555	0.424	0.457	0.378	-0.133	-0.433	-0.078	-0.015	0.085	-0.170	0.097	0.480	0.204
32	0.009	0.071	0.524	-0.058	0.168	0.174	0.206	0.428	0.424	0.558	0.482	0.485	0.460	0.431	-0.165	-0.300	0.302	0.140	0.006	-0.129	-0.003	0.213	0.264
33	0.109	-0.153	0.363	-0.165	-0.070	-0.039	0.114	0.242	0.292	0.344	0.428	0.375	0.364	0.121	-0.013	-0.281	-0.142	-0.030	0.041	-0.096	-0.113	0.266	0.114
34	0.074	-0.094	0.236	-0.311	-0.186	-0.109	0.154	0.559	0.542	0.338	0.417	0.355	0.407	0.418	0.077	-0.211	-0.043	-0.020	0.002	-0.029	0.170	0.491	0.130
35	0.022	0.151	0.442	0.073	0.050	0.105	-0.012	0.353	0.447	0.487	0.581	0.278	0.351	0.344	0.020	-0.316	-0.035	0.103	0.154	-0.018	0.120	0.372	0.255
36	-0.123	-0.027	0.524	-0.070	-0.022	-0.017	0.055	0.408	0.430	0.611	0.668	0.492	0.495	0.181	-0.033	-0.383	-0.045	0.034	0.150	-0.057	-0.008	0.450	0.304
37	-0.204	0.037	0.232	0.078	0.118	0.167	0.025	0.344	0.422	0.475	0.396	0.263	0.292	0.106	0.038	0.021	0.160	0.214	0.313	0.273	0.173	0.441	0.316
38	-0.046	0.073	0.416	-0.008	0.033	0.061	0.065	0.360	0.385	0.524	0.601	0.432	0.459	0.197	-0.055	-0.389	-0.004	-0.021	0.048	-0.142	0.105	0.498	0.195
39	0.057	0.087	0.365	-0.078	0.100	0.153	0.198	0.387	0.415	0.529	0.537	0.437	0.486	0.236	-0.047	-0.159	0.093	0.110	0.224	0.046	0.016	0.425	0.304
40	0.284	-0.056	-0.184	0.082	-0.170	-0.150	-0.212	-0.084	-0.029	-0.110	-0.052	-0.267	-0.139	-0.138	0.303	0.404	-0.136	-0.112	-0.040	0.068	0.173	-0.057	-0.019
41	0.064	-0.246	-0.272	0.010	-0.271	-0.257	-0.234	-0.108	-0.079	-0.125	-0.021	-0.371	-0.254	-0.139	0.145	0.266	-0.104	0.019	0.058	0.136	0.257	0.226	0.082
42	-0.182	0.024	-0.094	-0.286	-0.102	-0.106	0.208	0.095	0.102	-0.065	0.043	-0.014	-0.061	0.005	-0.103	-0.133	-0.136	-0.134	0.142	-0.070	0.412	0.629	-0.731
43	-0.516	-0.492	-0.204	-0.151	-0.315	-0.325	-0.139	-0.055	-0.147	-0.063	-0.075	-0.051	-0.148	0.092	-0.225	-0.322	-0.054	0.007	-0.227	-0.078	0.050	0.265	0.042
44	0.091	0.067	0.069	0.054	0.068	0.068	0.019	-0.026	-0.034	-0.024	-0.133	0.195	0.134	0.093	0.156	0.021	-0.096	-0.318	-0.351	-0.210	-0.167	-0.457	-0.230
45	0.073	-0.082	0.333	-0.191	-0.169	-0.222	0.040	0.114	0.023	0.080	0.216	0.203	0.173	0.052	-0.046	-0.445	-0.254	-0.224	-0.213	-0.368	-0.276	-0.097	-0.103
46	-0.204	-0.063	-0.002	0.060	-0.146	-0.194	-0.217	-0.037	-0.067	-0.093	-0.037	-0.083	-0.102	-0.099	0.016	-0.200	-0.097	-0.165	-0.259	-0.208	0.084	0.041	-0.146
47	-0.052	-0.150	0.199	-0.050	-0.080	-0.108	-0.052	0.065	0.074	0.169	0.124	0.151	0.116	0.030	0.012	0.034	-0.057	0.092	0.156	0.113	-0.163	-0.095	0.177
48	-0.152	-0.004	-0.012	0.207	0.119	0.085	-0.104	0.048	0.071	0.216	0.052	0.069	0.065	-0.287	0.188	0.271	0.150	0.097	0.177	0.381	-0.107	0.073	0.239

24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
1.000																								
0.691	1.000																							
0.947	0.782	1.000																						
0.633	0.897	0.696	1.000																					
0.654	0.693	0.721	0.608	1.000																				
0.439	0.573	0.488	0.425	0.747	1.000																			
0.423	0.551	0.408	0.539	0.569	0.563	1.000																		
0.513	0.628	0.538	0.566	0.684	0.761	0.716	1.000																	
0.333	0.657	0.409	0.717	0.560	0.433	0.539	0.539	1.000																
0.411	0.499	0.485	0.553	0.512	0.356	0.444	0.430	0.453	1.000															
0.571	0.446	0.537	0.400	0.607	0.576	0.415	0.543	0.319	0.395	1.000														
0.594	0.631	0.618	0.532	0.701	0.747	0.504	0.754	0.479	0.488	0.570	1.000													
0.508	0.660	0.564	0.530	0.771	0.594	0.578	0.731	0.564	0.587	0.391	0.696	1.000												
0.536	0.641	0.568	0.595	0.581	0.455	0.375	0.514	0.466	0.391	0.437	0.531	0.602	1.000											
0.489	0.577	0.517	0.499	0.626	0.571	0.586	0.789	0.424	0.578	0.474	0.615	0.824	0.530	1.000										
0.682	0.713	0.655	0.643	0.625	0.539	0.648	0.712	0.445	0.424	0.619	0.640	0.635	0.669	0.671	1.000									
0.325	-0.427	0.153	-0.415	-0.089	-0.168	-0.232	-0.167	-0.432	-0.135	0.131	-0.014	-0.200	-0.134	-0.110	-0.101	1.000								
0.364	-0.202	0.327	-0.419	0.078	0.020	-0.207	-0.062	-0.391	-0.088	0.154	0.102	0.020	-0.025	0.040	-0.019	0.810	1.000							
-0.167	-0.198	-0.129	-0.256	0.121	0.158	0.118	0.146	-0.079	0.042	0.214	0.003	0.011	0.037	0.154	0.073	-0.022	0.068	1.000						
-0.061	0.300	0.258	0.215	0.235	0.150	-0.038	0.072	0.181	0.264	-0.051	0.068	0.175	0.129	0.096	-0.051	-0.438	-0.022	0.077	1.000					
-0.219	-0.275	-0.261	0.169	-0.227	-0.308	-0.081	-0.157	0.105	0.076	-0.159	-0.235	-0.319	-0.162	-0.232	-0.220	-0.015	-0.508	-0.140	-0.137	1.000				
-0.111	-0.061	-0.093	-0.122	0.116	0.055	0.160	0.120	0.046	0.191	-0.067	0.089	0.311	-0.553	0.189	-0.137	-0.080	-0.001	-0.031	0.025	-0.101	1.000			
-0.261	-0.252	-0.210	-0.248	-0.081	-0.052	-0.199	-0.016	-0.127	0.036	-0.216	-0.159	0.087	-0.247	0.250	-0.527	0.047	0.099	0.077	0.153	0.023	0.358	1.000		
0.059	0.151	0.099	0.082	0.257	0.082	0.036	-0.068	0.286	0.058	-0.114	0.173	0.313	0.145	-0.269	-0.017	-0.130	-0.041	-0.252	0.112	-0.102	0.186	-0.319	1.000	
0.198	0.196	0.209	0.274	-0.001	-0.387	-0.112	-0.122	0.115	0.135	-0.071	-0.097	0.141	0.626	0.094	0.224	0.005	-0.023	-0.139	0.069	0.096	-0.586	-0.180	0.072	1.000

1. AGE	11. LFORARMG	21. TRUNKROT	31. LARMDIAG	41. F/E DHIP
2. HT	12. UARM G	22. TRUNKEXT	32. UFORSUP	42. T F/E
3. WT	13. LARM G	23. TRUNKEXT	33. LFORPRO	43. D/G FLEX
4. STICK L	14. PUCKVEL	24. GLHIPFLE	34. UWRISTST	44. D/G EXT
5. UARM L	15. UWRISTFX	25. GLHIPEXT	35. LWRISTST	45. U F/E EL
6. LARM L	16. LWRISTFX	26. DRHIPFLE	36. UELBFLEX	46. L F/E EL
7. ARM/STI	17. USHROT	27. DRHIPEXT	37. UELBEXT	47. U/L F EL
8. UWRISTG	18. LSHROT	28. USHABD	38. LELBFLEX	48. U/L E EL
9. LWRISTG	19. UFORROT	29. LSHADD	39. LELBEXT	
10. UFORARMG	20. LFORROT	30. UARMDIAG	40. F/E GHIP	

Correlation Matrix with Transformed Variables

	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66
1	-0.212	0.087	0.057	-0.150	-0.110	-0.101	-0.236	-0.037	0.105	-0.085	-0.017	0.144	0.103	-0.029	-0.124	-0.242	0.008	0.005
2	0.005	0.056	-0.040	0.015	-0.122	0.083	-0.130	-0.020	-0.031	-0.036	0.012	-0.134	-0.033	0.075	-0.025	0.033	0.092	0.060
3	0.151	0.159	0.333	0.383	0.293	0.509	0.385	0.208	0.501	0.333	0.488	0.323	0.291	0.384	0.481	0.225	0.414	0.355
4	-0.190	0.173	0.009	0.044	0.002	0.099	-0.265	-0.148	-0.049	-0.021	-0.075	-0.149	-0.312	0.006	-0.091	0.008	-0.004	-0.102
5	-0.064	0.127	-0.133	0.011	-0.155	0.098	-0.190	-0.084	0.030	-0.008	0.109	-0.027	-0.186	-0.041	-0.053	0.087	0.015	0.008
6	-0.072	0.125	-0.114	0.036	-0.140	0.117	-0.138	0.001	0.016	-0.002	0.135	0.001	-0.100	-0.003	-0.042	0.143	0.052	0.061
7	0.146	-0.085	-0.148	-0.066	-0.159	-0.038	0.081	0.079	0.049	-0.009	0.174	0.129	0.162	-0.054	0.050	0.062	0.046	0.126
8	0.310	0.092	0.314	0.341	0.318	0.392	0.451	0.270	0.317	0.315	0.430	0.277	0.469	0.333	0.376	0.402	0.332	0.395
9	0.386	0.144	0.324	0.337	0.305	0.389	0.436	0.327	0.310	0.321	0.438	0.317	0.457	0.396	0.401	0.455	0.372	0.407
10	0.240	0.203	0.410	0.467	0.388	0.520	0.511	0.301	0.490	0.436	0.647	0.251	0.341	0.485	0.593	0.462	0.549	0.533
11	0.341	0.132	0.374	0.448	0.359	0.438	0.573	0.402	0.519	0.541	0.578	0.342	0.395	0.587	0.675	0.376	0.632	0.523
12	0.191	0.097	0.241	0.339	0.218	0.458	0.422	0.221	0.453	0.420	0.540	0.334	0.386	0.339	0.484	0.256	0.487	0.444
13	0.136	0.113	0.308	0.352	0.250	0.450	0.425	0.233	0.436	0.429	0.540	0.314	0.428	0.400	0.482	0.288	0.504	0.498
14	0.233	0.193	0.216	0.393	0.284	0.389	0.392	0.473	0.249	0.441	0.494	0.155	0.444	0.373	0.281	0.140	0.330	0.300
15	-0.254	0.204	-0.019	-0.039	-0.042	-0.034	-0.210	-0.215	-0.002	-0.118	0.050	-0.466	-0.461	-0.186	-0.167	0.038	-0.154	-0.046
16	-0.004	0.010	0.108	-0.120	0.030	-0.044	-0.153	-0.117	-0.291	-0.198	-0.195	0.035	0.027	-0.061	-0.020	0.067	-0.056	-0.016
17	-0.150	0.050	-0.055	-0.307	-0.183	-0.314	-0.382	-0.297	-0.441	-0.472	-0.310	-0.257	-0.216	-0.392	-0.390	0.023	-0.377	-0.154
18	0.166	0.322	0.145	0.188	0.147	0.197	-0.061	0.070	-0.173	-0.150	0.265	-0.152	-0.019	-0.072	-0.060	0.155	-0.006	0.106
19	0.188	0.380	0.149	0.242	0.171	0.114	-0.026	0.161	-0.179	-0.095	0.064	-0.025	-0.036	0.060	0.032	0.196	-0.019	0.079
20	0.264	0.016	0.129	0.121	0.084	0.006	-0.021	0.127	-0.158	-0.018	-0.082	0.058	-0.038	0.114	0.107	0.281	0.002	0.158
21	0.227	0.201	0.183	0.057	0.142	0.061	-0.160	-0.131	-0.095	-0.223	-0.200	-0.075	-0.103	-0.058	-0.107	0.236	-0.198	0.024
22	0.431	-0.144	0.014	-0.077	0.030	-0.180	0.066	0.289	0.092	0.064	-0.020	-0.143	0.161	0.084	0.008	0.152	0.119	0.021
23	0.985	0.018	0.398	0.422	0.488	0.268	0.518	0.467	0.346	0.508	0.217	0.259	0.424	0.443	0.478	0.406	0.503	0.451
24	0.047	0.975	0.503	0.598	0.506	0.521	0.282	0.270	0.137	0.279	0.234	0.087	0.080	0.325	0.323	0.254	0.228	0.295
25	0.376	0.533	0.967	0.675	0.921	0.673	0.633	0.474	0.387	0.503	0.289	0.370	0.563	0.600	0.504	0.507	0.499	0.723
26	0.417	0.588	0.675	0.969	0.790	0.902	0.690	0.607	0.490	0.659	0.619	0.441	0.457	0.686	0.660	0.618	0.602	0.719
27	0.465	0.521	0.907	0.768	0.965	0.728	0.708	0.536	0.394	0.557	0.372	0.420	0.530	0.640	0.569	0.531	0.531	0.693
28	0.249	0.499	0.635	0.836	0.716	0.980	0.602	0.455	0.472	0.574	0.664	0.502	0.434	0.557	0.517	0.586	0.531	0.660
29	0.565	0.265	0.662	0.724	0.752	0.657	0.985	0.771	0.477	0.728	0.550	0.457	0.606	0.766	0.780	0.559	0.665	0.649
30	0.483	0.194	0.497	0.651	0.573	0.487	0.774	0.968	0.484	0.757	0.437	0.323	0.559	0.771	0.620	0.432	0.621	0.557
31	0.333	0.159	0.433	0.506	0.430	0.531	0.515	0.503	0.954	0.689	0.520	0.423	0.378	0.492	0.553	0.338	0.602	0.601
32	0.492	0.209	0.538	0.655	0.592	0.602	0.686	0.721	0.689	0.948	0.546	0.386	0.472	0.766	0.735	0.464	0.791	0.694
33	0.266	0.240	0.319	0.612	0.428	0.703	0.545	0.415	0.511	0.526	0.967	0.408	0.364	0.461	0.551	0.451	0.476	0.436
34	0.317	0.075	0.333	0.449	0.414	0.530	0.482	0.340	0.382	0.387	0.442	0.973	0.422	0.443	0.564	0.359	0.584	0.367
35	0.515	0.139	0.585	0.480	0.552	0.459	0.609	0.541	0.407	0.498	0.336	0.430	0.954	0.597	0.409	0.488	0.498	0.667
36	0.393	0.228	0.580	0.682	0.639	0.591	0.703	0.710	0.448	0.739	0.478	0.413	0.542	0.962	0.705	0.493	0.648	0.630
37	0.482	0.245	0.489	0.657	0.570	0.553	0.736	0.586	0.490	0.705	0.568	0.515	0.398	0.715	0.981	0.531	0.828	0.603
38	0.443	0.282	0.524	0.636	0.564	0.635	0.545	0.413	0.304	0.477	0.478	0.362	0.450	0.535	0.568	0.978	0.523	0.677
39	0.532	0.171	0.494	0.589	0.545	0.545	0.620	0.581	0.560	0.734	0.482	0.520	0.459	0.628	0.815	0.462	0.975	0.643
40	0.440	0.320	0.719	0.709	0.707	0.689	0.605	0.526	0.578	0.660	0.444	0.383	0.614	0.646	0.611	0.646	0.674	0.972
49	1.000	0.038	0.392	0.441	0.492	0.302	0.553	0.497	0.348	0.520	0.265	0.309	0.466	0.470	0.513	0.407	0.544	0.463
50		1.000	0.498	0.608	0.502	0.522	0.295	0.305	0.141	0.302	0.213	0.062	0.088	0.313	0.282	0.232	0.217	0.310
51			1.000	0.683	0.945	0.696	0.652	0.538	0.388	0.522	0.282	0.296	0.583	0.599	0.486	0.510	0.505	0.782
52				1.000	0.806	0.881	0.749	0.708	0.454	0.720	0.599	0.400	0.487	0.760	0.683	0.619	0.639	0.732
53					1.000	0.774	0.756	0.632	0.403	0.611	0.396	0.359	0.548	0.676	0.582	0.538	0.568	0.760
54						1.000	0.667	0.530	0.467	0.623	0.674	0.488	0.490	0.628	0.553	0.633	0.586	0.719
55							1.000	0.820	0.429	0.752	0.546	0.437	0.615	0.784	0.769	0.529	0.679	0.640
56								1.000	0.433	0.771	0.416	0.310	0.525	0.771	0.632	0.380	0.651	0.549
57									1.000	0.671	0.518	0.360	0.340	0.427	0.475	0.271	0.573	0.539
58										1.000	0.536	0.343	0.440	0.807	0.743	0.419	0.779	0.655
59											1.000	0.391	0.374	0.467	0.569	0.471	0.537	0.444
60												1.000	0.439	0.377	0.503	0.346	0.537	0.327
61													1.000	0.567	0.416	0.516	0.496	0.691
62														1.000	0.745	0.497	0.680	0.654
63															1.000	0.506	0.849	0.594
64																1.000	0.457	0.683
65																	1.000	0.658
66																		1.000

1. AGE	11. LFORARMG	21. LFORROT	31. UARMDIAG	49. TRUNKFLE^3	59. UFORSUP^3
2. HT	12. UARM G	22. TRUNKROT	32. LARMDIAG	50. TRUNKEXT^3	60. LFORPRO^3
3. WT	13. LARM G	23. TRUNKFLE	33. UFORSUP	51. GLHIPFLE^3	61. UWRISTST^3
4. STICK L	14. PUCKVEL	24. TRUNKEXT	34. LFORPRO	52. GLHIPEXT^3	62. LWRISTST^3
5. UARM L	15. HAND	25. GLHIPFLE	35. UWRISTST	53. DRHIPFLE^3	63. UELBFLEX^3
6. LARM L	16. UWRISTFX	26. GLHIPEXT	36. LWRISTST	54. DRHIPEXT^3	64. UELBEXT^3
7. ARM/STI	17. LWRISTFX	27. DRHIPFLE	37. UELBFLEX	55. USHABD^3	65. LELBFLEX^3
8. UWRISTG	18. USHROT	28. DRHIPEXT	38. UELBEXT	56. LSHADD^3	66. LELBEXT^3
9. LWRISTG	19. LSHROT	29. USHABD	39. LELBFLEX	57. UARMDIAG^3	
10. LFORARMG	20. UFORROT	30. LSHADD	40. LELBEXT	58. LARMDIAG^3	