THE RELATIONSHIP BETWEEN THE HUMAN MOTOR PERFORMANCE DOMAINS OF LEG STRENGTH AND SPEED OF BODY MOVEMENT

A Dissertation
Presented to
the Faculty of the College of Education

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Education

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by
Robert Stacey Williams
December, 1974

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ABSTRACT

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The purpose of this study was to determine the relationship between selected multiple tests of leg strength and speed of body movement. A review of literature presented and discussed findings of the factor structure of leg strength and body speed. In addition, the relationships between various leg strength and body speed variables, as determined through bivariate correlation, analysis of variance, multiple regression, and canonical correlation, were reported and evaluated.

Subjects utilized in this study included 169 sixth and seventh grade boys who were tested during a two-week period. Each subject was measured on the static leg strength tests of knee extension, hip extension, and ankle plantar flexion; leg power tests of the bicycle ergometer and Margaria power index; sprinting speed tests of acceleration (0-10 yards) and velocity (10-30 yards); controlled speed tests of the right boomerang and dodge run; and jumping speed tests of the box jump and vertical jump. Also, eleven anthropometric measures were determined for each subject. The factor analysis of the anthropometric variables yielded body fat and maturity factors.

Two analytic strategies were used in this study. One utilized raw scores, the other, residual scores. The effects of the eleven anthropometric variables, the body fat and maturity factors, were removed from the raw scores to form the residual scores. Because a part of the error variance of the experimental variables was accounted for by individual differences associated with body fat and maturity, a clearer picture of the relationship between the two sets of experimental variables was gained by using the residual scores.

When the raw scores were factor analyzed, two factors were derived: leg strength, which included all the strength measures; and speed of body movement, which included all the speed measures. The bicycle ergometer test, a leg strength measure, loaded on both derived factors, but considerably higher on the leg strength factor. Sprint acceleration, a body speed measure, also loaded on both factors, but much higher on the speed of body movement factor.

Factor analysis of the residual scores produced the same two factors of leg strength and speed of body movement, with the bicycle ergometer and sprint acceleration loading as they did in the raw score analysis. In addition, the analysis of the residual scores produced a task specific third factor composed of one leg strength measure, ankle plantar flexion, and one body speed measure, the box jump.

Canonical correlation results of both raw and residual scores indicated a significant relationship between linear combinations of the leg strength and speed of body movement domains. In addition to providing the clearer picture of the relationship between the two domains, the residual scores also produced a higher correlation coefficient than the raw scores. The primary contributors to the significant correlation were two leg strength tests, the bicycle ergometer and Margaria power index, and one body speed test, sprint acceleration.

Although a significant relationship between leg strength and speed of body movement was found in this study, it was concluded that additional extraneous variables need to be controlled in the quest to determine the "true" relationship between leg strength and body speed. Based on these additional variables, suggestions for future research were presented.

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THE RELATIONSHIP BETWEEN THE HUMAN MOTOR PERFORMANCE DOMAINS OF LEG STRENGTH AND SPEED OF BODY MOVEMENT

Scientifically conducted research determines answers in a systematic and objective manner (Kerlinger, 1966). The scientific method of defining the structure of human motor performance is committed to using the most powerful, stable, and relevant statistical techniques available. This commitment is enhanced by recent advances in computer technology which allow investigators to utilize highly refined statistical techniques.

A major goal of human motor performance research has been the definition of the structure of its elements. The definition has been attempted, primarily, from two different strategies. One strategy is designed to determine the dimensions, or constructs, by which the domains of human motor performance can be identified. A domain is an area of phenomena that can be represented in factor analysis (Thurstone, 1947). The second strategy is designed to determine the relationships between specific variables in the various domains of human motor performance. Both research strategies have merit in the quest for an adequate definition of the structure of human motor performance.

Factor analysis has traditionally been used in determining the constructs, or domains, of human motor performance. Although this approach is accepted as a valid method of determining these constructs, the factor analytic model employed influences the results. Orthogonal models are based on uncorrelated factors, and the various methods of rotation, such as Kaiser's (1958) varimax method, maintain orthogonality throughout the analysis. Oblique models, on the other hand, are based on correlated factors, which may be a more accurate approximation to reality in terms of the human motor performance domains.

Relationships within the human motor performance domains have been determined in a variety of ways besides factor analysis, the results of which are as varied as the statistical techniques applied to the data. Among the statistical techniques utilized to determine relationships are bivariate correlation, analysis of variance, and multiple regression.

Although these techniques have definite strengths and weaknesses, each has generated some amount of controversy as to its applicability. These methods may be viewed as steps in an evolutionary process leading to more efficient methods of determining relationships between variables. A fuller understanding of relationships between variables is crucial to an accurate structuring of the components of such scientific phenomena as human motor performance. It is essential that a comprehensive technique of determining these relationships be utilized.

Statement of the Problem

This study will investigate the relationship between the human motor performance domains of leg strength and speed of body movement. These domains emcompass constructs of human motor performance that have been derived previously through factor analytic research. The basic problem of this study will be to answer the question: Are there relationships between the domains of leg strength and speed of body movement?

Need for the Study

At the present time there is no "best" method of determining relationships between human motor performance variables. The more researchers are able to utilize improved techniques and computer programs, the clearer the structure becomes in regard to these relationships. A clear conception of the structure and relationships of the basic physical abilities involved in human motor performance should result in improved training and conditioning procedures in physical education and athletics, and ultimately to improved physical performance.

Historically, the first method of determining relationships between these variables was through a bivariate model, bivariate correlation. This method is used to determine the variance shared by two variables. The second method of determining relationships between variables was through a univariate model, analysis of variance. In this method the effect of a certain treatment on the mean score of a group is determined. The third method was based on multiple regression analysis. This method determines the relationship between one independent variable and a set of dependent variables.

It is obvious that the explanation of human behavior should be based on a sound theoretical model for meaningful results to occur. Thus far in the determination of the relationships between human motor performance variables, there has not been an adequate theoretical approach, regardless of the statistical technique applied. Since motor performance relationships are multidimensional in nature, i.e., multiple measures of speed may be related to multiple strength measures in a multiple number of ways, a multivariate approach provides more realistic interpretations than does the bivariate or univariate approach. A theoretical model which allows for variables to be correlated with other variables in multidimensional space while retaining domain membership should result in a more adequate interpretation of the relationships between variables of human motor performance than has been possible with other theoretical models of the same basic problem.

Representative of the multidimensionality of human motor performance are the domains leg strength and speed of body movement. Their existence is substantiated by numerous factor analytic studies. For purposes of this investigation the following factor structure of the two domains will be utilized.

Category I: Basic Dimensions of Leg Strength

1. Static strength
2. Power

Category II: Basic Dimensions of Speed of Body Movement

1. Sprinting speed
2. Controlled speed
3. Jumping speed

Review of Related Literature

To provide an adequate base for the study, three basic literature areas were reviewed:

1. Theoretical models that have been utilized in the study of human motor performance.
2. Factor analytic findings related to the domains of leg strength and speed of body movement.
3. Relationships between the domains of leg strength and speed of body movement.

Theoretical Models That Have Been Utilized in the Study of Human Motor Performance

Theoretical models of human motor performance that have been utilized to date include: (1) the general motor ability approach; (2) the specific motor ability approach; and (3) the theory of basic abilities approach.

General motor ability approach. The general motor ability approach relies heavily on subjective judgment in determining relationships between human motor performance variables. This is evident in that general motor ability and general athletic performance tests involved the establishment of a criterion (usually subjectively, i.e., a "good athlete" should have certain amounts of strength, speed, coordination, and agility) which was correlated with a series of measures intended to show the amount of variables such as strength and speed possessed by an individual. Clarke (1967) states:

> Traditionally, general motor ability has been considered as one's level of ability in a wide range of activities. It has been thought of as an integrated composite of such individual traits as strength, endurance, power, speed, agility, balance, reaction time, and coordination, traits underlying performance in many motor complexes. In successful motor performances, these traits function in a coordinated manner and in effective sequence to achieve an accurate and efficient movement, whether it be a single effort, as in the golf drive, or in a series of complex and rapidly changing movements, as in basketball (p. 262).

General motor ability tests were developed by McCloy (1934), Cozens (1936), Humiston (1937), Powell and Howe (1939), Larson (1941), Carpenter (1942), Scott (1943), Latchaw (1954), and Barrow (1954). As an example of these tests, the Barrow Motor Ability Test (1954) had as an objective, the measuring of motor ability for classification, guidance, and achievement purposes. Its components included: (1) standing broad jump; (2) softball throw; (3) zig zag run; (4) wall pass; (5) six-pound medicine ball put; and (6) 60-yard dash.

Tests of general motor and athletic ability evolved out of the attempt by early physical educators to classify individuals into equivalent groups, both in athletics and physical education. Clarke (1967) states:

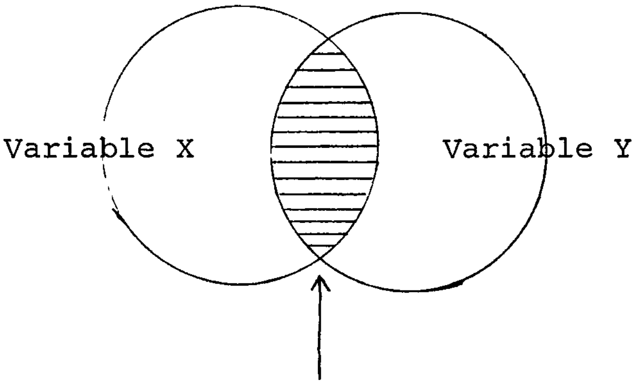
> In the initial stages of motor or physical ability testing, the aim was to use the tests primarily to arouse the interest of boys and girls in all-round physical proficiency. Standards of achievement were set up and scoring tables were devised, on a point basis in many instances, with divisions into junior and senior groups or into various combinations of age, height, and weight. More recently, the gross scores obtained on these tests have been used to classify boys and girls into homogeneous groups. Specific physical education objectives are thus being met by organizing classes whereby effective instruction can be given and equal athletic participation can be had (p. 266).

Although the concept of general motor ability is a logical approach to the study of human motor performance, it has several weaknesses. Primary among these is the use of the composite standard score as the criterion. Cumbee and Harris (1953) indicated that the use of this technique is subject to statistical limitations. The composite standard score criterion represents only one of several factors if a set of independent variables has interrelationships greater in rank than one and if the interrelationships are functions of more than one common factor. In utilizing multiple regression and the composite criterion (which was the case in determining general motor ability) the analysis is incomplete because only one dimension of a multidimensional test plane has been revealed.

Specific motor ability approach. The specific motor ability approach emphasizes that abilities are task specific rather than general in nature. Henry (1958) contended that individuals may possess either great or small degrees of aptitude in certain specific abilities. Unless the specific abilities (or tasks) are quite similar, it is largely a matter of chance whether an individual possesses a high degree of aptitude in more than one of the tasks (and vice versa with a low degree of aptitude).

The theory of specificity does not deny the existence of individual differences, but does imply little intercorrelation between different tasks (unless the tasks are highly related because of the logical similarity of two or more tasks). Task specificity suggests that individual abilities in performing a specified motor task with a particular group of muscles tend to have only low correlations with individual abilities in performing a different task using largely the same group of muscles (Henry & Whitley, 1960).

Research in the task specificity of motor abilities has, for the most part, been conducted with bivariate models; that is, the correlation between two variables. The amount of common variance has been interpreted as the amount of generality shared by the two variables, while that not common is referred to as the amount of specificity. This concept is illustrated in the following Venn diagram:



$$r_{xy} = .30$$

$$r^2 = .09 \text{ (generality)}$$

$$1 - r^2 = .91 \text{ (specificity)}$$

An obvious weakness of this concept is the lack of control for variables other than the ones being analyzed. A re-analysis of Jackson's (1969) original data revealed the relationship of extraneous variables to those under study. Table 1 presents a re-analysis of the data.

Table 1

Product-Moment Correlation Between Physical Performance Measures and Weight and Height

	Variable	Weight	Height
1.	Knee extension	.35*	.21
2.	Knee flexion	.41*	.20
3.	Ankle plantar flexion	.51*	.44*
4.	Vertical jump	-.15*	-.02
5.	Running vertical jump	-.06	.28*
6.	Standing broad jump	-.26**	-.01
7.	Sprint (0-20 yards)	-.43*	-.24**
8.	Sprint (20-30 yards)	-.45*	-.19
9.	Sprint (30-40 yards)	-.41*	-.14
10.	Sprint (40-50 yards)	-.41*	-.11
11.	Shuttle run	-.02	.21
12.	Right boomerang	-.26**	-.07
13.	Left boomerang	-.23**	.00
14.	Zig zag run	-.15	.09

*$p < .01$

**$p < .05$

Product-moment correlations between several physical performance measures and height and weight were significant. If height and weight are related to these performance measures, it is logical to expect other extraneous factors also to be related to performance. To base decisions on the amount of generality-specificity of two measures simply from their correlation coefficients is inadequate and may be misleading.

Theory of basic abilities approach. The theory of basic abilities isolates basic abilities common to many specific skills through factor analytic methodology. It is a method of exploring an unknown domain with the basic purpose being to determine relationships among many variables and, therefore, reduce many variables to fewer underlying variables (Kerlinger & Pedhazur, 1973). For a detailed discussion of the theory of factor analysis the reader is directed to Horst (1965), Harman (1967), or Rummel (1970).

Guilford (1958) compiled the results of several factor analytic studies, including those by Hempel and Fleishman (1955), McCloy (1940), Shapiro (1947), Thurston (1944), Wendler (1938), and others. The results are presented in Figure 1.

The psychomotor factors represented in Guilford's matrix are regarded as hypotheses to a general theory of psychomotor abilities. Some of the individual hypotheses were supported by much evidence, some little, and some had no supportive evidence. The empty cells represent those hypotheses with no support and are areas Guilford cited as future research areas.

Fleishman (1965) offered a hypothetical factor structure of the flexibility-speed domain of human motor performance. This factor structure is presented in Figure 2.

The hypothesizing of a factor structure is critical to the statistical approach utilized by this group of researchers. Once hypothesized, multiple tests measure each of the

Part of Body Involved	Type of Ability						
	Strength	Impulsion	Speed	Static Precision	Dynamic Precision	Coordination	Flexibility
Gross	General strength	General reaction time		Static balance	Dynamic balance	Gross bodily coordination	
Trunk	Trunk strength						Trunk flexibility
Limbs	Limb strength	Limb thrust	Arm speed	Arm steadiness	Arm aiming		Leg flexibility
Hand		Tapping			Hand aiming	Hand dexterity	
Finger			Finger speed			Finger dexterity	

Figure 1

Guilford's Matrix of the Psychomotor Factors (Guilford, 1958) components within the structure. The multiple tests are then factor analyzed and the congruence of the empirically determined structure to the hypothesized one is used as evidence of the model's validity.

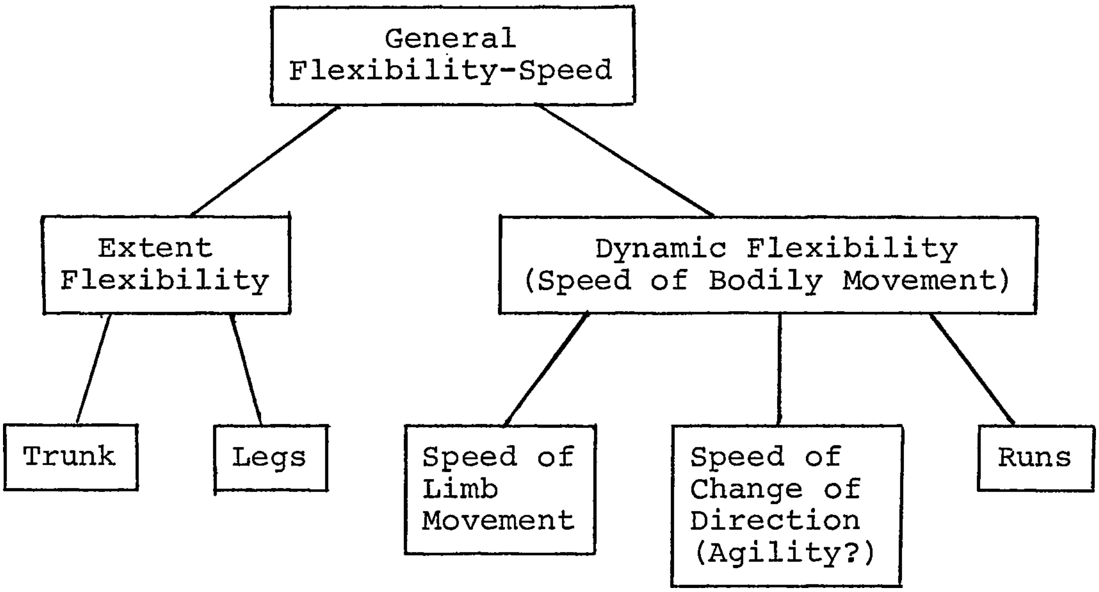


Figure 2

A Possible Hierarchical Factor Structure Hypothesized to Describe the Flexibility-Speed Area (Fleishman, 1965)

Fleishman's theory of basic abilities provides the base for most of the current research in identification of the factors of human motor performance. His work has provided a fuller understanding of the factorial structure of the domains associated with physical performance.

A key issue in Fleishman's theory is the distinction made between the concepts of "ability" and "skill." Fleishman (1966) states:

> ...ability refers to a more general trait of the individual which has been inferred from certain response consistencies (e.g., correlations) on certain kinds of tasks. These are fairly enduring traits, which in the adult are more difficult to change. Many of these abilities are, of course, themselves a product of learning, and develop at different rates, mainly during childhood and adolescence. Some abilities (e.g., color vision) depend more on genetic than learning factors, but most abilities depend on both to some degree. In any case, at a given stage of life, they represent traits or organismic factors which the individual brings with him when he begins to learn a new task. The abilities are related to performances in a variety of human tasks. For example, the fact that spatial visualization has been found related to performance on such diverse tasks as aerial navigation, blueprint reading, and dentistry makes this ability somehow more basic.
>
> ...skill refers to the level of proficiency on a specific task or limited group of tasks. As we use the term skill, it is task oriented. When we talk about proficiency in flying an airplane, in operating a turret lathe, or in playing basketball, we are talking about a specific skill. Thus, when we speak of acquiring the skill of operating a turret lathe, we mean that this person has acquired the sequence of responses required by this specific task. The assumption is that the skills involved in complex activities can be described in terms of the more basic abilities. For example, the level of performance a man can attain on a turret lathe may depend on his basic abilities of manual dexterity and coordination. However, these same basic abilities may be important to proficiency in other skills as well (pp. 147-148).

Predicted performances in specific skills can be determined by measuring the individual differences in abilities. An individual's skill proficiency is, therefore, dependent upon the basic abilities possessed. It follows that factor analysis of specific skill tests should determine the basic abilities innate to the skill tests.

In essence, Fleishman's distinction between "ability" and "skill" has provided greater flexibility in understanding, describing, and predicting the components of human motor performance.

Factor Analytic Findings Related to the Domains of Leg Strength and Speed of Body Movement

The most significant identification of the structure of human motor performance has been through factor analysis. Guildford's matrix of psychomotor factors (see Figure 1) and Fleishman's hypothesized flexibility-speed domain (see Figure 2) exemplify the many factors necessary to explain human motor performance. These factors range from fine manipulative abilities to abilities of a more gross nature that involve large body segments. It is not the purpose of this review to present and discuss this massive amount of research; rather, this section of the review of literature will present research relating to and substantiating the existence of two specific domains of human motor performance. These domains are: (1) leg strength; and (2) speed of body movement. Their factor structure, as presented in Figure 3, is supported by the results of the following factor analytic studies.

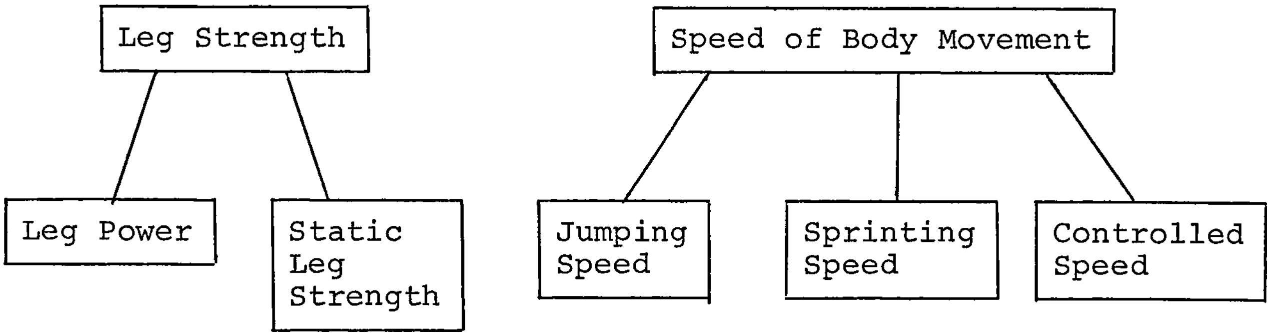


Figure 3

A Possible Factor Structure of the Domains of Leg Strength and Speed of Body Movement

Rarick (1937), in a factor analytic study that involved many velocity, strength, power, and anthropometric variables, isolated factors that included general strength (measured primarily by back and leg dynamometer tests) and speed of movement (measured by jumps and sprints).

Hutto (1938), in a factor analysis of the velocity factor and athletic power, identified a velocity factor that consisted primarily of sprints and jumps. Other factors identified were somewhat more complex.

Henry, et. al. (1962), in a factorial study of limb speed, reaction time, and strength, isolated two factors. These included a factor of ratio of strength to limb mass and a factor of isometric leg strength.

Several factor analytic studies of human motor performance were reviewed and re-analyzed by Harris and Liba (1965). This review is presented in Table 2. Re-analysis included

Table 2

Robust Factors Related to Leg Strength and Speed of Body Movement Isolated in Harris and Liba's (1965) Re-analyses

Study	Robust Factors
Brogden, et. al. (1952	1) Items represented by measures of jumping ability 2) Items represented by measures involving straight runs of at least 50 yards
Cousins (1951)	1) Jump-type tests 2) Long runs (200 yards up) 3) Short runs (under 100 yards) 4) Agility runs
Fleishman, et. al. (1961) (Speed Matrix)	1) Speed of leg movement
Fleishman, et. al. (1961) (Strength Matrix)	1) Body-projection variables (running tests, jumping tests, softball throw, medicine ball put) 2) Dynamometric strength 3) Moving a barbell against gravity
McCraw (1949)	1) Eight body- and object-projection variables
Phillips (1949)	1) Body-projection variables 2) Dynamometric strength
Benson (1965)	1) Body-projection tests
Liba (1967)	1) Dynamometric strength tests as represented by three factors 2) Body-projection variables
Wendler (1938)	1) Body-projection variables 2) Tests of strength as measured by an instrument

incomplete principal components analysis, alpha factor analysis, Joreskog's approximation to canonical factor analysis, and incomplete image analysis. For purposes of the present study, reference will be made only to isolated factors that represent leg strength and speed of body movement.

Results of the studies reported in Table 2 indicated the existence of the domains of leg strength and speed of body movement. Factors were isolated for jumping, sprinting, agility runs, static strength, and leg speed. Although no clear-cut factor structure was derived, the repetition of the factors associated with leg strength and speed of body movement in the results indicated existence of the two domains.

Start, et. al. (1966), in a factorial study of the lower limb that included, among others, seven measures of isometric leg strength and four measures of leg power, found little similarity between the factors of leg strength and leg power. Measures of isometric strength included various cable-tension tests, while the power measures included various jumping tests. The authors concluded that the low correlations between measures of leg power and leg isometric strength indicated the complex nature of the factor of leg strength.

Borchardt (1968), in an analysis of twenty-four static strength tests that involved various body parts, isolated as one cluster those items that measured leg strength. The strength measures were obtained by use of the cable tensiometer. Among the items that clustered on leg strength were measures of thigh flexion, thigh adduction, leg extension, and thigh extension.

An investigation by Jackson (1971), utilizing both oblique and orthogonal factor rotation, revealed five robust factors. Among these factors were those of leg strength, sprinting, and body change of direction. Jumping was tentatively verified as a factor.

In an attempt to identify factors of physical fitness, Baumgartner and Zuidema (1972) hypothesized, among others, the factor of leg strength and endurance. Tests of this hypothesized factor included the standing broad jump and a dash (75 yards for men and 50 yards for women). Factor analysis revealed that for men the factor of leg strength and endurance was accounted for by two factors, each containing various strength, endurance, and cardiorespiratory tests relevant to different areas of the body. For women the factor was not supported by the data analysis.

Disch (1973), in a factor analysis of the speed domain, found several factors to be robust. Among these were: (1) sprinting speed, as measured by straight runs and runs on a curve; and (2) controlled speed of running, as measured by certain agility tests.

Summary of factor analytic studies. The factor structures of leg strength and speed of body movement (see Figure 3) are substantiated by numerous factor analytic studies. Although it is obvious that no clear factor structure was revealed by these studies, the hypothesized components in Figure 3 are logical explanations of the factors leg strength and speed of body movement.

Relationships Between the Domains of Leg Strength and Speed of Body Movement

A survey of the literature revealed a vast quantity of research purporting various relationships between speed and strength. Many of the studies reviewed are directly related to the factors under consideration in this study, leg strength and speed of body movement. Other studies are related, more generally, to the broader concepts of speed and strength. For purposes of the present study, research that utilized correlation techniques, analysis of variance techniques, and multiple regression techniques in determining relationships between strength and speed variables was reviewed.

Bivariate techniques. A large percentage of statistical analysis in the study of human motor performance, and specifically in the determination of relationships between strength and speed, has been of the bivariate correlation technique.

Bivariate correlation is the determined relationship between two variables and is usually computed with product-moment techniques.

Correlation techniques in the study of human motor performance have basically been utilized in two ways: (1) to determine the significance of the relationship between two variables, and (2) as proof of the specificity-generality between two variables. Presented in Table 3 are the results of bivariate correlation of various strength and speed measures.

An obvious difference in studies using either of the preceding concepts pertains to the number of variables correlated in each type of study. Studies designed to determine relationships between two variables (Berger & Henderson, 1966; Costill, et. al., 1968; Nelson & Fahrney, 1965; and Clarke & Degutis, 1964) correlated multiple pairs of variables. Although the variables were correlated in a bivariate manner, different combinations of variables produced different correlation coefficients (i.e., Clarke & Degutis, 1964, found $r = .17$ to .75 for various strength tests when correlated to one measure of leg power). Some variables were significantly related to one another, while others were not.

Table 3

Summary of Bivariate Correlation Studies of Strength and Speed

Study	Variables Correlated	Sample	Results
Smith and Whitley (1963)	1) Arm speed (horizontal adductive swing) 2) Arm strength (as measured by dynamometer prior to arm swing)	College men N = 60	r (arm speed and arm strength) = .033 to .219
Clarke (1960)	1) Speed of lateral arm movement 2) Arm strength/mass ratio	College men N = 48	r (arm speed and arm strength/mass ratio) = -.277. Author concludes a high degree of specificity exists between the two variables.
Smith (1961)	1) Explosive leg strength (measured by leg dynamometer) 2) Vertical jump (modified Sargent Jump)	College men N = 70	r (leg strength/mass and vertical jump) = .168. Author concludes different neuromotor programs needed for the two movements.
Gray, et. al. (1962)	1) Leg speed (ergometer) 2) Leg power (vertical jump)	College men N = 62	r = .47**. Authors conclude high specificity, low generality (22%).
Berger and Henderson (1966)	1) Leg power (modified vertical jump) 2) Leg strength a. Static (leg dynamometer) b. Dynamic (squat lifts)	College men N = 66	r (static leg strength and leg power = .64**, r (dynamic leg strength and leg power) = .71**

Costill, et. al. (1968)	Tests of leg strength and power, including (1) vertical jump, (2) standing broad jump, (3) 40 yard dash, (4) squat weight lift, (5) anaerobic power, (6) vertical velocity, and (7) measures of height, % body fat, and lean body weight	College men (primarily football team members) N = 76	r = -.625 to .848**. Authors conclude anaerobic power is related to dynamic leg strength. Vertical velocity is related to 40 yard dash, but only moderately influenced by explosive leg strength.
Henry and Whitley (1960)	1) Arm strength (dynamometer) 2) Arm mass/speed of movement ratio	College men N_1 = 35 N_2 = 30	r_1 = .178, r_2 = .215. Authors conclude neuromuscular control patterns are specific to the movement.
Lotter (1961)	1) Arm speed of cranking a. Two hands b. One hand 2) Leg speed of cranking a. Two feet b. One foot	College men N = 80	Author concludes a high degree of task specificity due to few significant r's.
Rasch (1954)	1) Length, weight, and strength of arm 2) Maximum arm speed	Males (ages 17-47)	Author concludes there is no relationship between speed of arm movement and length, weight, and strength of the arm because no significant correlations were found.

Nelson and Fahrney (1965)	1) Arm strength (static) 2) Speed of elbow flexion	College men $N_1 = 23$ $N_2 = 31$ $N_3 = 19$	r = .74 to .79**
Clarke and Degutis (1964)	1) Leg power (standing broad jump) 2) Various maturational, anthropometric, and strength tests.	Boys (age 12) N = 81	r (anthropometric measures) = .40 to .86*, r (strength measures) = .17 to .75*. Measures that correlated significantly with standing broad jump included five cable tension strength tests (r = .28 to .47), back lift (r = .26), and strength index (r = .32). Authors conclude that leg power is partly dependent upon body size and muscular strength.
Eckert (1964)	1) Propulsive force of the body (standing broad jump) 2) Isometric strength measures of the lower limb 3) Standing broad jump	Boys (same group measured at ages 8, 10, 12) N = 10	Significant relation ($p < .05$) between isometric extensor strength of the hip joint and speed of movement during standing broad jump. No significant relation ($p > .05$) between propulsive force and isometric strength.

*$p < .05$
**$p < .01$

The studies that tested the specificity of motor performance variables (Smith & Whitley, 1963; Clarke, 1960; Smith, 1961; Gray, et. al., 1962; and Henry & Whitley, 1960) commonly correlated only two measures (i.e., Gray, et. al., 1962, found r = .47, therefore, generality = 22 per cent, and specificity = 78 per cent between one measure of leg power and one measure of leg speed).

The results of the majority of the studies utilizing correlation techniques were distorted to an unknown degree by the lack of control for such influential variables as height, weight, and other anthropometric measures. The degree of relationship between two variables may have been so effected by these and other non-controlled factors that little significance could be attributed to the derived relationship.

Although as in the correlation studies mentioned thus far, Costill, et. al., (1968), did not control for the effects of extraneous variables, but instead, correlated variables of height, weight, per cent body fat, and lean body weight with certain strength and power variables. These correlations are presented in Table 4. The authors conclude that body weight may account for the relationship between such variables as the squat lift and anaerobic power.

Table 4

Correlation Coefficients Among Tests of Explosive Leg Power

Test Item	1	2	3	4	5	6
1. Vertical jump		.672	-.625	-.350	-.252	-.467
2. Standing broad jump			-.621	-.271	-.155	-.486
3. 40 yard dash				.201	.117	.711
4. Squat weight lift					.751	.119
5. Anaerobic power						-.172
6. Vertical velocity						
Height	-.167	-.040	.114	.077	.129	.024
Weight	-.518	-.427	.512	.783	.848	.364
Per cent body fat	-.633	-.612	.640	.585	.580	.392
Lean body weight	-.331	-.235	.322	.742	.842	-.203

Note.--Reprinted from an article by David L. Costill, et. al., published in the October 1968 Research Quarterly.

Univariate techniques. Univariate techniques are characterized by analysis of variance models. Analysis of variance is basically a method of determining if the means of two specified groups differ significantly.

A review of analysis of variance studies related to the human motor performance domains of strength and speed produced a variety of results. A summary of the analysis of variance studies is presented in Table 5. Of importance in this group of studies is the fact that relations between variables were determined from a different frame of reference than the correlation studies presented in Table 4. This frame of reference is one of determining the effect of certain treatments on selected

Table 5

Summary of Analysis of Variance Studies of Strength and Speed

Study	Variables Analyzed	Sample	Treatment Conditions	Results
Bangerter (1968)	Vertical jump as effected by: 1) Plantar flexion 2) Knee extension 3) Hip extension	College men N = 100	Group 1 exercised plantar-flexor muscles only in a weight training program, Group 2 exercised knee extensors only, Group 3 exercised hip extensors only, Group 4 exercised all three, Group 5 was control	Plantar flexors did not significantly contribute to vertical jump ($p > .05$). Knee extensors, hip extensors, and a combination of the two did contribute significantly to the vertical jump ($p < .05$).
Payne (1968)	Strength training programs: 1) Isometric 2) Isotonic in relation to static strength gains	8th grade girls N = 72	Group 1 participated in an isotonic exercise program for five weeks, Group 2 was control, Group 3 participated in an isometric exercise program for five weeks	Group 1 (isotonic) was significantly superior in static strength gain due to treatment ($p < .05$).
Colgate (1966)	Effect of various arm strengthening programs on arm speed	College men N = 49	Group 1 performed adduction and flexion exercises for a six week training period, Group 2 abduction and extension, Group 3 all exercises, Group 4 no training	An increase in mean strength of arm-shoulder muscles was accompanied by an increase in mean arm speed ($p < .05$).

McClements (1966)	1) Body power (jumping height X body weight) as compared to leg strength (thigh flexion and extension) 2) Effect on power of strength development of agonistic and antagonistic muscle groups	College men N = 86	Group 1 participated in leg extension weight training program for 19 class periods, Group 2 in leg flexion, Group 3 in flexion and extension, Group 4 in the "normal" program	There was no significant difference in the four methods of increasing leg power ($p > .05$). Strength was not related to gains in power.
Chui (1964)	Strength and speed of single movements as effected by: 1) Isometric weight training exercises 2) Dynamic weight training exercises	College men N = 96	Group I weight trained by isometric contraction method, Group R by rapid contraction method, Group S by slow contraction method, Group C was control	1) Strength gains made by isometric and dynamic training methods were not different ($p > .05$). 2) Strength gains are accompanied by speed gains. 3) Speed gains made by isometric and dynamic training methods were not different ($p > .05$).

performance variables, i.e., vertical jump performance as effected by training programs utilizing either plantar flexion, knee extension, or hip extension exercises (Bangerter, 1968). This is a form of physically controlling for the effects of certain variables on other variables.

In all but one of the analysis of variance studies reviewed, significant relations were found between some aspect of strength and speed. Bangerter (1968) found that knee and hip extension exercise programs significantly contributed to vertical jump performance. Payne (1968) found that isotonic weight training provided more strength gain than did isometric weight training. Colgate (1966) found that as arm strength significantly increased, arm speed also increased significantly. Chui (1964) found that increases in strength were accompanied by speed gains, but isotonic and isometric weight training programs did not significantly effect the gains in either strength or speed. In essence, greater strength was obtained when mass and/or acceleration was increased (i.e., Force = Mass X Acceleration).

Multidimensional techniques. The basic task of multiple regression analysis is to explain the variance of a dependent variable. Estimating the contribution of two or more independent variables in the prediction of the dependent variable allows the task to be accomplished (Kerlinger & Pedhazur, 1973).

The analysis of variance and multiple regression techniques commonly approach the study of relations from a multidimensional view. Because the explanation of human motor performance generally involves multidimensional factors, utilization of either of the two techniques results in more accurate approximations to the "true" explanation of phenomena than does the bivariate correlation technique of determining the relationship between only two variables. Multiple regression analysis, then, significantly contributes to the explanation of the relationships existing in the domains of human motor performance. For the present study only those experiments concerned with relationships between strength and speed variables were reviewed. A summary of the multiple regression studies is presented in Table 6.

Each of the studies summarized in Table 6 determined significant relationships between various strength and speed measures. The common feature of the multiple regression technique was the prediction of a dependent variable from a set of independent variables (i.e., Huffman & Berger, 1972, predicted vertical jump performance from AAHPER Youth Fitness Test items).

Table 6

Summary of Multiple Regression Studies of Strength and Speed

Study	Dependent Variable	Independent Variables	Sample	Results
Huffman and Berger (1972)	1) Vertical jump 2) Modified leg power test	AAHPER Youth Fitness Test items	College men N = 50	R = .73* for vertical jump, R = .67* for modified leg power test. Authors conclude that the modified leg power test and the vertical jump predict motor ability and physical fitness with similar accuracy.
Jackson and Cooper (1970)	Movement time (0-10 yards)	Six cable tension strength tests of the leg	College men N = 12	R = .952* for all tests with movement time. Authors conclude that the differences among the angles of the rear knee may be due to leg strength factors.
Considine and Sullivan (1973)	Leg power performance tests	Measures of cable tension leg strength	College men N = 38	R = .4862* between cable tension leg strength and power in non-dominant knee (only significant R reported).

$*p < .05$

A major weakness noted in the studies summarized in Table 6 relates to the sample size employed by each. Kerlinger and Pedhazur (1973) emphasize the need for a sample size of thirty subjects per variable in the regression equation. Huffman and Berger (1972) tested 13 variables and utilized only 50 subjects; Jackson and Cooper (1970) tested 6 variables and utilized only 12 subjects; Metz and Alexander (1970) tested 17 variables and utilized only 30 subjects; and Considine and Sullivan (1973) tested 13 variables and utilized only 38 subjects. For stability of results it is obvious that sample sizes were inadequate in these studies.

Canonical variate analysis is an extention of the multiple regression technique. Whereas multiple regression is limited to the prediction of a single dependent variable from a multiple set of independent variables, canonical variate analysis is expanded to include the prediction of multiple dependent from multiple independent variables.

Darlington, et. al. (1973) indicated that the purpose of canonical variate analysis is to determine: (1) the number of traits needed to explain the relationships between two sets of variables; and (2) the nature of those traits.

Press (1972), in discussing the place of canonical variate analysis in the general schema of analysis techniques states:

> The canonical correlations model selects weighted sums of variables from each of two sets to form new variables in each of the sets, so that the correlation between the

> new variables in different sets is maximized while the new variables within each set are constrained to be uncorrelated with mean zero and variance one. The ordinary (product-moment) correlation between two random variables is by now very familiar. The generalization of this simple idea to a measure of association between one random variable and a vector of others...is in terms of the multiple correlation coefficient. The canonical correlation coefficient generalizes the notion even further to correlation between two random vectors (pp. 330-331).

Few studies in human motor performance have been conducted that utilized canonical variate analysis. One such study, by Considine and Sullivan (1973), indicated a non-significant canonical correlation between strength, dependent variables, and power, independent variables. A canonical correlation of .6407 ($p > .05$) was derived for the first canonical variate. Several reasons exist for the lack of significant correlation between these variables. Primary reasons include: (1) the fact that there may actually be no linear combination of strength variables correlated with a linear combination of power variables; and (2) the non-significant findings may be due to a small sample size, N = 38.

A re-analysis of Jackson's (1969) original data indicated significant canonical correlations between the domains of leg strength, running speed, and jumping. Presented in Table 7 are the results of this re-analysis.

Table 7

Canonical Correlation Coefficients of Leg Strength and Body Projection Variables

Domains Compared	First Canonical Factor			
	Rc	Chi.sq.	df	p
Leg Strength-Running Speed	.5139	32.4522	12	.0012
Leg Strength-Running Agility	.4912	22.6513	12	.0309
Leg Strength-Jumping	.4020	17.2016	9	.0457

The domains in Table 7 were measured as follows: Leg Strength--three cable tension strength tests; Running Speed--four sprinting tests; Running Agility--four speed tests involving change of body direction; and Jumping--three tests of horizontal and vertical jumping ability. From the results it can be concluded that certain linear combinations of leg strength variables are significantly correlated with certain linear combinations of running speed, running agility, and jumping.

Summary of relationships between strength and speed. The study of relationships between the factors of human motor performance has been conducted, primarily, from three approaches: (1) bivariate techniques; (2) univariate techniques; and (3) multivariate techniques.

Because the relationships between variables of the human motor performance domains are logically multidimensional in nature, the most meaningful results are obtained when multivariate models are applied to the data. The ultimate multivariate model available at this time is canonical variate analysis.

Although the two studies reviewed that have utilized canonical correlation in the determination of relationships between human motor performance variables presented contradictory results, the power and importance of this technique cannot be denied. Canonical variate analysis can be usefully applied if the variables in question are of a multidimensional nature and a sufficient number of subjects are included in the sample.

Hypothesis

Based on the review of literature, the following null hypothesis was developed:

There will be no significant relation between any linear combination of dependent variables (leg strength) and any linear combination of independent variables (speed of body movement).

Methods

Independent Variables

The independent variables included six tests designed to measure the speed of body movement domain. The review of literature indicated the existence of at least three distinct factors within this domain of human motor performance. Included in these factors were sprinting speed, controlled speed, and jumping speed. Therefore, to adequately describe the speed of body movement domain, each of the three areas had to be measured.

Sprinting speed. Sprinting speed was defined as the linear total running speed generated in a specified distance (Disch, 1973). Two measures of sprinting speed were obtained for each subject:

1. sprint acceleration (0-10 yards)
2. sprint velocity (10-30 yards)

Studies by Jackson (1969) and Disch (1973), and pilot research by the investigator utilized these tests to determine sprinting speed. The 0-10 and 10-30 yard distances were selected because they adequately measure the two components of the sprint velocity curve (Henry & Trafton, 1951) under consideration in the present study. Both acceleration and velocity times were recorded on the same performance run.

The subject began each trial from a point 24 inches behind a starting line, in an upright position, and with one foot in advance of the other. By positioning the subject in such a way, the learning effects and errors associated with the traditional three- or four-point sprint start were minimized.

A multiple timing system manufactured by Lafayette Instrument Company, Lafayette, Indiana, the Reaction-Sprint Timer, was used to measure all sprint times. In addition, two photocell units, two light sources, and one switch mat were used in these measures. The Reaction-Sprint Timer is illustrated in Figure 4, page 41.

One photocell and light source was placed at a distance of 10 yards and another set placed at a distance of 30 yards from the starting line. The switch mat was placed on the starting line. When the investigator was ready to record the subject's times in each sprint performance, the verbal command "ready" was given. The subject, at his own discretion, stepped on the switch mat and sprinted through the designated 30 yard distance. By depressing the switch mat, both clocks in the Reaction-Sprint Timer were activated. Breaking the light beam on the photocell unit at 10 yards produced the time for the sprint acceleration measure (0-10 yards). Breaking the light beam at 30 yards produced a time for the 0-30 yard distance. The time for the 0-10 yard distance was subtracted from the time for the 0-30 yard distance to produce the sprint velocity measure (10-30 yards).

Elapsed times were recorded to the last 1/1000th of a second. Each subject was allowed one warm-up trial at less than maximum speed followed by three trials at maximum. The subjects were measured in groups of approximately 20, with a rest period between trials of four to five minutes.

Controlled speed. Controlled speed was defined as the nonlinear running speed generated in a specified distance (Disch, 1973). Two tests were used to measure controlled running speed:

1. right boomerang
2. dodge run

The right boomerang was utilized by Jackson (1969) and Disch (1973) and was an adaptation of a test reported by McCloy and Young (1954). A diagram of the test course for the right boomerang is presented in Figure 13, Appendix A.

The dodge run was used by Jackson (1969) and Disch (1973) and was an adaptation of a test reported by Barrow and McGee (1964). A diagram of the test course for the dodge run is presented in Figure 14, Appendix A. This test was similar to the right boomerang except that the length of the running start and the course route were somewhat modified. Administrative procedures, number of trials, and accuracy of the recorded scores were identical for both the right boomerang and the dodge run.

A timing system composed of Data Cubes, two photocell units, two light sources, and one electric clock was used to determine times in these two tests. The Data Cubes, manufactured by Lafayette Instrument Company, Lafayette, Indiana, are a series of switches and relays which can be arranged in a variety of patterns. The photocells and light sources were constructed in the Research Laboratory, University of Houston Physical Education Department. The electric clock was a Model 120A Klockounter unit manufactured by Hunter Manufacturing Company, Iowa City, Iowa. A schematic diagram of the wiring procedure of the Data Cube series and the other components of the timing system for the right boomerang and the dodge run is presented in Figure 15, Appendix B.

One photocell unit and light source was placed on the start line and another set on the finish line. When the investigator was ready to record the subject's time in each of the two tests, the verbal command "ready" was given. The subject, at his own discretion, ran through the starting line, through the designated test course, and through the finish line. By breaking the light beam on the photocell unit at the start line, the subject started the electric clock. It was stopped when the subject broke the light beam on the photocell at the finish line.

Running starts were allowed in both the right boomerang and the dodge run in order to minimize the errors associated with the stationary start. Two trials were allowed for learning the course, followed by three timed trials at maximum effort. Elapsed times were recorded to the last 1/1000th of a second. In certain limited instances in the two tests, more than two practice trials were allowed for learning the course. There were approximately 20 subjects in each test group and a rest period of three to four minutes was allowed between trials.

Jumping speed. Jumping speed was defined as the linear speed generated by the body as it moves, unsupported, through the air. Two tests were used to measure jumping speed:

1. box jump
2. vertical jump

The box jump test was originally reported by Jackson and Frankiewitz (1973). In this test the subject (in a standing position) started with one foot elevated on a box 15 inches in height and the other foot flat on the floor. After the command "ready" by the investigator, the subject, at his own discretion: (1) pushed off with his "floor" foot, (2) pushed off with his "box" foot, and (3) completed a jump over the box. The starting position for the box jump test is illustrated in Figure 5.

Equipment used in the box jump test included Data Cubes, two switch mats, and one electric clock. (The manufacturers of this equipment were noted in the discussion of the controlled speed measures.) A schematic diagram of the wiring procedures of the Data Cubes and associated components for the box jump test is presented in Figure 16, Appendix B.

One switch mat was secured on the floor in front of the box and the other mat secured to the top of the box. By lifting the foot on the floor, the electric clock was activated. It was stopped when the foot on top of the box was lifted. The box jump test, then, measured the elapsed time between lifting the foot on the floor and lifting the foot on the box.

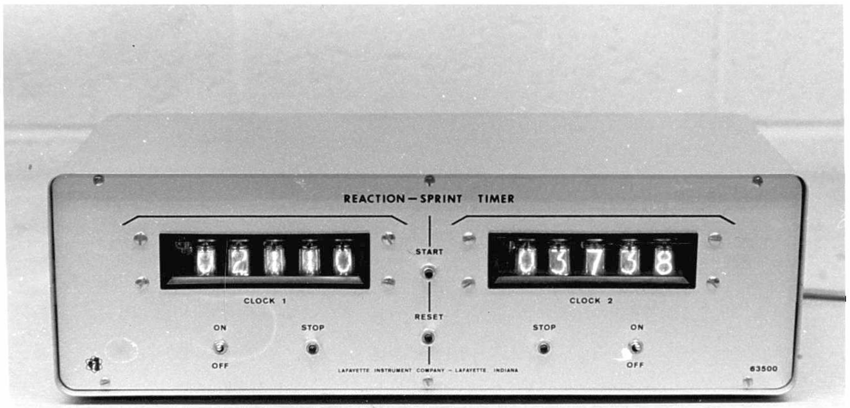


Figure 4

The Reaction-Sprint Timer

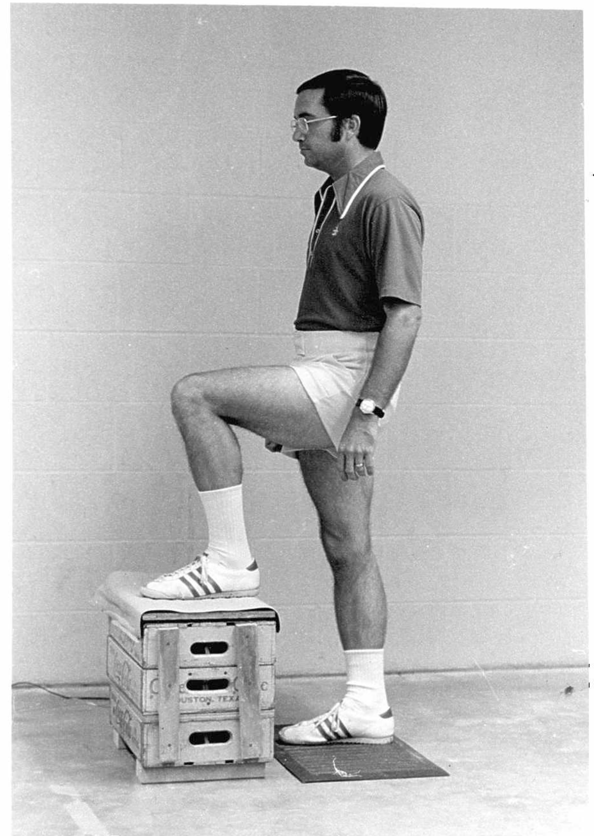


Figure 5

Starting Position for the Box Jump

Two practice trials for learning the task were followed by ten recorded trials at maximum effort. Times were recorded to the last 1/1000th of a second. The subjects were measured in groups of approximately 20, with a rest period of 20-30 seconds allowed between trials.

In the vertical jump, the subject's ability to generate speed in a vertical plane was measured. Rather than obtain a measure of time (i.e., actual speed generated in the jump), vertical distance jumped was determined. The height jumped was easier to obtain, more accurately administered, and as relevant to the concept of jumping speed as the actual speed of the jump.

To measure the vertical height jumped, an adjustable jump board similar to that reported by Considine and Sullivan (1973) was utilized. The procedure of extending one arm as high as possible and adjusting the sliding measurement scale to the height of the reach was followed. Figure 6 illustrates the subject with the board adjusted to his reach. The subject then crouched and, using a two-foot take-off, jumped vertically with maximum effort. At the peak of his jump, the subject touched the jump board at the highest possible point. Figure 7 illustrates the subject touching the jump board at the peak of his jump.

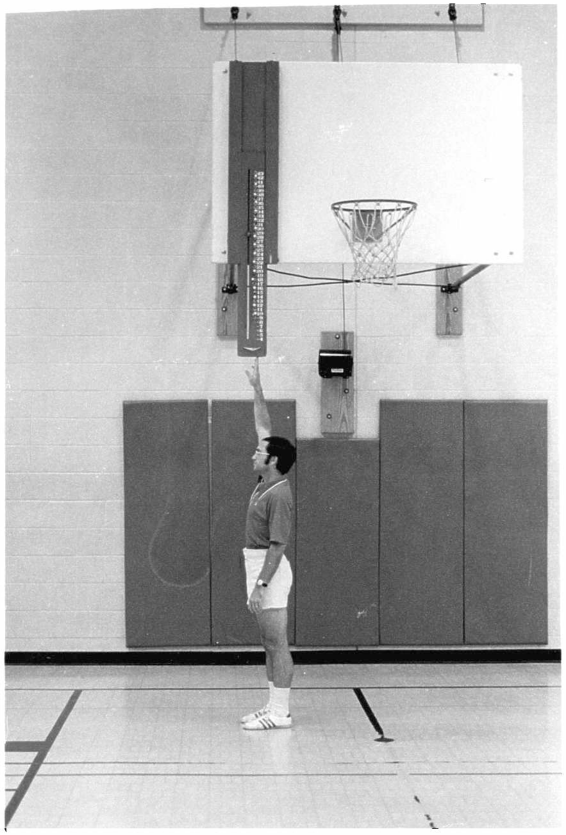


Figure 6

Board Adjustment for the Vertical Jump

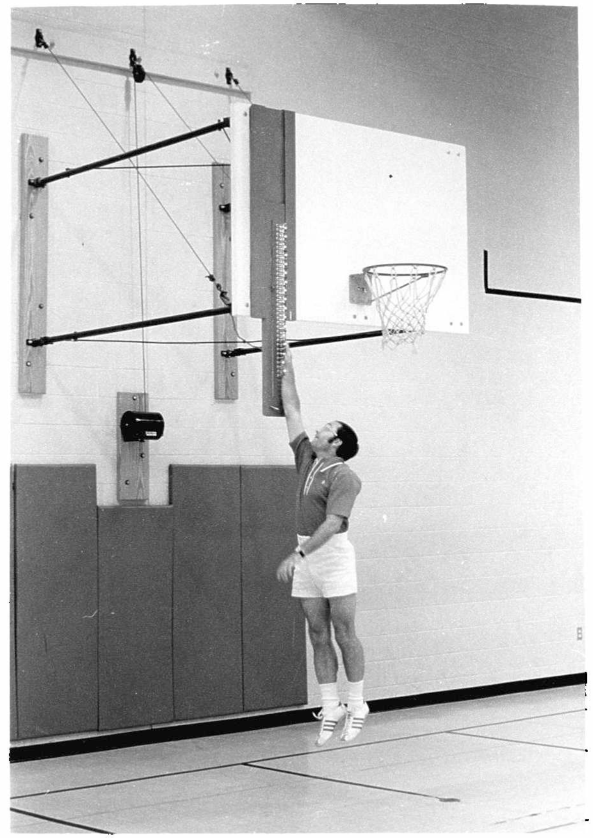


Figure 7

Vertical Jump-Peak of the Jump

In the vertical jump test, each subject was allowed two practice trials followed by six recorded trials. Scores were recorded to the last inch. The subjects were measured in groups of approximately 20, with a rest period of approximately 30 seconds allowed between trials.

Dependent Variables

The dependent variables included five tests designed to measure the leg strength domain. The review of literature indicated the existence of at least two factors within the domain of leg strength. These factors included static leg strength and leg power. To adequately describe the leg strength domain, both areas had to be measured.

Static leg strength. Static leg strength was defined as the amount of tension the leg muscles could generate in a single maximum contraction (Clarke, 1966). The static leg strength of each subject was determined by three specific tests:

1. knee extension
2. hip extension
3. ankle plantar flexion

Figures 8, 9, and 10 illustrate the administration of the three static leg strength tests. In each case, the leg opposite the dominant arm was tested. The use of this type of test to determine static leg strength is common in the areas

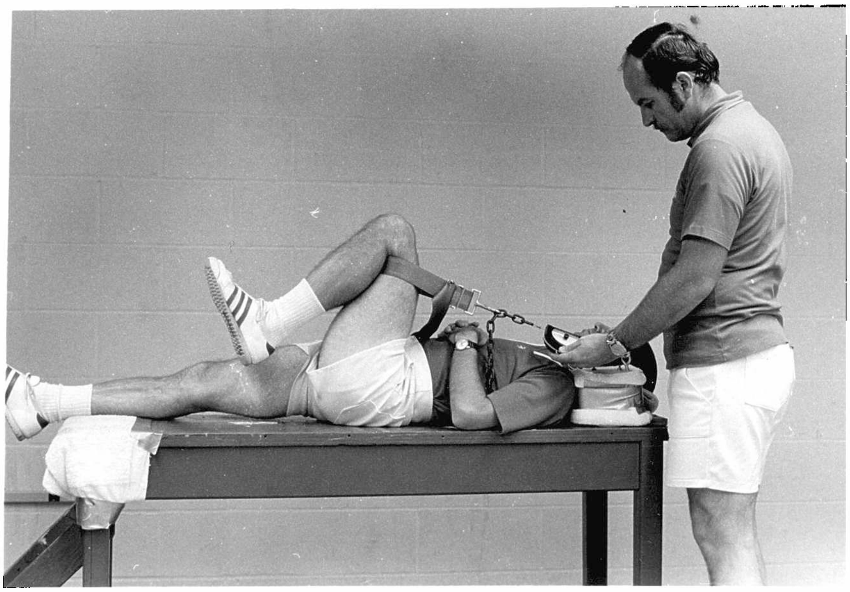


Figure 8

Hip Extension

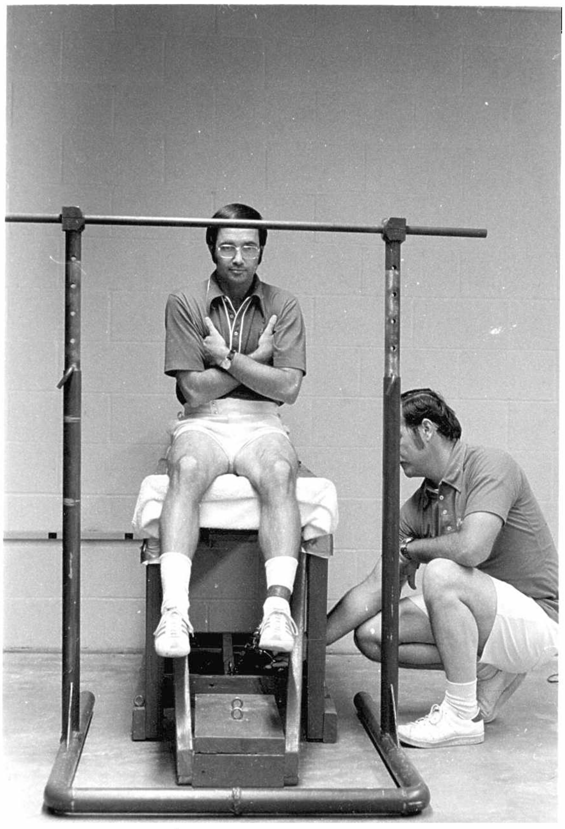


Figure 9

Knee Extension

of exercise physiology and measurement. Clarke (1966), utilized these tests extensively and presents a comprehensive description of their administration.

Equipment used in the measurement of static leg strength included:

1. a measuring table

2. three pulling assemblies (each consisting of a length of chain, a length of 1/16 inch stainless steel cable, a web strap, and snap hooks)

3. a goniometer (to measure joint angle prior to muscular contraction)

4. a tensiometer (indicated the number of tension units produced on each trial of the three static strength tests)

The tension generated in the ankle plantar flexion test for the selected sample was relatively low. Therefore, for the ankle plantar flexion variable, a tensiometer was utilized that registered twice as many tension units as the one used in the other two static strength measures.

For each of the three static strength measures one warm-up trial at approximately 75 per cent of maximum effort preceded three trials at 100 per cent effort. The subjects were instructed to apply steady force rather than jerk the cable. Each measure was recorded to the last one-half tension unit. The subjects were measured in groups of approximately 20, with a rest period of 20-30 seconds allowed between trials.

Leg power. Leg power was defined as the rate of performing muscular work with the legs, i.e., Power = $\frac{\text{Work}}{\text{Time}}$ (Gray, et. al., 1962). Two tests were used to calculate leg power:

1. bicycle ergometer test
2. Margaria power index

The bicycle ergometer test was developed by Doyle (1973). Leg power was derived by the formula:

$$\text{Leg Power} = \frac{\text{Distance (meters) X Workload (kp)}}{\text{Time (seconds)}}$$

Because distance and workload were held constant, time was the only variable measured. The elapsed time required to pedal five complete revolutions against a workload of 3kp on a Crescent Monark bicycle ergometer was recorded. After the command "ready" by the investigator, the subject, at his own discretion, pedaled the required number of revolutions as fast as possible and discontinued on the command "stop." The subject was allowed a one-half revolution rolling start in order to overcome the initial stages of inertia. The starting position for the bicycle ergometer test is illustrated in Figure 11.

A timing system composed of Data Cubes, one photocell unit, one light source, and one electric clock was used to measure elapsed time in the bicycle ergometer test. (The manufacturers of this equipment were noted in the discussion of the controlled speed measures.) A schematic diagram of

Figure 10

Ankle Plantar Flexion

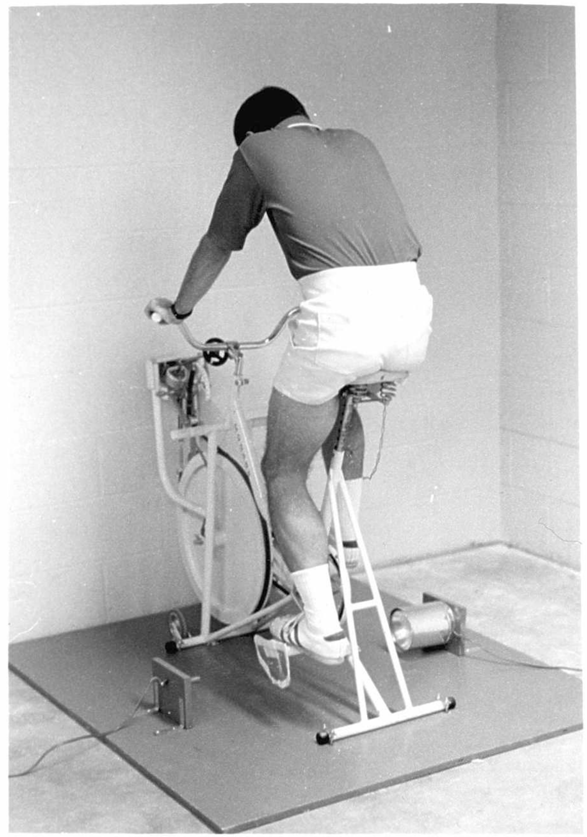


Figure 11

Bicycle Ergometer-Starting Position

the wiring procedure of the Data Cubes and associated components for the bicycle ergometer test is presented in Figure 17, Appendix B. The photocell, light source, and bicycle ergometer were attached to a 3/4 inch plywood section for stability. Figure 10 illustrates the equipment mounted on the plywood section. In addition, a metal strip was attached to the left pedal of the ergometer to aid in interrupting the light beam to the photocell.

From the starting position, the subject pedaled as quickly as possible until told to stop by the investigator. As the left pedal passed the bottom of its arc, it broke a light beam to the photocell. This break caused the electric clock to start. A pre-determined counter unit (Data Cube series), set to count five revolutions, was activated each time the metal strip on the left pedal broke the light beam on the photocell. When five revolutions of the pedal had been counted, the electric clock automatically switched off.

One warm-up trial was allowed at approximately 50 per cent of maximum effort, followed by three trials at maximum. Times were recorded to the last 1/1000th of a second. The subjects were measured in groups of approximately 20, with a rest period of 45-60 seconds allowed between trials.

The Margaria power index was developed by Margaria (1966) to calculate leg power. The leg power measurement was based on the formula:

$$P = \frac{W \times D}{T}$$

where P = power
W = body weight
D = vertical height run
T = time required to run vertical height

The elements of the formula were determined by measuring the elapsed time required to run up a flight of stairs. The subject began the test at a spot 36 inches behind the first step. He then proceeded to run as fast as possible up the stairs, stepping on every other step.

An Automatic Performance Analyzer, Model 631, manufactured by Dekan Timing Devices, Glen Ellyn, Illinois, was used to measure the time element of the Margaria power index. The device consisted of a timing unit and two switch mats. One switch mat was placed at the bottom of the steps and the other on the tenth step. By depressing the first switch mat, the timer was started. It was stopped when the switch mat on the tenth step was depressed. A moving start was allowed to minimize errors associated with a stationary start.

The vertical distance run in the test was 1.6 meters, which was used as a constant in the computation of each subject's power index score. Two warm-up trials at less than maximum effort were followed by three trials at maximum. Times were recorded to the last 1/100th of a second. The subjects were measured in groups of approximately 20, with a rest period of three to four minutes allowed between trials.

Control Variables

In addition to the various dependent and independent variables, selected anthropometric measures were recorded. The anthropometric measures were used to facilitate partialling in certain post hoc analyses. The following anthropometric measures were recorded for each of the subjects in this study:

1. Height
2. Weight
3. Age
4. Leg length
5. Thigh circumference
6. Calf circumference
7. Subscapular skinfold
8. Thigh skinfold
9. Anterior abdominal skinfold
10. Lateral abdominal skinfold
11. Maturity

Height was measured to the last one-half inch. Weight was measured to the last pound. Age was measured to the last month. Leg length was determined by subtracting sitting height from standing height and recorded to the last one-half inch. Thigh and calf circumference were measured at the approximate midpoints of each muscle group with a Lufkin cloth tape. Measurements were recorded to the last centimeter. The four skinfold measurements were determined with a Lange skinfold caliper with a pressure of ten grams per square millimeter applied to the skinfold. Skinfold sites measured were: (1) subscapular, at the inferior border of the scapula, (2) front thigh, at approximately the midpoint, (3) lateral abdomen, just above the iliac crest, and (4) anterior abdomen, in the general area of the umbilicus. The average of three pinches served as the measure for each site. Criteria were established for determining the maturity level of each subject. These criteria are presented in Appendix C.

Sample

The sample for this study consisted of 169 seventh and eighth grade male students who were regularly enrolled in physical education classes at Humble Middle School, Humble Independent School District, Humble, Texas. The subjects were randomly selected from five available sections of physical education. Two hundred subjects were originally selected, but 31 were deleted from the sample due to absenteeism or injury during the two week testing period. Subjects with obvious physical disabilities, such as debilitating injuries, atrophied limbs, etc., were excluded from the original sample of 200.

Testing Procedures

All the experimental tests in this study were individually administered to the subjects. Each test session began with a 60 second run-in-place by the group of subjects being tested that day. Following the warm-up, the tester demonstrated and verbally described the mechanics of the experimental test. There were multiple testing stations during each test session and as the subject completed one test battery he went to the next station.

Each of the five boys' physical education classes provided approximately 40 subjects for the sample. Due to time restrictions, the 40 subjects in each class could not be measured in one day on all items in a test session. For this reason each class was divided into two groups of 20. The day Group 1 was being tested, Group 2 was involved in its regular physical education class activities. The following day, Group 2 was tested and Group 1 had its regular physical education class.

In general, the subjects remained enthusiastic about the tests and appeared to exert maximum efforts until all the test variables had been administered. This was probably due to the age of the subjects in the sample, the novelty of the tests and the testing apparatus, and the method of testing the subjects on every other class day.

The tests were administered in five test sessions during a two week time period from May 6 to May 17, 1974. The tests in each session included:

Session I

1. Knee extension
2. Hip extension
3. Ankle plantar flexion
4. Bicycle ergometer

Session II

1. Margaria power index
2. Anthropometric measures

Session III

1. Sprint acceleration (0-10 yards)
2. Sprint velocity (10-30 yards)
3. Anthropometric measures (those not completed in Session II)

Session IV

1. Right boomerang
2. Vertical jump

Session V

1. Dodge run
2. Box jump

Analysis of Data

Statistical models used in the analysis of the data included analysis of variance, factor analysis, multiple regression analysis, and canonical correlation. The computer facilities at the University of Houston were used for all analyses.

The subjects included 169 seventh and eighth grade male students enrolled in the regular physical education classes at Humble Middle School, Humble, Texas. The human motor performance domains of leg strength and speed of body movement were determined for each subject by eleven experimental tests. The leg strength domain, dependent variables, was measured by tests of knee extension, hip extension, ankle plantar flexion, bicycle ergometer, and Margaria power index. The speed of body movement domain, independent variables, was measured by tests of sprint acceleration, sprint velocity, right boomerang, dodge run, box jump, and vertical jump.

In addition to the eleven experimental variables, selected anthropometric variables were also measured for each subject. These variables included height, weight, age, leg length, thigh circumference, calf circumference, subscapular skinfold, thigh skinfold, lateral abdominal skinfold, anterior abdominal skinfold, and a maturity assessment.

The objective of this study was to determine the relationship between the speed and strength domains. To obtain this objective, a systematic analytical approach was followed. The first step was to determine trend-free measurement schedules for the eleven experimental variables. As multiple trials had been administered for each of the experimental tests, this was a matter of eliminating those trials which were significantly different from the others in a given test.

The second step in the determination of the relationship between leg strength and speed of body movement was to analyze the raw score data. This analysis included the use of bivariate correlation, factor analysis, and canonical correlation.

In the review of literature it was noted that certain anthropometric measures often were highly related to motor performance. Therefore, the relationship between the eleven experimental and the eleven control variables selected for this study was determined. This analysis represented the third step in the over-all analysis.

If the relationship between the eleven experimental variables and the eleven control variables was significant, the removal of the common variance between the two sets of variables was warranted. The fourth step, then, in the determination of the relationship between leg strength and speed of body movement was the removal of the effects of the control variables from the experimental variables.

The fifth, and last, step in the determination of the relationship between the two domains under study was to analyze the data of the residualized experimental variables. This analysis included the use of bivariate correlation, factor analysis, canonical correlation, and multiple regression.

The following computer programs were utilized in the data analyses:

1. BMDO2V, Analysis of Variance for Factorial Design (Dixon, 1971)

2. FACTOR2, Alpha Factor Analysis (StatJob Summary, 1971)

3. FACTOR2, Principal Components Factor Analysis (StatJob Summary, 1971)

4. FINNVER4, Univariate and Multivariate Analysis of Variance, Covariance, and Regression (NYBMUL, 1968)

5. STEPREG1, Stepwise Regression Analysis (StatJob Summary, 1971)

Description of Dependent, Independent, and Control Variables

Because random errors of measurement tend to confuse the lawfulness that may exist in nature, the reduction of such errors is advocated. Nunnally (1967) indicated that reliability is dependent upon measurement error being slight. Since this investigation was concerned with the replicability of the results obtained, high reliability coefficients for each of the experimental variable criterion scores were deemed essential. As emphasized by Carlson and Kroll (1971), the importance of reliability cannot be minimized in any testing procedure. Therefore, a reliable criterion measure, one which maximized each subject's mean performance, was imperative.

Baumgartner (1969) suggested the use of the analysis of variance repeated measures design (Glass & Stanley, 1970) which was utilized in determining intraclass reliability estimates for each of the experimental variables in the present study. Significant to the estimation of intraclass reliability was the determination of the presence or absence of trial-to-trial trend for each of the experimental variables.

Trend-free measurements tend to reduce the number of random measurement errors, thereby creating high reliability coefficients. Fatigue and improvement, two inherent characteristics of motor performance tests, are considered measurement errors in the present study. The objective was to maximize the group performance on each of the experimental variables while minimizing the effects of improvement and fatigue. To aid in deriving trend-free measurements, multiple trials were administered for each of the eleven experimental variables.

The criterion score of each of the eleven experimental variables was determined in the following manner:

1. Lack of a significant trial effect resulted in the average of all trials being used as the criterion score. To test for trend, the formula;

$$F = \frac{MS_T}{MS_E}$$

as suggested by Alexander (1947) was used. A significant F value indicated trend. The reliability of each variable was calculated by the formula suggested by Baumgartner (1969);

$$R = \frac{MS_S - MS_E'}{MS_S}$$

where;

$$MS_E' = \frac{SS_E + SS_T}{DF_E + DF_T}$$

2. A significant trial effect resulted in an attempt to find a set of trials within the measurement schedule

which was trend-free. Tukey's (1953) method for judging contrasts was used in the search for trend-free trial clusters. If a trend-free cluster was found, reliability was calculated by the same formula as in the preceding item.

3. If a trend-free schedule could not be found, the technique described by Safrit (1973) and Baumgartner (1969) was applied. This technique, which used the average of all trials as the criterion score, was based on the following formula by Safrit (1973):

$$R = \frac{MS_S - MS'_E}{MS_S}$$

where,

$$MS'_E = \frac{SS_E}{DF_E}$$

This reliability formula uses an error term which compensates for significant trial-to-trial trend.

The computed F values for the trials selected (k') for use as criterion scores and the reliability estimates for the selected trials are presented in Table 8. All selected trials represent a consecutive block of trials for each experimental test.

Table 8

F Values and Intraclass Reliability Estimates for the Selected Schedule of Trials

Experimental Variable	Total Trials	k'	F-Ratio for Trend	R
Dependent Variables				
Knee extension	3	1-3	.063	.960
Hip extension	3	2-3	5.022	.987
Ankle plantar flexion	3	1-3	1.877	.952
Bicycle ergometer	3	2-3	3.567	.972
Margaria power index	3	1-3	61.369*	.968
Independent Variables				
Right Boomerang	3	2-3	.934	.942
Dodge run	3	2-3	4.313	.930
Sprint acceleration	3	1-3	1.493	.911
Sprint velocity	3	1-2	.187	.928
Box jump	10	2-10	1.179	.920
Vertical jump	6	1-4	3.535	.958

*$p < .05$

Trend-free measures were obtained for knee extension, ankle plantar flexion, and sprint acceleration for all trials administered. Hip extension, bicycle ergometer, right boomerang, dodge run, sprint velocity, box jump, and vertical jump were made trend-free by the elimination of selected trials. In one experimental variable, the Margaria power index, trend could not be elminiated regardless of the various trial combinations. By using Safrit's (1973) technique for computing reliability when trend is present, an R of .968 was obtained. Although trial effect could not be eliminated in the original block of three trials, the high reliability estimate indicated a consistent ordering of the scores. Obviously, the learning effect could not be overcome in this particular test with only three trials.

All trial means of the experimental variables are presented in Tables 26 and 27, Appendix D. The descriptive statistics for the eleven control and eleven experimental variables are presented in Table 9.

The variables were measured in a variety of ways. Knee extension, hip extension, and ankle plantar flexion scores were recorded in tension units, with a higher score representing a better performance. Bicycle ergometer, right boomerang, dodge run, sprint acceleration, sprint velocity, and box jump were timed measures, with a lower score representing a better performance. The Margaria power index was a result of the formula:

$$\text{Power} = \frac{\text{Weight X Distance}}{\text{Time}}$$

with a higher score representing a better performance. The vertical jump, height, and leg length were recorded in inches. Weight was recorded in pounds. Age was recorded in months. Thigh and calf circumferences were recorded in centimeters. All skinfold measures were recorded in millimeters. Maturity was scored as 0 for not meeting the established criteria and 1 if the criteria were met. The criteria for the maturity assessment are presented in Appendix C.

Table 9

Descriptive Statistics of the Eleven Experimental Tests

and Eleven Anthropometric Measures

Variable	Mean	Standard Deviation	Minimum	Maximum
	Dependent Variables			
Knee extension	30.376	7.238	15.000	57.300
Hip extension	46.240	9.212	26.500	74.500
Ankle plantar flexion	18.654	4.936	9.600	53.300
Bicycle ergometer	2.778	.449	1.985	4.932
Margaria power index	62.629	14.168	33.500	102.300
	Independent Variables			
Right boomerang	8.515	.586	7.079	10.485
Dodge run	8.122	.435	7.346	9.780
Sprint acceleration	1.804	.142	1.489	2.172
Sprint velocity	2.799	.260	2.150	3.564
Box jump	.242	.042	.160	.380
Vertical jump	16.364	2.719	9.200	24.700
	Control Variables			
Height	63.595	3.841	55.000	74.000
Weight	116.230	23.102	73.000	179.000
Age	166.570	9.138	136.000	198.000
Leg length	31.027	2.242	19.750	37.000
Thigh circumference	47.964	4.760	38.500	65.000
Calf circumference	32.962	3.040	24.500	43.000
Subscapular skinfold	8.237	5.163	3.000	31.000
Thigh skinfold	12.917	8.952	3.000	49.000
Lateral abdominal skinfold	13.367	9.033	3.000	43.000
Anterior abdominal skinfold	15.024	6.290	6.000	44.000
Maturity	.379	.486	.000	1.000

Analysis of Raw Scores of the Experimental Variables

The analyses of the raw score data included bivariate correlation, alpha factor analysis, and canonical correlation. Bivariate correlation provided knowledge of the relationships between each of the experimental variables. Alpha factor analysis determined the factor structure of the experimental variables. Canonical correlation analysis determined the relationship between linear combinations of the dependent variables (leg strength domain) and the independent variables (speed of body movement domain).

Bivariate correlation analysis. The intercorrelations among the eleven experimental variables are presented in Table 10. Calculation of the intercorrelations was through the FACTOR2 program of the StatJob Package (StatJob Summary, 1971). Appropriate significance levels were obtained through Fisher and Yates' table of critical values of the correlation coefficient (Fisher, 1925).

The experimental variables were highly interrelated as evidenced by the fact that all the correlation coefficients in Table 10 were significantly different from zero ($p < .05$). Although all the correlations were significant, the correlations within the domains of leg strength (dependent variables) and speed of body movement (independent variables) were generally higher than those between the two domains. This was an indication, although only superficial, that the human

Table 10

Table of Intercorrelations for the Eleven Experimental Variables

Variable	Variable Number 1	2	3	4	5	6	7	8	9	10	11
Dependent Variables											
1. Knee extension	1.000										
2. Hip extension	.693	1.000									
3. Ankle plantar flexion	.498	.396	1.000								
4. Bicycle ergometer	-.742	-.718	-.417	1.000							
5. Margaria power index	.802	.737	.477	-.800	1.000						
Independent Variables											
6. Right boomerang	-.356	-.314	-.211	.464	-.337	1.000					
7. Dodge run	-.385	-.356	-.246	.416	-.325	.753	1.000				
8. Sprint acceleration	-.577	-.527	-.342	.670	-.551	.693	.687	1.000			
9. Sprint velocity	-.548	-.475	-.306	.660	-.541	.673	.667	.878	1.000		
10. Box jump	-.309	-.221	-.316	.369	-.209	.372	.390	.502	.482	1.000	
11. Vertical jump	.526	.436	.304	-.595	.514	-.599	-.619	-.734	-.718	-.472	1.000

$p < .01$ for values of .254 or greater

$p < .05$ for values of .195 or greater

motor performance domains of leg strength and speed of body movement do exist (as indicated by the higher correlations within each hypothesized domain) and that they were related (as indicated by the significant correlations between the two hypothesized domains).

All negative values in Table 10 were the result of the correlation between timed and non-timed experimental variables. Therefore, only the magnitude of the coefficient was of importance.

Factor analysis of the dependent and independent variables. Factor analysis was used to analyze the raw data of the experimental variables. The purpose of this analysis was to determine if the hypothesized factor structure (see Figure 2, page 13) could be supported. The two hypothesized domains of human motor performance were leg strength and speed of body movement.

Alpha factor analysis (Kaiser & Caffey, 1965), with an orthogonal rotation to the varimax criterion (Kaiser, 1958), was used to examine the dimensionality of the dependent and independent variables. The FACTOR2 program of the StatJob package (StatJob Summary, 1971) was utilized for this calculation. The factor loadings for the rotated factor matrix are presented in Table 11. Factor loadings of .400 or above are underlined for reference. The unrotated factor matrix is presented in Table 28, Appendix D.

Table 11

Factor Loadings of the Eleven Experimental Variables, Raw Scores, Using Alpha Factor Analysis and Varimax Rotation

Experimental Variable	Rotated Factors 1	2	h^2
Dependent Variables			
Knee extension	-.285	.842	.790
Hip extension	-.232	.753	.620
Ankle plantar flexion	-.217	.477	.274
Bicycle ergometer	.416	-.768	.763
Margaria power index	-.202	.903	.857
Independent Variables			
Right boomerang	.788	-.151	.644
Dodge run	.791	-.168	.654
Sprint acceleration	.819	-.417	.845
Sprint velocity	.800	-.384	.788
Box jump	.485	-.224	.285
Vertical jump	-.718	.374	.656
Per cent of total variance	33.7	31.6	

Two common factors accounted for 65.2 per cent of the total variance. Factor 1 accounted for 33.7 per cent of the variance and was represented primarily by the speed of body movement variables. Factor loadings of above .400 were indicated for the variables right boomerang, dodge run, sprint acceleration, sprint velocity, box jump, vertical jump, and bicycle ergometer. Factor 2 accounted for 31.6 per cent of the variance and was represented primarily by the leg strength variables. Factor loadings of above .400 were indicated for the variables knee extension, hip extension, ankle plantar flexion, bicycle ergometer, Margaria power index, and sprint acceleration.

In Factor 1, sprint acceleration and sprint velocity were the highest loading variables. Each of the other speed of body movement variables, with the exception of the box jump, also produced relatively high loadings on this factor.

The Margaria power index and knee extension variables produced the highest factor loadings on Factor 2. All the other leg strength variables also loaded above .400 on this factor, with ankle plantar flexion producing the lowest loading.

Two variables, bicycle ergometer and sprint acceleration, loaded above .400 on both derived factors. Both variables loaded highest in the factors they were hypothesized to be in. However, the loading on both factors by the two variables was an indication of some amount of commonality between these two variables.

In general, the results of the alpha factor analysis of the raw data of the dependent and independent variables confirmed the hypothesized factor structure of leg strength and speed of body movement. These results also tend to support previous research reported in the review of literature.

<u>Canonical analysis of the dependent and independent variables</u>. Canonical variate analysis (Cooley & Lohnes, 1966) provides a multivariate test to determine the independence

of the two sets of variables, the dependent variables (leg strength) and the independent variables (speed of body movement). Canonical analysis provides knowledge of which dependent variables are associated with the independent variables through the determination of the linear combinations of the two sets of variables.

The alpha factor analysis of the raw experimental variable data revealed two orthogonal factors (see Table 11, page 67). The variables of the independent set represented one derived factor, while the variables of the dependent set represented the other derived factor. The objective of this portion of the data analysis was to determine if a significant relationship existed between the raw score data of the two sets of variables. The FINNVER4 program (NYBMUL, 1968) was used for the canonical analysis.

The first canonical correlation coefficient calculated was .7167, which was significantly different from zero (chi square = 146.918, df = 30, $p < .0001$). A linear combination of dependent variables (leg strength) was significantly correlated with a linear combination of independent variables (speed of body movement). The standardized vector weights of each experimental variable are presented in Table 12.

Table 12

First Canonical Correlation Coefficient and Accompanying Vector Weights of the Leg Strength and Speed of Body Movement Variables, Raw Scores

(Canonical Variate One = .7167*)

Dependent Variables (Leg Strength)	Standardized Weights	Independent Variables (Speed of Body Movement)	Standardized Weights
Knee extension	.257	Right boomerang	.017
Hip extension	-.031	Dodge run	.203
Ankle plantar flexion	.043	Sprint acceleration	-.534
Bicycle ergometer	-.848	Sprint velocity	-.368
Margaria power index	-.060	Box jump	-.031
		Vertical jump	.314

*$p < .0001$

The standardized weights presented in Table 12 indicated that sprint acceleration and sprint velocity were the speed of body movement variables most associated with the leg strength variables as a group. The bicycle ergometer was the leg strength variable most associated with the speed of body movement variables as a group. In addition, knee extension, although of considerably less magnitude than the bicycle ergometer, was the only other leg strength variable associated with the speed of body movement variables as a group. The vertical jump, and, to a lesser degree, the dodge run, were speed of body movement variables that also indicated an association to the leg strength variables as a group.

The second canonical correlation coefficient was calculated to be .3280, which was not significantly different from zero (chi square = 30.1202, df = 20, $p > .05$). Because this canonical correlation coefficient was not significant, all other correlations were also non-significant. Therefore, the two sets of variables were significantly related in only one way and the remaining variance was random.

The hypothesis of this study was: There will be a significant relation between a linear combination of dependent variables (leg strength) and a linear combination of independent variables (speed of body movement). This hypothesis is supported on the basis of the significant correlation of the first canonical variate for the raw data of the experimental variables.

Relationship of the Control Variables to the Dependent and Independent Variables

To determine the relationship between the control variables and the dependent and independent variables, bivariate correlation analysis, alpha factor analysis, and principal components factor analysis was applied to the data. Bivariate correlation provided knowledge of the relationships (1) between the control variables and the experimental variables, and (2) within the control variables. Alpha factor analysis determined the factor structure of the control variables. Principal components analysis was used in the derivation of factor scores for each of the derived factors.

<u>Bivariate correlation analysis</u>. Presented in Table 13 are the intercorrelations among the eleven control variables. The FACTOR2 program of the StatJob package (StatJob Summary, 1971) was used in this calculation. Appropriate significance levels were obtained through Fisher and Yates' table of critical values of the correlation coefficient (Fisher, 1925).

Of the correlation coefficients presented in Table 13, 53 of the 66 coefficients were significantly different from zero ($p < .05$). The skinfold measures accounted for 10 of the 13 non-significant coefficients, while the maturity measure accounted for the other three.

The correlations between the eleven control and eleven experimental variables are presented in Table 14. They were calculated in the same manner as the preceding correlations.

Correlations between the control variables and the experimental variables indicated that 89 of the 121 possible correlations were significantly different from zero ($p < .05$). Several patterns appeared to emerge in the various significant correlations between the control and experimental variables. Of the control variables, height, weight, thigh circumference, and calf circumference indicated the highest correlations with the leg strength variables. Age, leg length, and maturity were somewhat equally distributed in regard to the magnitude of the correlations across all eleven experimental variables. The four skinfold measures correlated most highly with the speed of body movement variables.

Table 13

Table of Intercorrelations for the Eleven Control Variables

Variable	Variable Number 1	2	3	4	5	6	7	8	9	10	11
1. Height	1.000										
2. Weight	.748	1.000									
3. Age	.480	.351	1.000								
4. Leg length	.883	.547	.403	1.000							
5. Thigh circumference	.519	.889	.244	.324	1.000						
6. Calf circumference	.549	.875	.262	.365	.885	1.000					
7. Subscapular skinfold	-.024	.477	.013	-.096	.597	.502	1.000				
8. Thigh skinfold	-.060	.410	-.044	-.087	.557	.432	.844	1.000			
9. Lateral abd. skinfold	-.032	.451	.011	-.069	.592	.456	.821	.938	1.000		
10. Anterior abd. skinfold	-.266	.232	-.169	-.241	.424	.355	.770	.817	.802	1.000	
11. Maturity	.653	.557	.431	.497	.418	.408	-.015	-.088	-.039	-.242	1.000

$p < .01$ for values of .254 or greater

$p < .05$ for values of .195 or greater

Table 14

Table of Correlations Between the Eleven Experimental and Eleven Control Variables

Control Variables	Experimental Variables 1	2	3	4	5	6	7	8	9	10	11
Height	.665	.609	.446	-.732	.768	-.288	-.347	-.493	-.504	-.278	.467
Weight	.720	.657	.505	-.712	.892	-.052	-.055	-.264	-.277	-.060	.263
Age	.308	.302	.282	-.416	.383	-.201	-.250	-.325	-.370	-.137	.327
Leg length	.487	.498	.372	-.587	.560	-.344	-.409	-.407	-.386	-.275	.354
Thigh circumference	.633	.522	.423	-.581	.743	.067	.071	-.123	-.122	.033	.174
Calf circumference	.612	.508	.426	-.632	.735	.013	.061	-.168	-.168	.009	.252
Subscapular skinfold	.135	.096	.120	-.064	.245	.345	.378	.350	.335	.296	-.317
Thigh skinfold	.074	.052	.046	.018	.178	.404	.397	.410	.404	.362	-.352
Lateral abd. skinfold	.119	.067	.096	-.027	.227	.398	.388	.355	.377	.297	-.316
Anterior abd. skinfold	-.100	-.080	-.069	.193	-.021	.445	.466	.527	.538	.419	-.481
Maturity	.557	.549	.386	-.593	.671	-.316	-.356	-.545	-.523	-.242	.508

1 = Knee extension
2 = Hip extension
3 = Ankle plantar flexion
4 = Bicycle ergometer
5 = Margaria power index
6 = Right boomerang
7 = Dodge run
8 = Sprint acceleration
9 = Sprint velocity
10 = Box jump
11 = Vertical jump

$p < .01$ for values of .254 or greater

$p < .05$ for values of .195 or greater

Over-all performance on the eleven experimental variables, therefore, was highly related to the amount of each of the control variables possessed by each subject. Performance on the leg strength variables apparently was most effected by the control variables associated with growth and developmental aspects. Because strength is directly related to muscle mass and lever length, this was a biomechanically supportable finding (DeVries, 1971).

The speed of body movement variables appeared to be most related to the four skinfold measures. The positive correlations between skinfold scores and body speed times indicated that higher body fat was related to slower movement times. Speed of body movement was partially predicted, then, by the amount of fat on the body.

This evidence of high relation between motor performance and the anthropometric measures associated with growth and development and body fat supports similar results reported by Espenchade (1940), Eckert (1965), Fleishman (1965), and the AAHPER (1965) and Texas (1973) tests of physical fitness and motor ability. Scores based on age, weight, and sex were used in constructing the norms for the fitness tests.

The significance of the high degree of relationship exhibited between the experimental and control variables lies in the fact that the significant canonical correlation calculated for the raw scores (see Table 12, page 70) may have been due to that variance shared by both domains with the control variables. The following analysis was directed to the identification and removal of the variance common to the experimental and control variables, and to a re-examination of the relationship between the modified dependent and independent variables.

Factor analysis of the control variables. As the control and experimental variables were obviously highly related, factor analysis was used to identify the factor structure of the control variables. Alpha factor analysis (Kaiser & Caffey, 1965), with an orthogonal rotation to the varimax criterion (Kaiser, 1958), was used to examine the dimensionality of the control variables. The FACTOR2 program of the StatJob package (StatJob Summary, 1971) was utilized for this calculation. The factor loadings for the rotated factor matrix are presented in Table 15. Factor loadings of .400 or above are underlined for reference. The unrotated factor matrix is presented in Table 29, Appendix D.

Two common factors accounted for 73.2 per cent of the total variance. Factor 1 accounted for 39.1 per cent of the variance and was represented by the four skinfold measures, which loaded only on this factor, and by weight, thigh circumference, and calf circumference, each of which loaded on both derived factors. The identifying and common element to this factor appeared to be body fat. Obviously, the skinfold variables were measures of body fat, but each of the other

Table 15

Alpha Factor Analysis of the Control Variables,

Rotated Orthogonal Factor Matrix

Control Variable	Rotated Factors 1	2	h^2
1. Height	-.059	.962	.929
2. Weight	.514	.816	.931
3. Age	-.043	.510	.262
4. Leg length	-.111	.744	.565
5. Thigh circumference	.677	.610	.829
6. Calf circumference	.565	.626	.711
7. Subscapular skinfold	.886	.035	.787
8. Thigh skinfold	.928	-.040	.864
9. Lateral abdominal skinfold	.916	.015	.839
10. Anterior abdominal skinfold	.869	-.239	.812
11. Maturity	-.059	.725	.529
Per cent of total variance	39.1	34.1	

variables that loaded on this factor were also at least partial measures of body fat. Body weight is partially composed of fat. Thigh and calf circumference were measures of bone, muscle mass, and fat at the specific measurement sites. Because circumference measures were not fine enough to distinguish between the three components, they loaded on the factor attributed to body fat. Factor 1 of the control variables, therefore, was named body fat.

Factor 2 accounted for 34.1 per cent of the variance and included height, age, leg length, and maturity, each of which loaded only on this factor. Weight, thigh circumference, and calf circumference loaded on both derived factors. As discussed in regard to Factor 1, these three control variables had components common to both derived factors. The circumference measures loaded similarly on both factors, while weight loaded considerably higher on Factor 2. The control variables to load on the second derived factor were all, in some respect, related to growth and development characteristics. Therefore, Factor 2 of the control variables was named maturity.

The factors derived from the control variables retained the high degree of relationship with the experimental variables. This degree of relationship was essentially the same as that expressed in the correlations between the experimental and control variables (see Table 14, page 74). Therefore, Factor 1 (body fat) and Factor 2 (maturity) were deemed important in explaining the performance of each subject on each of the experimental variables.

The body fat measures, which included the four skinfold variables, weight, and the two leg circumference variables, were detriments to high performance levels on the experimental variables. It was obvious (see Table 14, page 74) that all the body fat items had definite negative relationship to the speed of body movement variables (i.e., the more body fat, the poorer were the times for the speed of body movement measures). The greater the weight and leg circumference measures, the better performance was on the leg strength variables. Greater mass in the equation:

$$\text{Force} = \text{Mass X Acceleration}$$

resulted in better performance on the leg strength variables.

The maturity measures of height, weight, age, leg length, thigh circumference, calf circumference, and maturity were important because the greater the amounts of these items possessed by the subject, the better his performance was on both the leg strength and speed of body movement variables. The age range of the selected sample was such that the subjects had varying amounts of the maturity components. That is, the older subjects possessed more of the maturity components than the younger subjects, and therefore, had a better chance of achieving a high performance level on the experimental variables.

Because the purpose of this study was to determine the relationship between leg strength and speed of body movement, the elimination of such extraneous items as body fat and maturity allowed for a more accurate assessment of the relationship. Therefore, Factor 1 (body fat) and Factor 2 (maturity) were statistically removed from the experimental variables in anticipation of obtaining less contaminated results than those obtained through the analysis of the raw score data.

Incomplete principal components analysis. To further validate the factor structure of the control variables derived through alpha factor analysis, incomplete principal components analysis (Cooley & Lohnes, 1966) was applied to the control variable data. In addition, calculated factor scores could also be derived through this analysis for use in the residualization of experimental variables. The FACTOR2 program of the StatJob package (StatJob Summary, 1971) was utilized for this calculation. The factor loadings for the rotated factor matrix are presented in Table 16. Factor loadings of .400 or above are underlined for reference. The unrotated factor matrix is presented in Table 30, Appendix D.

Table 16

Incomplete Principal Components Analysis of the Control Variables, Rotated Orthogonal Factor Matrix

Control Variable	Rotated Factors 1	Rotated Factors 2	h^2
1. Height	-.054	.941	.889
2. Weight	.510	.814	.923
3. Age	-.067	.596	.359
4. Leg length	-.130	.806	.666
5. Thigh circumference	.684	.626	.859
6. Calf circumference	.584	.663	.781
7. Subscapular skinfold	.914	.028	.837
8. Thigh skinfold	.940	-.043	.886
9. Lateral abdominal skinfold	.935	.005	.874
10. Anterior abdominal skinfold	.888	-.238	.846
11. Maturity	-.074	.779	.612
Per cent of total variance	40.7	36.8	

The results of the incomplete principal components analysis confirmed the factors identified by the alpha factor analysis. Two common factors accounted for 77.5 per cent of the total variance. Factor 1 (body fat) accounted for 40.7 per cent of the variance and was represented by the four skinfold measures, which loaded only on this factor, and by weight and the two leg circumference measures, each of which loaded on both derived factors. Factor 2 (maturity) accounted for 36.8 per cent of the variance and was represented by height, age, leg length, and maturity, each of which loaded only on this factor, and by the three measures which loaded on both derived factors.

A comparison of the results produced by the alpha factor analysis (see Table 15, page 77) and the incomplete principal components analysis of the control variable data indicated almost identical results. As previously stated, one of the purposes in applying the incomplete principal components procedure to the data was to derive factor scores for the control variables. The factor scores were used in the computation of the experimental variables' residual scores.

Residualization of the Dependent and Independent Variables

DuBois (1965) indicated that residualization is a statistical method of controlling, by elimination or reduction, the influence of extraneous variables. Because of the high degree of relationship between the control and experimental variables, the common variance between the two sets of variables was residualized from the experimental variables through the following procedure:

1. Through the incomplete principal components procedure (Cooley & Lohnes, 1966), factor scores were derived for the eleven control variables. Factor scores are numerical values assigned to each subject in the sample for each factor derived through factor analysis. Factor scores are orthogonal and, therefore, uncorrelated. Morrison (1967) and Nunnally (1967) provide excellent descriptions of factor scores and their use in investigations concerning correlations among sources of individual differences.

2. Using the derived factor scores of the control measures as independent variables and the eleven experimental measures as dependent variables, a stepwise regression analysis was conducted. For this procedure, the STEPREG1 program of the StatJob package (StatJob Summary, 1971) was used. Appropriate significance levels were obtained through Fisher and Yates' table of critical values of the correlation coefficient (Fisher, 1925). By regressing the independent variables (factor scores of the control variables) on each of the dependent variables (the eleven experimental tests), a residual score for each subject on each experimental test was computed. In effect, the residual scores derived for each subject on each of the eleven experimental tests represented the variance unique to the experimental variables.

That portion of the variance accounted for by the control variables was removed. The correlations between each of the experimental variables and the factor scores derived from the control variables, as well as the multiple correlation coefficients,are presented in Table 17.

Table 17

Table of Correlations Between the Experimental Variables and the Derived Factor Scores of the Control Variables

Experimental Variable	Factors FS1 (Body Fat)	FS2 (Maturity)	Mult. R
Dependent Variables			
Knee extension	.215	.733	.740
Hip extension	.136	.676	.680
Ankle plantar flexion	.122	.518	.526
Bicycle ergometer	-.086	-.802	.803
Margaria power index	.478	.873	.881
Independent Variables			
Right boomerang	.433	-.359	.524
Dodge run	.466	-.407	.568
Sprint acceleration	.468	-.601	.677
Sprint velocity	.472	-.606	.681
Box jump	.360	-.300	.446
Vertical jump	-.391	.569	.630

$p < .01$ for values of .254 of greater

$p < .05$ for values of .195 or greater

Correlations between FS1 (body fat) and the experimental variables indicated that this factor was more generally related to the speed of body movement variables than to the leg strength variables. This finding supported the alpha factor analysis results (see Table 15, page 77) and the results of the bivariate correlation analysis between the experimental and control variables (see Table 14, page 74). Because both body fat and body speed were measured with lower scores representing less fat and more speed, respectively, the magnitude of the correlation coefficients indicated a high relationship.

FS2 (maturity) was significantly correlated with all the experimental variables, but the highest correlations were between FS2 and the leg strength measures. Again, the results of the previous factor analysis and bivariate correlations of the control variables were supported. The more physically developed (mature) the subject was, the better his performance on the leg strength measures. The significant correlations with the speed of body movement variables indicated that maturity was also a definite influence on speed performance.

Analysis of the Residualized Experimental Variables

The analyses of the residualized experimental variables included bivariate correlation, alpha factor analysis, canonical correlation, and multiple regression. With the effects of body fat and maturity removed from the scores, it was hoped that clearer results would occur.

Bivariate correlation analysis. The intercorrelations among the eleven residualized experimental variables are presented in Table 18. They were calculated through the FACTOR2 program of the StatJob package (StatJob Summary, 1971). Appropriate significance levels were obtained through Fisher and Yates' table of critical values of the correlation coefficient (Fisher, 1925).

As in the bivariate correlation of the raw experimental variables (see Table 10, page 65), the variables in the present analysis were also highly inter-related. However, 14 of the 66 possible correlations were not significantly different from zero ($p < .05$). In addition, there was a general lowering in magnitude of the correlation coefficients. No clear pattern emerged between and among the dependent and independent variables in this analysis. Rather, the correlations between and among the dependent and independent variables were relatively similar. The most notable observation was the lack of significant relationships demonstrated by the leg strength variable ankle plantar flexion and the speed of body movement variable box jump. Ankle plantar flexion significantly correlated ($p < .05$) only with the box jump, while the box jump correlated with three of the leg strength variables and only two of the speed of body movement variables. This was an indication of the possible independence of these two variables.

Table 18

Intercorrelations of the Eleven Experimental Variables with

the Eleven Control Variables Partialled Out

Variable	Variable Number										
	1	2	3	4	5	6	7	8	9	10	11
Dependent Variables											
1. Knee extension	1.000										
2. Hip extension	.386	1.000									
3. Ankle plantar flexion	.191	.061	1.000								
4. Bicycle ergometer	-.382	-.400	.001	1.000							
5. Margaria power index	.482	.415	.040	-.396	1.000						
Independent Variables											
6. Right boomerang	-.313	-.216	-.118	.439	-.412	1.000					
7. Dodge run	-.332	-.253	-.146	.296	-.328	.650	1.000				
8. Sprint acceleration	-.473	-.360	-.156	.564	-.532	.562	.520	1.000			
9. Sprint velocity	-.406	-.266	-.102	.531	-.499	.542	.517	.769	1.000		
10. Box jump	-.259	-.100	-.272	.302	-.143	.181	.185	.321	.289	1.000	
11. Vertical jump	.355	.189	.094	-.393	.398	-.435	-.437	-.539	-.519	-.298	1.000

$p < .01$ for values of .254 or greater

$p < .05$ for values of .195 or greater

Factor analysis of the dependent and independent variables. Factor analysis was used to analyze the residualized scores of the experimental variables. The purpose of this analysis was to determine if the hypothesized factor structure (see Figure 2, page 13) could be supported by the residualized experimental variables. Alpha factor analysis (Kaiser & Caffey, 1965), with an orthogonal rotation to the varimax criterion (Kaiser, 1958) was used to examine the dimensionality of the dependent and independent variables. The FACTOR2 program of the StatJob package (StatJob Summary, 1971) was used in this calculation. The factor loadings for the rotated factor matrix are presented in Table 19. Factor loadings of .400 or above are underlined for reference. The unrotated factor matrix is presented in Table 31, Appendix D.

Three common factors were derived in this analysis and accounted for 47.7 per cent of the total variance. Although the factor structure was not as clearly defined as the original factor analysis of the experimental variables (see Table 11, page 67), the results were highly consistent with the bivariate correlation findings of the residualized experimental variables (see Table 18, page 86).

Factor 1 accounted for 24.0 per cent of the variance and was comprised of all the speed of body movement variables with the exception of the box jump. In addition, the leg

Table 19

Factor Loadings of the Eleven Experimental Variables, Residual Scores, Using Alpha Factor Analysis

Experimental Variable	Rotated Factors 1	2	3	h^2
Dependent Variables				
Knee extension	-.239	.568	-.304	.472
Hip extension	-.122	.595	-.042	.370
Ankle plantar flexion	-.052	.013	-.480	.233
Bicycle ergometer	.409	-.520	.079	.445
Margaria power index	-.366	.607	-.018	.503
Independent Variables				
Right boomerang	.756	-.184	.088	.613
Dodge run	.659	-.170	.158	.489
Sprint acceleration	.665	-.476	.229	.721
Sprint velocity	.695	-.376	.154	.648
Box jump	.195	-.147	.538	.349
Vertical jump	-.544	.271	-.200	.409
Per cent of total variance	24.0	16.7	7.0	

strength variable bicycle ergometer also loaded on this factor. Factor 2 accounted for 16.7 per cent of the variance and consisted of all the leg strength variables except ankle plantar flexion. The speed of body movement variable sprint acceleration also loaded on this factor. Factor 3 accounted for 7.0 per cent of the variance and was represented by two measures, one from each of the two human motor performance domains under study. This factor was evidently somewhat task specific. The variables included in Factor 3 were ankle plantar flexion and the box jump.

In comparing the results of the alpha factor analysis of the raw scores of the experimental variables and the analysis of the residualized scores, it was noted that the only basic difference was the forming of a third factor by the task specific items (ankle plantar flexion and box jump) in the latter analysis. The first two factors in both analyses were otherwise similar, although the factor loadings and per cents of variance accounted for were lower in the analysis of the residualized data. This lowering effect was due to the removal of that portion of the variance accounted for by the control variables. Therefore, the factor analysis of the residualized experimental variables may represent a more accurate description of the human motor performance domains of leg strength and speed of body movement than did the factor analysis of the raw scores.

Based on the results of the alpha factor analysis of the residualized experimental variables, the hypothesized factor structure of the domains under study (see Figure 2, page 13) was again confirmed. Previous research reported in the review of literature was also supported by these results.

<u>Canonical analysis of the dependent and independent variables</u>. Following the derivation of three orthogonal factors through alpha factor analysis of the residualized experimental variables, canonical analysis was applied to the data. The same procedures as previously discussed (see page 68) were

used in this analysis. The basic objective of this analysis was to determine if a significant relationship existed between the residualized leg strength variables and the residualized speed of body movement variables.

The value of the first canonical correlation coefficient was .7327, which was significantly different from zero (chi square = 150.213, df = 30, $p < .0001$). Table 20 presents the standardized weights for each of the variables in the first correlation.

Table 20

First Canonical Correlation Coefficient and Accompanying Vector Weights of the Leg Strength and Speed of Body Movement Variables, Residual Scores

(Canonical Variate One - .7327*)

Dependent Variables (Leg Strength)	Standardized Weights	Independent Variables (Speed of Body Movement)	Standardized Weights
Knee extension	.211	Right boomerang	-.267
Hip extension	-.076	Dodge run	.117
Ankle plantar flexion	.192	Sprint acceleration	-.508
Bicycle ergometer	-.617	Sprint velocity	-.256
Margaria power index	.434	Box jump	-.164
		Vertical jump	.153

*$p < .0001$

The standardized weights presented in Table 20 indicated that sprint acceleration, followed by the right boomerang and sprint velocity, were the speed of body movement variables most associated with the leg strength variables as a group. The bicycle ergometer and the Margaria power index were the leg strength variables most associated with the speed of body movement variables as a group.

The second canonical correlation coefficient was calculated to be .2934, which was not significantly different from zero (chi square = 25.524, df = 20, $p > .05$). Because this correlation was not significant, all other canonical correlations were also non-significant. Therefore, the two sets of variables were significantly related in only one way and the remaining variance was random.

A comparison of the weights obtained for the variables in canonical correlation analyses of the raw data (see Table 12, page 70) and the residualized data indicated several obvious differences. In the leg strength domain, the bicycle ergometer lost in magnitude, but was still the highest variable in the set. The most notable increase was that of the Margaria power index. In the speed of body movement domain, sprint acceleration retained the highest weighting in the set. The right boomerang gained, while the vertical jump lost in magnitude.

The results of the canonical correlation analysis of the residualized experimental variables strengthened the previous rejection of the null hypothesis of this study. The canonical correlation of the raw data was significant, but it was not known whether this was due to an actual relation between leg strength and speed of body movement or if it was due to unknown individual differences within the sample. The canonical correlation of the residualized data indicated the existence of a significant relationship between the leg strength and speed of body movement domains, with the individual differences due to body fat and maturity held constant.

Multiple regression analysis of the dependent and independent variables. To further analyze the relationships between the dependent variables (leg strength) and independent variables (speed of body movement), multiple regression analysis (Kerlinger & Pedhazur, 1973) was used. Because there were a number of significant correlations among both the dependent and independent variables, the use of either set as a series of criterion variables in regression analysis would violate the statistical assumption of independence. To avoid violation of this assumption, orthogonal factor scores were derived by a complete principal components analysis of the residualized experimental variables. FACTOR2 of the StatJob package (StatJob Summary, 1971) was used in this computation.

The principal components factor analysis program was forced to override the standard eigenvalues by calling for the identical number of factors as number of variables input. As a result, the eigenvalue for inclusion was reduced to zero and orthogonalized factor scores for all of the dependent and independent variables were generated.

Factor loadings for the rotated factor matrix for the dependent variables are presented in Table 21 and for the independent variables in Table 22. The highest factor loading in each factor is underlined for reference. The unrotated factor matrices are presented in Tables 32 and 33, Appendix D.

Table 21

Factor Loadings of the Leg Strength (Dependent) Variables, Residual Scores, Using Complete Principal Components Analysis with Varimax Rotation

Dependent Variable	Rotated Factors 1	2	3	4	5	h^2
Knee extension	.083	.148	.178	-.139	.959	1.000
Hip extension	.011	.962	.132	-.188	.146	1.000
Ankle plantar flexion	.996	.010	-.041	.016	.074	1.000
Bicycle ergometer	.018	-.190	-.159	.959	-.139	1.000
Margaria power index	-.046	.132	.961	-.158	.176	1.000
Per cent of total variance	20.0	20.0	20.0	20.0	20.0	

Table 22

Factor Loadings of the Speed of Body Movement (Independent) Variables, Residual Scores, Using Complete Principal Components Analysis with Varimax Rotation

Independent Variable	Rotated Factors 1	2	3	4	5	6	h^2
Right boomerang	-.186	.062	.885	.299	.213	.206	1.000
Dodge run	-.222	.064	.302	.883	.194	.196	1.000
Sprint acceleration	-.202	.148	.234	.220	.367	.836	1.000
Sprint velocity	-.199	.128	.228	.207	.856	.340	1.000
Box jump	-.120	.980	.051	.052	.094	.101	1.000
Vertical jump	.927	-.141	-.168	-.197	-.168	-.161	1.000
Per cent of total variance	17.3	17.1	16.9	16.7	16.5	15.5	

Each of the derived factors in Tables 21 and 22 were primarily characterized by only one of the experimental variables (i.e., Factor 1 in Table 21 was obviously best represented by only one variable, ankle plantar flexion, which loaded .996). Although each derived factor was represented primarily by only one of the experimental variables, the fact that small loadings did occur for the other variables in each factor indicated that the forced factors were slightly different from the experimental variables. Because each derived factor was best represented by each of the experimental variables, the factors were named for the experimental variable that loaded highest on that factor.

To lend interpretation and support to the canonical correlation analysis, the two sets of orthogonalized variables were analyzed with multiple regression in both directions. In the first analysis, the independent variables were the speed of body movement measures and the dependent variables were the leg strength measures. The second analysis utilized the leg strength measures as independent variables and the speed of body movement measures as dependent variables. The multiple correlation coefficients of the first analysis are presented in Table 23.

Using the six complete principal component factors derived from the speed of body movement variables to predict each of the leg strength variables, the highest obtained multiple correlation was .540 ($p < .001$). This coefficient represented the relationship between the speed of body movement variables and the Margaria power index. Speed of body movement variables included in this relationship and their order of inclusion in the regression equation were: sprint acceleration, vertical jump, right boomerang, sprint velocity, and box jump. A multiple correlation coefficient of .502 ($p < .001$) was obtained for the speed of body movement variables and the bicycle ergometer variables. Speed of body movement variables included in this relationship and their order of inclusion in the regression equation were: box jump, sprint acceleration, vertical jump, and dodge run.

Multiple correlations between the speed of body movement variables and two of the leg strength variables, knee extension, hip extension, and ankle plantar flexion, each resulted in significant correlations, but the coefficients were relatively low and included no more than any two speed of body movement variables in the regression equations. The multiple correlation between the speed of body movement variables and hip extension was not significant ($F = 1.92$; $df = 6$ & 162; $p > .05$). Conversely, the regression equations between the Margaria power index and bicycle ergometer and the independent variables included four and five speed of body movement variables, respectively.

The leg strength variables Margaria power index and bicycle ergometer, therefore, were the measures best predicted by the speed of body movement variables as a group. This finding supports the results of the canonical correlation of the residualized experimental variables in which the leg strength variables were best represented by the bicycle ergometer and the Margaria power index.

Table 23

Multiple Correlation Coefficients of Speed of Body Movement Variables with Individual Leg Strength Variables

Step	Independent Variables (Speed of Body Movement)	Std. Reg. Coeff.	R	R^2	Change in R^2	Sign. Level
Factor 1: Knee Extension (F = 3.23; p < .005)						
1	4	-.192	.192	.037	.037	.012
2	4,6	-.172	.258	.066	.030	.023
3	4,6,2	-.127	.287	.083	.016	.091
4	4,6,2,1	.096	.303	.092	.009	.198
5	4,6,2,1,5	-.093	.317	.101	.009	.211
6	4,6,2,1,5,3	-.079	.327	.107	.006	.290
Factor 3: Ankle Plantar Flexion (F = 2.72; p< .015)						
1	2	-.246	.246	.060	.060	.001
2	2,4	-.133	.280	.078	.018	.076
3	2,4,3	-.076	.290	.084	.006	.307
4	2,4,3,6	-.076	.300	.090	.006	.309
5	2,4,3,6,5	.039	.302	.091	.001	.603
6	2,4,3,6,5,1	.016	.303	.092	.001	.830
Factor 4: Bicycle Ergometer (F = 9.09; p < .001)						
1	5	.271	.271	.073	.073	.001
2	5,3	.252	.370	.137	.064	.001
3	5,3,6	.252	.448	.201	.064	.001
4	5,3,6,2	.189	.486	.236	.036	.006
5	5,3,6,2,1	-.105	.497	.247	.011	.126
6	5,3,6,2,1,4	.067	.502	.252	.004	.325
Factor 5: Margaria Power Index (F = 11.12; p < .001)						
1	3	-.293	.293	.086	.086	.001
2	3,6	-.274	.401	.161	.075	.001
3	3,6,1	.265	.481	.231	.070	.001
4	3,6,1,4	-.187	.516	.266	.035	.006
5	3,6,1,4,5	-.160	.540	.292	.026	.016
6	3,6,1,4,5,2	.007	.540	.292	.000	.920

1 = Right boomerang
2 = Dodge run
3 = Sprint acceleration
4 = Sprint velocity
5 = Box jump
6 = Vertical jump

In the second multiple regression analysis, the independent variables were the leg strength measures and the dependent variables were the speed of body movement variables. The resulting multiple correlation coefficients of this analysis are presented in Table 24.

The highest multiple correlation coefficient obtained when the complete principal component factors derived from the leg strength variables were used to predict each of the speed of body movement variables was .472 ($p < .001$). This coefficient represented the relationship between the leg strength variables and the sprint acceleration variable. Leg strength variables included in this relationship and their order of inclusion in the regression equation were: ankle plantar flexion, bicycle ergometer, hip extension, and Margaria power index.

The remainder of the multiple correlations in this analysis were characterized by individual leg strength variables which were not significantly correlated with more than any two of the speed of body movement variables. Therefore, sprint acceleration was the speed of body movement variable best predicted by the leg strength variables as a group. This finding supports the results of the canonical correlation of the residualized experimental variables in which the speed of body movement variables were best represented by the sprint acceleration variable.

Table 24

Multiple Correlation Coefficients of the Leg Strength Variables with Individual Speed of Body Movement Variables

Step	Independent Variables (Leg Strength)	Std. Reg. Coeff.	R	R^2	Change in R^2	Sign. Level
	Factor 1: Right Boomerang ($F = 6.35$; $p < .001$)					
1	3	-.293	.293	.086	.086	.001
2	3,4	.252	.387	.149	.064	.001
3	3,4,5	-.079	.395	.156	.006	.272
4	3,4,5,1	-.076	.402	.161	.006	.287
5	3,4,5,1,2	.038	.404	.163	.001	.592
	Factor 2: Dodge Run ($F = 3.86$; $p < .002$)					
1	5	-.192	.192	.037	.037	.012
2	5,3	-.187	.268	.072	.035	.014
3	5,3,1	-.133	.299	.089	.018	.075
4	5,3,1,2	-.109	.318	.101	.012	.144
5	5,3,1,2,4	.067	.325	.106	.004	.367
	Factor 3: Sprint Acceleration ($F = 9.32$; $p < .001$)					
1	3	-.274	.274	.075	.075	.001
2	3,4	.252	.372	.139	.064	.001
3	3,4,2	-.220	.432	.187	.048	.002
4	3,4,2,5	-.172	.465	.217	.030	.014
5	3,4,2,5,1	-.076	.472	.222	.006	.273
	Factor 4: Sprint Velocity ($F = 4.08$; $p < .002$)					
1	4,	.271	.271	.073	.073	.001
2	4,3	-.160	.315	.099	.026	.031
3	4,3,5	-.093	.328	.108	.009	.207
4	4,3,5,2	.044	.331	.110	.002	.548
5	4,3,5,2,1	.039	.333	.111	.001	.599
	Factor 5: Box Jump ($F = 4.15$; $p < .001$)					
1	1	-.246	.246	.060	.060	.001
2	1,4	.189	.310	.096	.036	.011
3	1,4,5	-.127	.335	.112	.016	.085
4	1,4,5,2	.018	.336	.113	.001	.803
5	1,4,5,2,2	.007	.336	.113	.000	.928
	Factor 6: Vertical Jump ($F = 3.35$; $p < .007$)					
1	3	.265	.265	.070	.070	.001
2	3,4	-.105	.285	.081	.011	.162
3	3,4,5	.096	.301	.091	.009	.197
4	3,4,5,2	.049	.305	.093	.002	.512
5	3,4,5,2,1	.016	.305	.093	.000	.829

1 = Knee extension
2 = Hip extension
3 = Ankle plantar flexion
4 = Bicycle ergometer
5 = Margaria power index

Summary of Findings

Analysis of the data followed two major strategies:

1. A determination of the relationship between the raw data of the dependent variables (leg strength) and the independent variables (speed of body movement).

2. A determination of the relationship between the residualized data of the two sets of variables.

The relationships of the raw scores were examined with bivariate correlation, factor analysis, and canonical correlation. Bivariate correlation indicated that the control and experimental variables were highly correlated within and among the two sets. Factor analysis of the experimental variables produced two orthogonal factors, which supported the two hypothesized domains of human motor performance, leg strength and speed of body movement. Factor analysis of the control variables indicated that two factors, body fat and maturity, accounted for the variance of the control variables. Canonical correlation of the raw scores indicated that a significant linear combination of the dependent variables (leg strength) and linear combination of the independent variables (speed of body movement) existed. The major contributors to the significant linear combinations were:

1. Leg strength domain--bicycle ergometer, knee extension.

2. Speed of body movement domain--sprint acceleration, sprint velocity, vertical jump, dodge run.

Due to the significant canonical correlation between the two domains, the null hypothesis was rejected.

As the effect of the control variables on the experimental variables was obviously important, the experimental variables were residualized in regard to the control variables. The residualized dependent (leg strength) and independent (speed of body movement) variables were then analyzed by bivariate correlation, factor analysis, canonical correlation, and multiple regression. Bivariate correlation indicated fewer significant correlations between and among the two sets of variables and a general lowering of over-all coefficient magnitude. Factor analysis produced three orthogonal factors as compared to two factors in the analysis of the raw data. The first two factors were essentially the same in both analyses, with factor three representing two task specific items. In general, the hypothesized factor structure was also supported by the factor analysis of the residualized data. Canonical correlation produced a significant linear combination between the two sets of variables. The major contributors to this significant linear combination were:

1. Leg strength--bicycle ergometer, Margaria power index.

2. Speed of body movement--sprint acceleration, right boomerang, sprint velocity.

Because of the significant canonical correlation between the two residualized sets of variables, the null hypothesis was again rejected. More credibility was associated with this rejection because the individual differences associated with body fat and maturity had been removed from the experimental variables. Therefore, a more accurate determination of the relationship between leg strength and speed of body movement was obtained.

The multiple regression analysis tended to support those variables in each hypothesized domain that were the greatest contributors to the significant canonical correlation. The Margaria power index and the bicycle ergometer were the leg strength variables which were best predicted by the speed of body movement variables as a group. Sprint acceleration was the speed of body movement variable best predicted by the leg strength variables as a group.

Discussion

Two basic strategies were followed in this study. One strategy used the raw scores of the experimental variables, while the other strategy used scores residualized to control for the effects of body fat and maturity. In both cases, the hypothesized factor structure of the leg strength and speed of body movement domains was supported. Likewise, both strategies produced significant canonical correlations between the two domains. The analyses which utilized residual scores indicated the clearest picture of the relationship between leg strength and speed of body movement because the variance accounted for by body fat and maturity was removed.

The factor analytic findings of this study supported the hypothesized domains of leg strength and speed of body movement. Therefore, findings in the review of literature (upon which the hypothesized factor structure was based) were also supported, although no single study arranged the variables or the factor structure of the domains exactly as they were hypothesized for the present study. Factor analytic studies by Rarick (1937), Hutto (1938), Henry, et. al. (1962), Start (1966), Borchardt (1968), Jackson (1971), Baumgartner and Zuidema (1972), Disch (1973), and re-analyses by Harris and Liba (1965) of studies by Cousins (1951), Fleishman, et. al. (1961), Phillips (1949), Liba (1967), and Wendler (1938) were, in one aspect or another, in agreement with the derived factor structure of the present study.

To test the relationship between the variables of the two domains, canonical correlation and multiple regression were utilized. Although the domains of leg strength and speed of body movement were orthogonal (as derived through factor analysis), linear combinations of the two sets of variables were significantly related. The individual variables within the leg strength domain were not independent of the variables of the speed of body movement domain as a group. Likewise, the variables within the body speed domain were not independent of the variables of the leg strength domain as a group.

Canonical correlation and multiple regression analyses both indicated that the bicycle ergometer and Margaria power index (leg strength) were most highly related to the speed of body movement domain. By the same analyses, sprint acceleration (body speed) was most highly related to the leg strength domain. Therefore, the best measurement index of the two domains was the interaction component, represented primarily by the bicycle ergometer, Margaria power index, and sprint acceleration. The interaction component is illustrated in Figure 12.

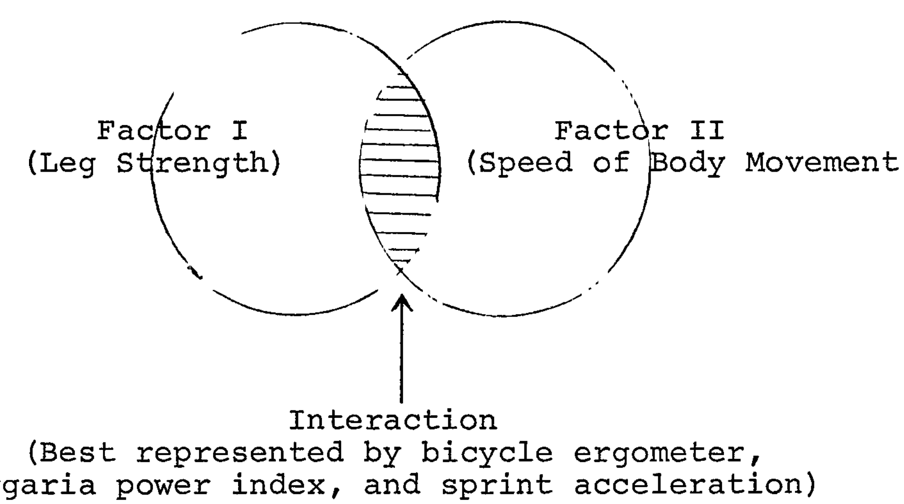


Figure 12

Interaction Component Between Leg Strength and Speed of Body Movement

The best explanation of the interaction component, and essentially, to the significant relationship between the two domains, is that of task specificity. Similarities among those variables that best represented the interaction between the two domains included:

1. Use of basically the same leg muscle groups, although the bicycle ergometer and Margaria power index were performed against added resistance.

2. Essentially the same biomechanical movement was required to execute all three tests.

3. All three tests were of short duration, involved limited moving starts, and were directly related to overcoming inertia.

The derivation of the interaction component, as well as the obvious similarities between the experimental tests, tends to support Henry's (1958) theory of specificity. In effect, the present study utilized two different types of leg strength measures--static strength, as determined by three cable tension tests, and two measures of strength that were dependent upon both speed and strength. The latter strength measure, termed strength in action, was represented by the bicycle ergometer test and the Margaria power index. The strength in action concept is alluded to in the literature as either power or dynamic strength. In both terms, mass, distance, and time are components of the respective formulas. This may be illustrated by the formula (DeVries, 1966):

$$F = 2\ md/t^2$$

where: F = force of contraction
m = mass moved
d = distance
t = time

When mass and distance are held constant, time is the only component that measures individual differences in performance. Both strength in action measures (bicycle ergometer and Margaria power index) were computed by holding either distance traveled, work load, or both, constant. In addition that variance accounted for by the body fat and maturity factors was residualized from the individual differences attributed to the two strength in action measures, so that mass was controlled for. Therefore, in correlating the individual differences of the speed of body movement variables with those of the leg strength measures, it would be logical to assume that the strength in action variables are significantly related to the body speed measures because both are, in effect, speed measures. Thus, the significant canonical correlations and the resulting standardized canonical weights presented in Table 20 are consistent with this reasoning.

A question unanswered concerns the relationship between speed and static leg strength measures. In order to gain clearer insight into the strength-speed relationship, multiple regression analysis was used to test the relationship between the static strength and speed measures. The three cable tension leg strength tests served as the independent variables and the six speed factors derived through complete principal components analysis (see page 92) were used as the dependent variables. The results of these six analyses are presented in Table 25.

Table 25

Multiple Correlation Coefficients of the Static Leg Strength Variables with Individual Speed of Body Movement Variables

Step	Independent Variables (Static Leg Strength)	Std. Reg. Coeff.	R	R^2	Change in R^2	Sign. Level
	Factor 2: Dodge Run ($F = 3.91$; $p < .009$)					
1	3	-.133	.192	.037	.037	.012
2	3,2	-.109	.234	.055	.018	.080
3	3,2,1	-.192	.258	.066	.012	.150
	Factor 3: Sprint Acceleration ($F = 5.03$; $p < .002$)					
1	3	-.076	.220	.048	.048	.004
2	3,2	-.220	.279	.078	.030	.022
3	3,2,1	-.172	.289	.084	.006	.309
	Factor 5: Box Jump ($F = 4.58$; $p < .004$)					
1	3	-.076	.246	.060	.060	.001
2	3,2	.038	.277	.077	.017	.091
3	3,2,1	-.079	.277	.077	.000	.806

1 = Knee extension
2 = Hip extension
3 = Ankle plantar flexion

The results of regressing the static strength measures to the speed of body movement measures indicated a low degree of relationship as illustrated by only three of the six body speed factors being significantly related to the static leg strength measures. The resulting significant relationships were logically explainable in terms of task specificity. The only static strength measure significantly related to the dodge run was ankle plantar flexion. Its relationship is probably due to the sharp change of direction required by the dodge run. Such a movement requires the subject to forceably contract the muscles measured by the ankle plantar flexion test. Sprint acceleration was significantly related to both ankle plantar flexion and hip extension, both involved in the pushing off or explosive movement associated with acceleration.

The box jump was significantly related only to ankle plantar flexion, which was evidently the prime mover in this test of body speed. It appears that the prime mover of the box jump would be the hip extension muscles (see Figure 5, page 41). However, when administering the test, the subjects were allowed to gather, and the movement was essentially initiated through the ankle plantar flexion of the leg resting on the floor. Thus, the movement needed for the test was initiated with a "jumping-type" action from the lower leg, rather than the force produced by the hip extensors of the leg resting on the box. Therefore, the significant correlation with ankle plantar flexion is logical.

Sprint velocity ($F = 0.68$; $df = 3$ & 165; $p > .05$) and the right boomerang ($F = 0.75$; $df = 3$ & 165; $p > .05$) were not significantly related to the static strength measures. For both tests, the subjects were given a running start and the tests required the subject to maintain a rate of movement. These findings support the mechanical principle that strength is not related to movement involving a constant rate of movement, i.e., velocity. However, it appears that strength is related to movement involving increases in speed, i.e., acceleration. This is consistent with Newton's second law of motion, force is the product of mass and acceleration.

The results of this regression analysis point to the fact that the static strength measures are direct functions of the angle at which they were measured. There may actually be a higher degree of relationship between static leg strength and body speed than was found in the present study. To determine this relationship, static strength throughout the range of a particular motion should be obtained. Rather than measuring knee extension, for example, at 90°, it might be measured at various angles ranging from less than 90° to more than 90°. The same type of measurement could be made in regard to all the static leg strength tests. Although the angles of measurement used in the present study were designed to measure the maximum amount of force in that particular movement, other angles are also likely to be important in relating strength to other domains of motor performance. By regressing more inclusive and comprehensive strength measures (i.e., measurements obtained at various joint angles), it is obvious that a better explanation of the strength-speed domains may be obtained. In addition, because body speed measures involve more than one joint, the determination of force generated over two or three joints may be of greater significance than the traditional measurement of force generated over only one joint.

Essentially, this study has revealed a relationship between strength and the explosive, or acceleration, phase of speed. That is, there appear to be common elements between strength (both static strength and strength in action) and those body speed variables related to acceleration or quick change of direction. These variables demand an explosive type movement to overcome inertia, which is acceleration.

These findings support the existing strength development training techniques practiced by many athletic coaches. If the proper muscle groups are strengthened, these findings would suggest that the increases in strength would be associated with increases in acceleration-type movements.

All other aspects being equal, the performer who can most quickly overcome inertia will execute the best performance. In a similar manner, such training techniques as increasing leg strength for those athletes who utilize quick running starts in their fields of athletic performance are also supported. Football linemen, whose quickness for 0-5 yards is essential to superior performance, and the sprinter in track events are examples of those athletes in need of strength improvement programs for the legs. Although, to some degree, strength is logically needed to perform well in any athletic performance, it is most essential to those types of movements associated with overcoming inertia.

Thus, one may speculate that appropriate increases in strength would result in faster starts for the football player and track sprinter. Stated in hypothesis form: Increases in acceleration are a function of changes in muscular strength of appropriate muscle groups. The acceptance of this hypothesis is obviously dependent upon experimental research designed to determine if this relationship is truly causal.

Conclusions

The basic problem of this study was: Are there relationships between the domains of leg strength and speed of body movement? Based on the results of this study, it is concluded that there is a linear relationship between the leg strength and speed of body movement domains.

Recommendations

To further explore the relationships among the various domains of human motor performance, the following recommendations are made.

1. Using experimental research, determine if the strength-speed relationship is a cause and effect relationship.

2. Use of canonical correlation and multiple regression analysis to determine the relationship between other orthogonally derived factors related to man's basic abilities.

3. Replication of the present study with several suggested changes. It is suggested that more elaborate testing equipment be used in obtaining static leg strength measures and that strength be measured at a variety of angles throughout the movement.

4. Determination of the relationship between leg strength and speed of body movement (as defined in the present study) for two additional samples:

   a. Pre-pubescent males

   b. Post-pubescent males

The purpose of this study would be to further ascertain the effects of removing that variance accounted for by body fat and maturity.

5. The use of multiple regression analysis to determine the linearity or non-linearity of the relationships between

the various domains of human motor performance. Because most statistical analyses have been utilized only to test the linear relationship of human motor performance variables, incomplete results may have been obtained. The testing of non-linear relationships where no significant relation was found with linear models may open new and meanfull avenues to a better understanding of motor performance.

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Appendix A

Controlled Speed Test Courses

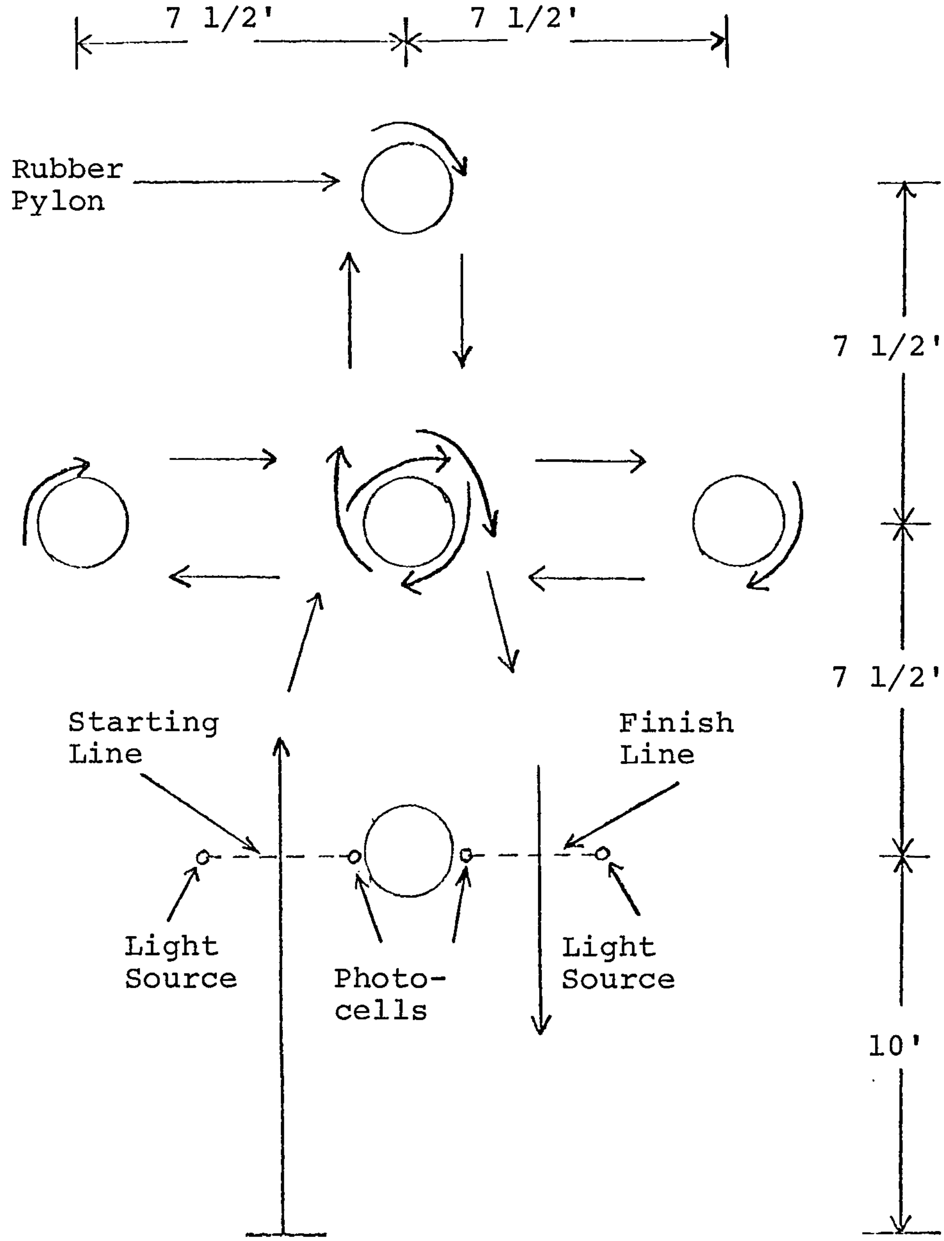


Figure 13

Right Boomerang Test Course

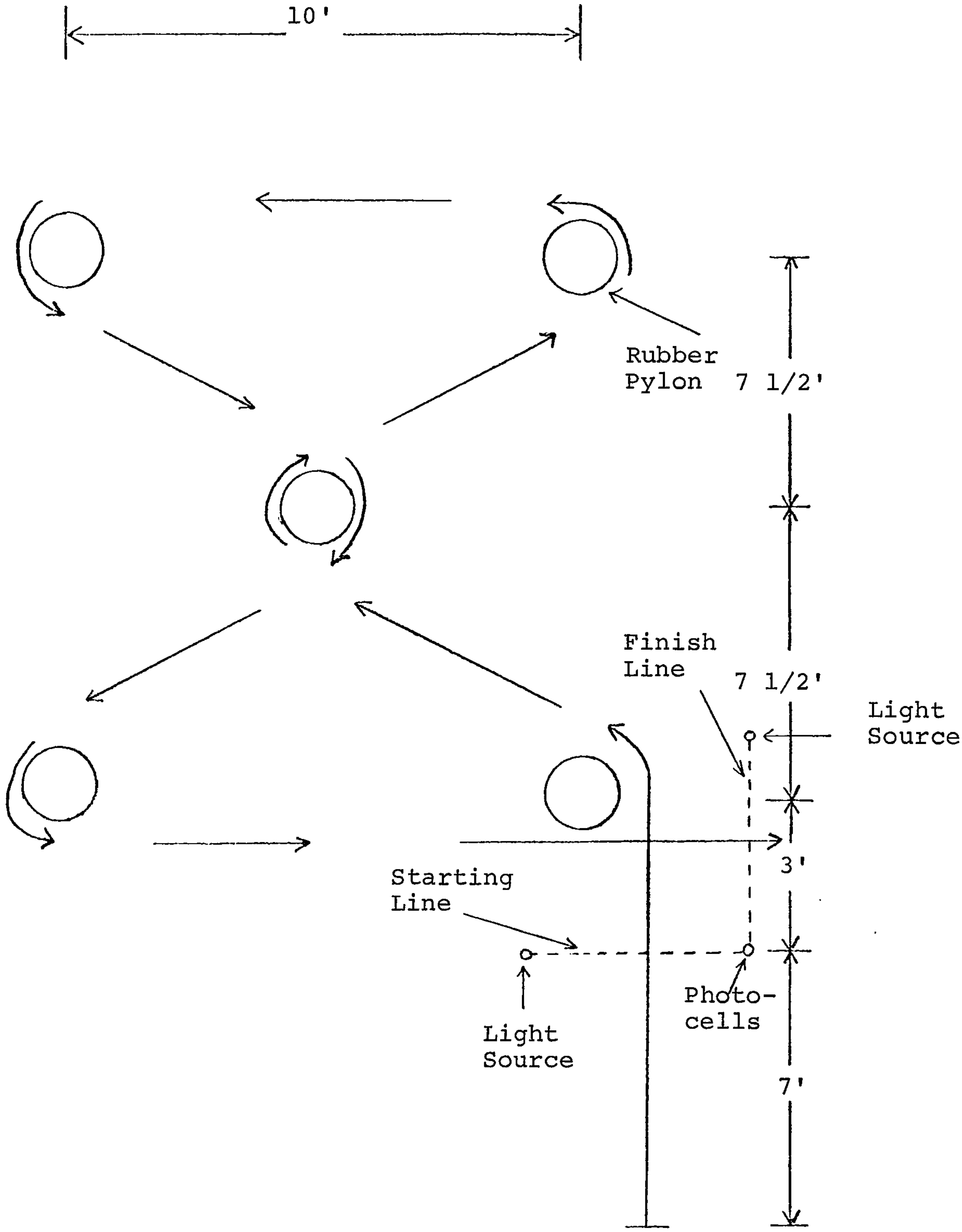


Figure 14

Dodge Run Test Course

Appendix B

Wiring Diagrams

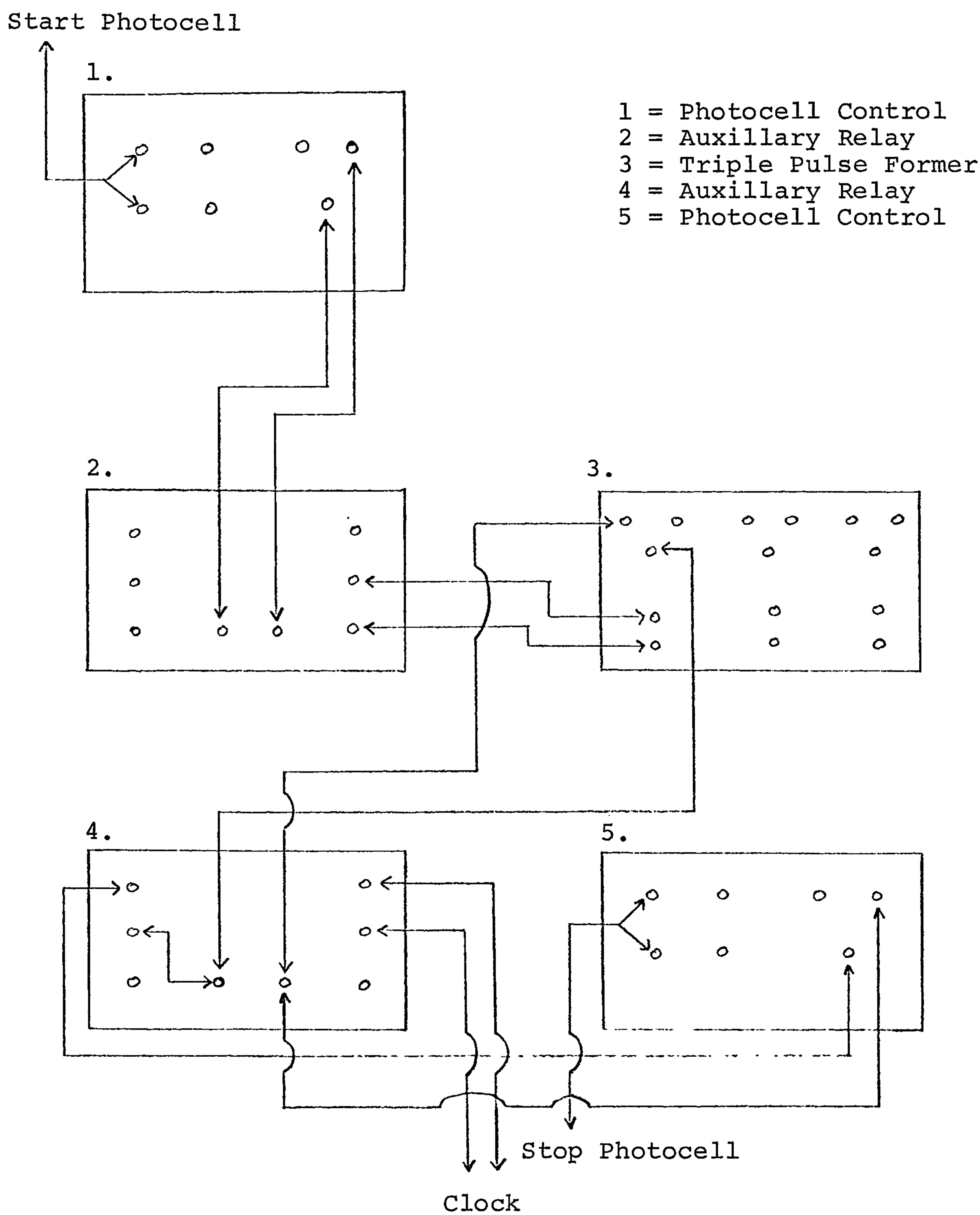
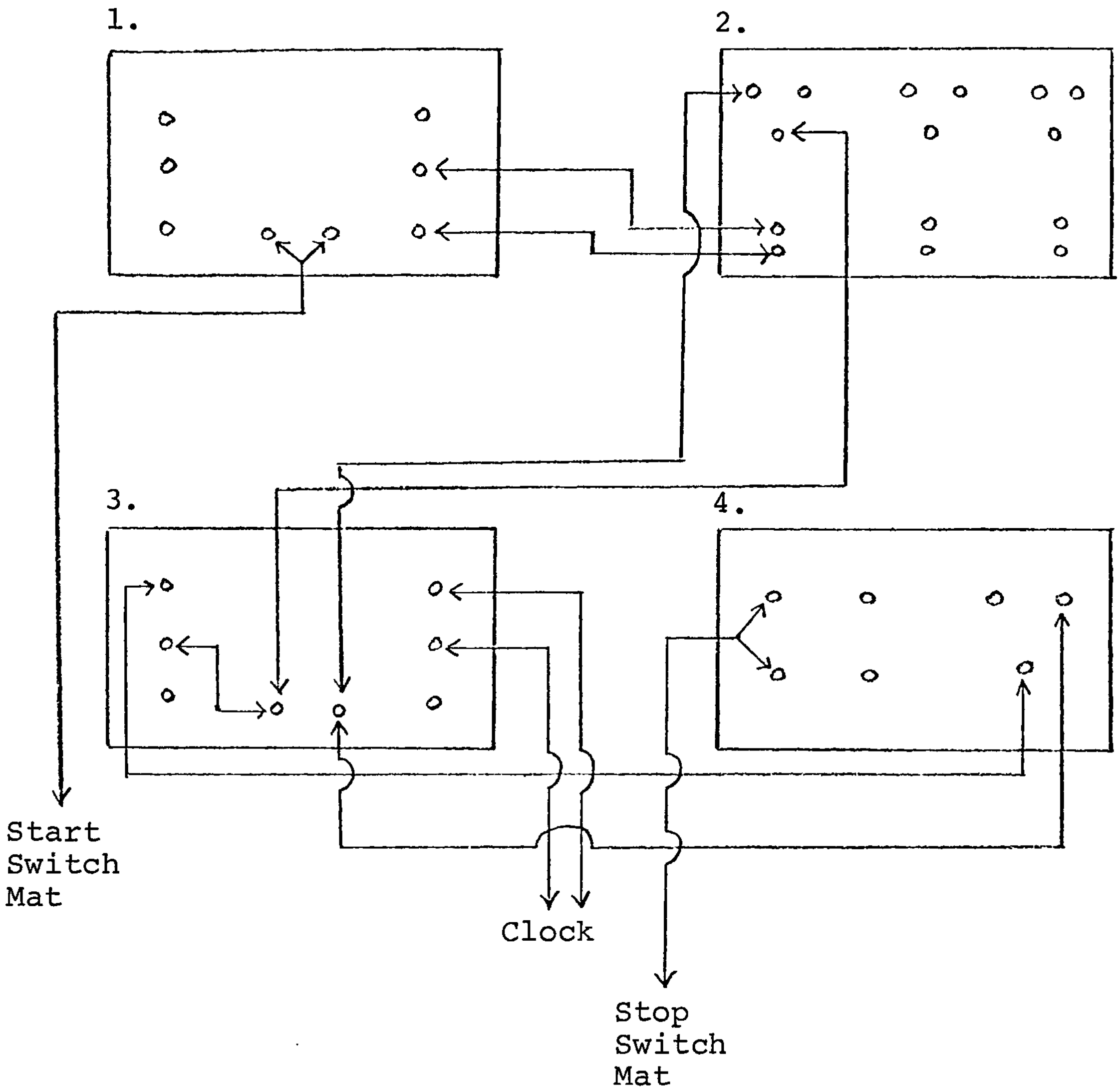


Figure 15

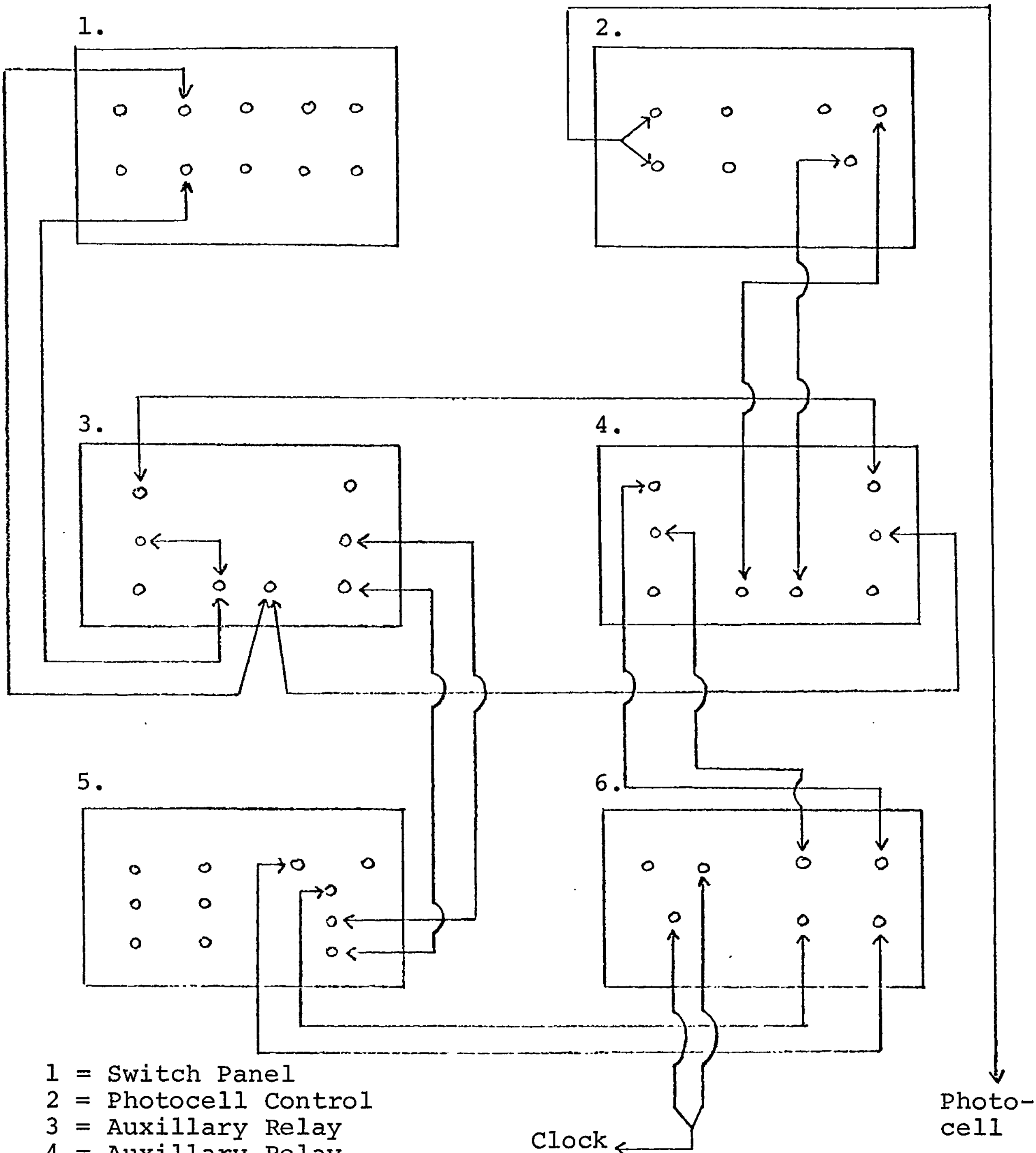
Wiring Diagram for the Right Boomerang and Dodge Run



1 = Auxillary Relay
2 = Triple Pulse Former
3 = Auxillary Relay
4 = Photocell Control

Figure 16

Wiring Diagram for the Box Jump



1 = Switch Panel
2 = Photocell Control
3 = Auxillary Relay
4 = Auxillary Relay
5 = Triple Pulse Former
6 = Predetermining Counter

Figure 17

Wiring Diagram for the Bicycle Ergometer

APPENDIX C

Assessment of Maturity

Assessment of Maturity

A list of criteria was established for assessing the maturity level of each subject. All items were discreetly checked by the investigator so that the subjects were unaware that they were being measured. Observations were made in the locker room, as well as during the test sessions. A score of 0 was recorded for those subjects failing to meet a majority of the established criteria and 1 for those who met a majority of the criteria. It should be noted that all measures were highly subjective and the results indicated only a "ball park" estimate of maturity. The criteria included:

1. Presence of facial hair--to the extent of shaving.
2. Presence of body hair, especially pubic hair.
3. A voice change, or in the process of changing.
4. A general observation that was intended to determine social interaction characteristics.
5. A general estimation of maturity by each subject's physical education instructor.

APPENDIX D

Miscellaneous Data

Table 26

Trial Means for the Tests of the Leg Strength Domain

Trial	Experimental Test: Knee Extension	Hip Extension	Ankle Plantar Flexion	Bicycle Ergometer	Margaria Power Index
1	30.367[1]	45.657	18.527[1]	2.802	1.390[1]
2	30.420[1]	46.112[1]	18.740[1]	2.770[1]	1.358[1]
3	30.432[1]	46.367[1]	18.793[1]	2.786[1]	1.340[1]

[1]Trials included in criterion score.

Table 27

Trial Means for the Tests of the Speed of

Body Movement Domain

Trial	Experimental Test: Right Boomerang	Dodge Run	Acceleration	Velocity	Box Jump	Vertical Jump
1	8.592	8.182	1.809[1]	2.801[1]	.249	16.420[1]
2	8.526[1]	8.135[1]	1.800[1]	2.798[1]	.241[1]	16.533[1]
3	8.511[1]	8.109[1]	1.802[1]	2.830	.240[1]	16.284[1]
4					.242[1]	16.308[1]
5					.241[1]	16.172
6					.246[1]	16.183
7					.245[1]	
8					.240[1]	
9					.241[1]	
10					.239[1]	

[1]Trials included in criterion score.

Table 28

Alpha Factor Analysis of the Eleven Experimental Variables (Raw Scores), Initial Solution

Experimental Variable	Unrotated Factors	
	1	2
Dependent Variables		
Knee extension	-.781	-.423
Hip extension	-.681	-.395
Ankle plantar flexion	-.483	-.202
Bicycle ergometer	.827	.281
Margaria power index	-.762	-.525
Independent Variables		
Right boomerang	.681	-.425
Dodge run	.694	-.414
Sprint acceleration	.885	-.251
Sprint velocity	.848	-.262
Box jump	.508	-.165
Vertical jump	-.781	.214

Table 29

Alpha Factor Analysis of the Eleven Control Variables, Initial Solution

Control Variable	Unrotated Factors	
	1	2
1. Height	-.737	-.621
2. Weight	-.962	-.074
3. Age	-.384	-.339
4. Leg length	-.531	-.533
5. Thigh circumference	-.893	.180
6. Calf circumference	-.840	.080
7. Subscapular skinfold	-.557	.691
8. Thigh skinfold	-.521	.769
9. Lateral abdominal skinfold	-.558	.726
10. Anterior abdominal skinfold	-.326	.840
11. Maturity	-.547	-.480

Table 30

Incomplete Principal Components Analysis of the Control Variables, Initial Solution

Control Variable	Unrotated Factors	
	1	2
1. Height	-.524	-.784
2. Weight	-.897	-.342
3. Age	-.306	-.516
4. Leg length	-.382	-.721
5. Thigh circumference	-.923	-.088
6. Calf circumference	-.866	-.178
7. Subscapular skinfold	-.747	.529
8. Thigh skinfold	-.725	.600
9. Lateral abdominal skinfold	-.749	.559
10. Anterior abdominal skinfold	-.566	.725
11. Maturity	-.410	-.666

Table 31

Factor Loadings of the Eleven Experimental Variables, Residual Scores, Using Alpha Factor Analysis (Initial Solution)

Experimental Variable	Unrotated Factors		
	1	2	3
Dependent Variables			
Knee extension	-.619	.044	-.295
Hip extension	-.466	-.195	-.339
Ankle plantar flexion	-.202	.433	-.072
Bicycle ergometer	.639	.162	.098
Margaria power index	-.641	-.247	-.176
Independent Variables			
Right boomerang	.685	.065	-.372
Dodge run	.631	-.015	-.302
Sprint acceleration	.845	.034	-.077
Sprint velocity	.781	.069	-.183
Box jump	.406	-.422	.079
Vertical jump	-.623	.028	.143

Table 32

Factor Loadings of the Leg Strength (Dependent) Variables, Residual Scores, Using Complete Principal Components Analysis, Initial Solution

Dependent Variable	Unrotated Factors				
	1	2	3	4	5
Knee extension	-.710	-.297	-.364	-.250	.468
Hip extension	-.714	.005	.496	-.442	-.221
Ankle plantar flexion	-.046	-.960	.058	.178	-.205
Bicycle ergometer	.729	-.139	-.337	-.538	-.213
Margaria power index	-.708	.201	-.486	.131	-.453

Table 33

Factor Loadings of the Speed of Body Movement (Independent) Variables, Residual Scores, Using Complete Principal Components Analysis, Initial Solution

Independent Variable	Unrotated Factors					
	1	2	3	4	5	6
Right boomerang	-.793	.280	.086	.350	.403	.006
Dodge run	-.794	.265	.231	.283	-.408	-.025
Sprint acceleration	-.846	-.003	-.365	-.150	-.047	.355
Sprint velocity	-.835	.019	-.389	-.190	-.010	-.339
Box jump	-.428	-.868	.030	.249	-.003	-.015
Vertical jump	.719	.103	-.515	.450	-.075	-.006