DOCUMENT RESUME

ED 099 344 SP 008 649

AUTHOR	Dintiman, George B.
TITLE	What Research Tells the Coach About Sprinting.
INSTITUTION	American Alliance for Health, Physical Education, and Recreation, Washington, D.C. National Association for Sport and Physical Education.
PUB DATE	74
NOTE	92p.
AVAILABLE FROM	American Alliance for Health, Physical Education, and Recreation, 1201 16th Street, N.W., Washington, D.C. 20036 (No price quoted)
EDRS PRICE	MF-$0.75 HC Not Available from EDRS. PLUS POSTAGE
DESCRIPTORS	Athletes; Athletic Coaches; *Athletics; Motion; Physical Characteristics; *Physiology; Research; *Training
IDENTIFIERS	*Sprinting

ABSTRACT

This booklet on sprinting is divided into four chapters. Chapter 1 "Introduction," provides an analysis of the 100-meter dash, summarizes world records, and discusses the reliability of timing the sprint race. Chapter 2, "Describing the Sprinter," discusses the following topics: anatomical characteristics, flexibility, reaction, strength/power, racial comparisons, circulatory characteristics, age and sprinting, body composition, hereditary influences, specificity of speed, sprinting mechanics, and stride length and frequency. Chapter 3, "Physiological Factors Affecting Speed and Its Development," examines speed improvement occurring through physiological changes in muscle and joint tissue, circulation, and the nervous system resulting from commonly used supplementary programs (any program other than sprint training). The final chapter, "Training the Sprinter," analyzes important research in miscellaneous areas that directly affects sprinting speed, supplementary training programs, and the critical area of sprint training programs, which includes sprint-resisted and sprint-assisted training. Lists of references and selected reading conclude each chapter. (JA)

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WHAT RESEARCH TELLS THE COACH ABOUT

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1201 Sixteenth St., N W. Washington, D.C. 20036

SP 008644

WHAT RESEARCH TELLS THE COACH SERIES

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What Research Tells the Coach About Wrestling
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Library of Congress Catalog Card No. 74-19588

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FOREWORD

This is the sixth in a series of booklets titled "What Research Tells the Coach" about a particular sport, and is a project of the National Association for Sport and Physical Education of the American Alliance for Health, Physical Education, and Recreation. The purpose of these booklets is to make available to coaches pertinent research findings with interpretations for practical application and to compile a list of research references about a specific sport. Authors selected for this series have not only a sound research background but also the practical experience in a given sport which qualifies them to select those research studies that have significance for coaches and competitors.

The author of this booklet, George B. Dintiman, chairman and professor of physical education, Virginia Commonwealth University, has also published a book titled *Sprinting Speed: Its Improvement for Major Sports Competition.* He has been a track competitor and coach at the secondary and college levels. We are fortunate to have secured his services for this book.

Dr. Dintiman has done an outstanding job in reporting what the coach should know, what the researcher has discovered and what is known and not known about the area of sprinting. Some technical language is used but the modern track and field coach has become knowledgeable about up-to-date research tools and techniques so that he can understand and utilize findings from numerous research studies.

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PREFACE

There is no single greater concern of coaches and athletes in all sports than "how to run faster." There is also no question more frequently left unanswered. Considerable inconsistency exists in the training of modern day sprinters. An air of secrecy surrounds the training methods used by coaches of several foreign countries. The sudden dethroning of American sprint supremacy by the Russians in the 1972 Olympic Games has some experts concerned about our present training methods. It is true that many of our programs in the past have been less than scientific: more aerobic than anaerobic, more haphazard than analytical, more mass oriented than personalized and more superficial than comprehensive. Yet, it is difficult to argue with success since it is a fact that the U.S. has produced the world's best sprinters for many years. Obviously, many individuals have been involved in participation in some very excellent training regimes.

This booklet has been prepared for all coaches and sprinters as a means of evaluating current sprint training programs in light of scientific facts discovered through the review of more than 250 studies. In several areas, where gaps were evident, the author attempted to investigate certain aspects as a means of uncovering critical data and then making recommendations for consideration by future researchers.

Information in this booklet is applicable to racing distances only up to 200 meters; energy expenditure and training approaches are quite different for runners competing in distances of 400 meters or more. It is hoped that the contents of the treatise will be helpful to both coach and athlete in elevating performance levels.

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1. INTRODUCTION

Analysis of 100-meter Dash

Henry and Trafton (4) identify a theoretical velocity curve of sprint running as a two-component form: primarily acceleration and velocity. They conclude that 90% acceleration is achieved at 15 yd and 95% at 22 yd. Although the curve is helpful, it fails to consider a 100-m dash and sprinting in its entirety. There are other considerations such as deceleration which critically affect the race. Terauds (8), through a cinematographical analysis of college men, found that maximum speed was reached by all individuals at distances of 20-50 yd, maximum velocity was held over a distance from 40-70 yd and deceleration commenced at 70-110 yd. A mean deceleration rate of 5.4% of maximum velocity was noted over the 100-yd distance.

Acceleration, maintaining maximum velocity, and deceleration vary among individuals. Superior sprinters will reach maximum speed later in the race, hold maximum speed for a longer distance and slow down (decelerate) less than the average or less conditioned sprinter. It is also safe to assume that there are variations among champion sprinters with perhaps a multi-causation scheme in operation (anaerobic capacity, explosive power, strength, reaction time, intrinsic speed of muscular contraction and neurological control of muscular contraction).

Table 1 indicates the factors involved in a 100-m dash and their approximate point of entry for champion sprinters. *Reaction to the stimulus* (RT) is important in providing a quick muscular movement forward while in contact with the blocks. *Explosive power* or forceful push-off both combine with RT for what may be the key phase of the race – the first 2-3 m. *Acceleration* to maximum

TABLE 1. DISTANCE OF ENTRY FOR FACTORS AFFECTING 100-METER DASH

FACTOR	0 10 20 30 40 50 60 70 80 90 100	Major Role
Reaction to Gun	0.10 sec	Response to Gun
Explosive Power (Departure from blocks)	0.5 sec	Block Clearance
Accelerating Power		Reaching Max. Speed
Stride Length/Rate		Maximum Speed
Anaerobic Capacity		Holding maximum, minimizing slowing

velocity occurs at different rates among champion sprinters with top speed generally attained at or slightly before the 60-m mark (5). *Stride length and rate* now become the limiting factors for the next 15-20 m and determine the maximum speed (mph) one can attain. *Anaerobic capacity* controls the degree of slowing that occurs in the final portion of the race. Unfortunately, a sprinter moves at maximum speed for only a short distance of 15-20-m before quick energy stores (ACP-CP lactate system) are depleted and slowing occurs (1). Contrary to the opinion of some sprinters, everyone decelerates in a 100-m dash. Any apparent surge of speed at the finish tape or in the final meters of the race occurs because an adjacent runner slows down or the successful sprinter was not running at maximum speed prior to the onset of the surge or could maintain near-maximum speed longer.

It is interesting to note that maximum velocity involves only a small portion of the race (15-20 m), a slowing effect a similar portion (10-15 m), and acceleration the main portion (45-60 m). It is difficult to weigh the importance of each area that controls the various parts of the racing distance. Inferior reaction time, inadequate explosive power and poor starting ability can cause a runner to lose the race in the first 2-3 m. Poor acceleration to maximum speed most certainly will affect the outcome of a race. An inefficient stride length (too long or too short) and leg rate will affect one's maximum speed. And, finally, poor conditioning or low anaerobic capacity will result in one's being overtaken late in the race. The model does, however, provide a breakdown for the analysis of each individual sprinter form and the weaknesses he displays during the racing distance. (The data is secured through the use of multiple timing systems.) This analysis then individualizes the focus that can be made upon the major training programs discussed in Chapter 4.

Major Attack Points

The preceding discussion may provide a logical deduction of the major attack points to be used in improvement. At first glance, one might conclude erroneously that a sprinter can take only a larger or faster step as a means of improving his time. Obviously, these two aspects affect only a small portion of the racing distance. A more thorough breakdown provides the basis for the selection of specific training programs (discussed in Chapter 4) that the coach may use in an attempt to improve the attack points: 1) RT and improved starting ability, 2) acceleration to maximum speed, 3) stride length, 4) stride rate or rate of leg alternation per second and 5) anaerobic capacity (2).

It is interesting to note, as we progress in later chapters, that researchers have oversimplified the task of acquiring greater speed. Few, if any, have viewed the total model and followed with a total approach. This may explain the variations of findings that have involved inexperienced, semi-inexperienced and experienced sprinters of all degrees of anaerobic capacity.

Sprinting Strategy

Knowledge of the limiting factors at various stages allows one to speculate on a strategy over the racing distance that should yield maximum efficiency. Although the use of strategy is limited, a basic pattern of emphasis is necessary and the course of events is fairly predictable. It is as follows:

Start - 30 m ... Rapid acceleration to 95% of maximum speed, with the greatest acceleration occurring during the first 15 yd. Considerable forward lean.

30 - 60 m ... Gradual acceleration to maximum speed and relaxed sprinting characterized by a lessening of tension at about 60 m prior to the point where fatigue begins to hinder performance. Relatively no forward lean.

60 - 85 m ... Constant speed. Maintain but do not try to increase speed. *Fighting* to increase speed can induce rapid fatigue, disrupt smoothness of form and cause slowing. Coasting and relaxation are not characterized by a change in form. Mastery of proper relaxation prevents speed loss and undue tightening in the final 10-15 yd.

85 - 100 m ... Slight slowing effect occurs, depending upon conditioning level and form. Top speed striding continues to a point 3-4 m beyond the finish line with no body position changes. A lunge or jump at the tape, although used by some champion sprinters, may have a slowing effect.

World Records

A brief review of world records makes it clear that man has improved somewhat through the years although the improvement is much less dramatic than in the 1-mi run. In 1890, the world's fastest human was John Owen who ran the 100-yd dash in 9.8. A 9.6 was recorded by Archie Hahn in 1902, lowered to 9.5 in 1926 by Charlie Paddock, lowered again to 9.3 in 1948 by Mel Patton, continuing to 9.2 in 1962 by Frank Budd and others, 9.1 in 1964 by Bob Hayes and currently to 9.0. Perhaps the most outstanding performance in a dash was recorded by Jesse Owens who ran a 10.2-sec, 100-m dash in the 1936 Olympic Games, a time which would be competitive in modern Olympic competition.

It is impossible to determine the cause of man's improvement through the years. The performances cited above that occurred before 1948 were run without starting blocks on rather poor (by today's standards) unresilient tracks. Clearly, starting blocks, lightweight shoes, composition track surfaces, new starting techniques, and modern training programs would have resulted in improved times in early track and field history. These factors also operate in comparing the progress of the mile run and other running events.

An improvement of 0.8 sec. in 83 years adds fuel to the theory of "innate ability as the main determiner" at first glance. In fact, the high school record of 9.4 by Jesse Owens in 1933 stood for 34 years until Bill Gaines ran a 9.3 in 1967. Thirty-four years passed before the record was lowered 0.1 sec – a tribute to the super-sprinter, Jesse Owens. At a closer look, one finds that 0.8 sec is an improvement of slightly more than 9%. A 9% improvement over the present 1-mi record would require approximately a 3:30 (four 52.5 sec quarters). This will be no easy task for runners of the next 73 years, nor will it be easy to reduce the current 100-yd dash record of 9.0 to 8.2.

The fact remains that times have improved and records are being broken and rebroken, occasionally by the same individual. Sprinting speed can and is being improved.

Reliability of Timing the Sprint Race

Timing accuracy must be viewed from two unique aspects: measurement of acceleration (9-20 yd) and measurement of velocity (exclusion of the first 20 yd). The greatest source of measurement error exists during the first 20 yd (6,7). To determine times in the acceleration component adequately, a minimum of three trials is recommended. Reliability increases with additional trials, up to seven, providing adequate rest is given and the fatigue factor does not enter (three trials = .851, four trials = .884, five trials = .905, six trials = .919, and seven trials = .930) (6). Obviously, these test results were attained with the use of automatic timing devices and photoconductive cells.

The second component, velocity, can be measured more accurately in two trials. A multiple timing system utilizing photoconductive cells placed at 20-, 30-, 40- and 50-yd intervals would reveal accurate velocity readings depending

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upon the conditioning level of the group. For highly trained sprinters, maximum velocity may not be reached until 60 m out, and the time for 10 m (60-m mark to the 70-m mark) would reveal maximum velocity without slowing. For untrained subjects, this distance is too great and slowing would occur. A multiple timing system that records times at various intervals would identify the 10-yd interval of greatest velocity.

A 50-yd dash with a 20-yd running start has been shown to yield high reliability (.93) with the use of three trials, three stopwatches, taking the median time in each trial and correlating the second and third trials. A 25-yd dash with a 20-yd running start is recommended for older individuals, unconditioned individuals, and women. A running start eliminates the variances in starting technique and skill that make up the acceleration phase of the sprint velocity (3).

SUMMARY AND RESEARCH NEEDS

Reaction time, speed of acceleration, reaching and holding maximum speed, and slowing down vary from individual to individual. Maximum speed is generally reached prior to the 60-m mark and held for 15-20 m before some slowing occurs over the remaining racing distance. It appears that anaerobic capacity, strength, reaction time and hereditary factors influence these occurrences in a race. The exact negative or positive contribution of each to the various segments or stages of a race is unknown at the present.

The breakdown study of a race allows an estimation of the importance of each major attack area. Based on a 10.0 sec, 100-m dash, reaction time represents 1% of the race, explosive power or departure from the blocks 5%, accelerating power 64%, stride length/rate and maximum speed 18%, and anaerobic capacity to minimize slowing down 12%. These approximations clearly identify acceleration as the major part of the race. Obviously, anaerobic capacity affects the second half of the race and controls the length of time that maximum speed is held and the degree of slowing that takes place.

There is a need to determine what and how much various factors affect different segments of a race. One of the major areas for researchers to investigate should be acceleration since its improvement would have the greatest effect upon overall times in a 100- or 200-m dash. More important, sprinters must be analyzed individually through cinematography to determine their stride rate, stride length, acceleration rate, reaction time, and slowing over the racing distance. An analysis of individual weaknesses provides the basis for individualized training. A total approach testing all factors that could theoretically affect reaction time, stride length/rate, acceleration, and anaerobic capacity would be helpful. Again, one sprinter's weakness is another's strength and individual analysis becomes essential to determine the exact focus of training to be used for each sprinter. It is good strategy also to analyze the opponents' weaknesses and strengths.

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2. DESCRIBING THE SPRINTER

Anatomical Characteristics

There does not appear to be one perfect body design for optimum sprinting speed. Any one of the numerous body types and differences in height, weight and length of levers may prove effective. Coleman (16), in studying the importance of height and weight in the 60-yd dash, for example, concluded that both factors played a negative role when correlated with sprinting speed (height: -.050, weight: .334). Cretzmeyer (19) identified championship sprinters from a wide range of characteristics with few falling outside the realm of 130-170 lb, 67"-75" in height, or more than 25 years of age. Jordan (51) found Negroes significantly more mesomorphic, possessing longer legs, shorter trunks, less body fat and more muscle and a faster patellar tendon reflex than whites. Several of these differences could have implications for superior speed of movement. As might be expected, sprinters are significantly heavier in body weight than distance runners (10).

A study of 245 Finnish athletes identified sprinters as the second tallest group (throwers-6', sprinters-5'9¾", long distance runners-5'7"), the group with the second longest limb lengths, and the third heaviest group (throwers-189 lb, jumpers-159 lb, sprinters-154.5 lb, and long distance runners-142 lb). While athletes who were weight competitors were found to have broader pectoral and pelvic girdle dimensions, no regular pattern existed among sprinters. Exceptions were found in all groups except in the weight group (75).

Hill (43) points out that, in uphill running, the effect of slope is inversely proportional to the linear size. Therefore, the smaller animal or individual should be faster in running uphill. Unfortunately, this does not aid the smaller sprinter running in flat surface.

Although times recorded in the sprint events have improved in Olympic competition, height and weight do not appear to be factors. Present day Olympic athletes are heavier and taller than those 30 years ago; however, they are geometrically no different from those of the past. There is, then, no automatic additional strength and power available because of an increase in height and weight.

Height, Weight of Children and Speed

Using nearly 100,000 subjects, Asmussen and Christensen (1) found no variations in speed (50-100 m) with body size. Twelve-year-olds outperformed 11-year-olds, and 14-year-olds outperformed 13-year-olds which appears to be the result of maturity, improved coordination and superior muscular function. Taller 14-year-old boys outperformed smaller boys which again represents a maturity factor since height ceases to be a factor affecting sprinting speed after the age of 18.

A longer limb merely results in a longer stride and fewer strides per second and is no advantage over short limbs which are capable of more strides per second. Wear and Miller (78) report that medium and thin physique junior high subjects had faster times in a 50-yd dash than heavy physique subjects. Rarick and Oyster (65) further complicate the picture by concluding from their study that skeletal maturity of second grade boys is not a factor in the 30-yd dash.

Girls tend to improve in maximum speed until approximately age 14 with no further improvement expected unless meticulous training occurs. Sexual maturity, then, is the main factor limiting speed for boys prior to maturity. Immaturity limits the body because of lack of coordination and muscular strength. Burley and his colleagues (12) conclude that height, weight and lever length do not correlate with speed of junior high school girls.

It can be concluded that maximum speed is independent of size and body weight including length of levers. There is no ideal profile for the champion sprinter. In fact, it may be impossible to predict the winner from a physical profile. The advantage of longer legs of the tall sprinters is offset by the fact that the weight is moved by a longer lever and this action requires more strength.

Flexibility, Reaction, Strength/Power

Observation suggests that superior sprinters possess a high degree of trunk and ankle flexibility. Physiological logic is also highly supportive of improved speed of motion through increased flexibility because of increased stride length, decreased muscle resistance and easier movement through the range of motion (dynamic flexibility). Unfortunately, research findings do not concur. There is no available literature to indicate that sprinters are more flexible than other athletes. Nor is there solid evidence that flexibility and speed are related or that increased flexibility will result in subsequent increases in sprinting speed. If flexibility is important, its value lies in the improvement of dynamic flexibility and decreasing the amount of torque needed to move a joint through the complete range of motion at high speeds.

RT affects time variance by approximately 4% from 30-40 yd, 7% at 20 yd, 15% at 10 yd, and 24% at 5 yd (38). A sprinter requires about 0.1 sec to respond to an auditory signal and 0.50 to leave the blocks after the stimulus (4). Conflicting evidence is presented concerning the relationship between RT and movement time (37,80).

Sprinters possess shorter RTs than middle distance runners:

Dash men .... 0.131 sec
Middle distance men .... 0.149 sec
Distance .... 0.169 sec

Varsity athletes have also been found to possess better RT than intramural participants and nonathletes (53, 56).

While the importance of superior strength in the muscles involved in sprinting is well established, there has been no attempt to compare the strength of sprinters in various muscle groups to other athletes or the nonathletic population.

Racial Comparisons

Black athletes (male and female) not only tend to dominate sprint events in track and field, they also represent above their population proportion in sports and positions where superior speed is necessary. Observation of this phenomenon has inspired numerous attempts to compare the speed of white and black children and adults and to uncover physiological differences between the races that may account for an apparent superiority. Jordan (51) identified numerous physiological and anthropometrical differences between blacks and whites. Several of these differences have implications for improved speed of movement: 1) a highly conditioned Negro athlete possesses 38% less fat, 2) Negroes have longer legs and arms than whites, 3) while Negroes and whites are of similar height, Negroes have shorter trunks in sitting height, 4) Negroes are significantly more mesomorphic than whites, and 5) Negroes are significantly faster in the knee-jerk or patellar tendon reflex. According to Marino (58), Negro athletes also possess a higher gastrocnemius insertion or greater percent of tibial height.

Hutinger (49) found black girls and boys to be significantly faster in the 35-yd dash than white children. In another study (50), he found a low correlation (-.017) between the patellar tendon reflex and 35-yd dash times among elementary school white boys. Browne (9) offers opposing findings and revealed a faster patellar reflex time among black children.

Sloan and Wiggett (70) compared 161 white and Negro boys and girls (mixed European and African or Asian descent with no children of pure African origin) aged 15-17, on seven items of the AAHPER Youth Fitness Test. Negro boys scored significantly higher than white boys in one area, the shuttle run. White boys ran the 100-yd dash significantly faster than black and Asian boys and slower than the African boys. In a similar study, white girls outperformed black and Oriental girls in the 100-yd dash (15). Hipple (44) found no significant differences between white and black athletes in muscular tension, reaction time and speed of movement. In a study by Botha, Clarke and Jokl (5), African boys and girls outperformed whites in the running events. Although evidence is conflicting, it is worth mentioning that white children in the above studies were significantly taller and heavier than Negro children. Although height and weight have been shown to be irrelevant, they are signs of maturity and nutritional status at certain ages. The influence of poor nutrition and its subsequent influence upon physiological maturity was not isolated within the age groups studied.

It is known that black athletes do tend to be more successful than whites in sprint events. White athletes, on the other hand, tend to outperform blacks in some other areas (distance runs). Researchers have been unable to link any one physiological trait or combination of traits with speed differences between the races. Differences may be sociologically based--a matter of cultural perception and expectation rather than racial. It is certainly true that some sports are more readily available to blacks and some are almost impossibly removed due to socioeconomic factors. Successes, then, in the available sports perpetuate the myth of a physical and/or mental superiority of one race over another and its effect upon sprinting or distance running. It is hoped that our society will desegregate to the point where all races have equal availability to all sports. When and if this occurs is the time for studies to be made comparing the performances of whites and blacks.

Circulatory Characteristics

Browning (10) compared sprinters and distance runners in a variety of areas and found sprinters to possess larger means than the distance group on heart rate (HR) recovery following sprint bouts, resting diastolic pressure, maximal recovery systolic pressure following the endurance bout, and minimal recovery diastolic pressure following the endurance bout. Distance men also had larger mean performances on the endurance work bout than sprinters.

Research currently in progress at Teachers College, Columbia University, under the direction of Dr. Bernard Gutin has revealed some important findings concerning the HRs of a small number of sprinters. Rather high negative correlations were found between submaximal HRs of sprinters and performance in the 100-, 200- and 440-yd dash. Individuals with higher submaximal workload HRs were the better sprinters.

Also, an inverse relationship exists between speed of muscular contraction, running speed and size of various animal species. A relationship also exists among the animal species between normal and maximal heart beat and speed of movement. One elaborate study was undertaken in conjunction with the author to determine the maximum heart beat (during vigorous activity) and running or movement speed of various animals (26). Since it was nearly impossible to control and consider all variables affecting these two aspects in various species, speeds and HRs were approximate with accuracy fairly high.

Several findings are worthy of mention:

1. In general, the smaller the animal, the faster the heart beat.
2. The greater the maximal HR, the faster the maximum speed of movement.
3. While some animals can increase their resting heart beat four- or five-fold through activity, man is capable of accelerating his rate only three to four times his resting pulse.

Age and Sprinting

Most champion sprinters are under 25 years of age. Unfortunately (especially in the U.S.), there has been little incentive to remain an active sprinter after college years. As body functional changes with age are examined, we find that the older individual of the same body size as a younger man is quite different in structure and function. His body weight, heart weight, and heart volume have increased. His oxygen transport per heart beat is the same. His maximum oxygen uptake, HR, stroke volume, pulmonary ventilation and muscular strength have decreased (2). Only one factor is evident that clearly affects sprinting speed, that of muscular strength. It is unrealistic to conclude that muscular strength will diminish after age 25 if the correct kind of training continues. None of the other changes should cause significant slowing prior to age 35. The inception of professional track, offering motivation for participation and training into the 30s, may change the arbitrary point of reference concerning the best age for sprinters. Even in 1973, the opening year of professional track, Mel Pender (age 36) was one of the fastest humans in the 50-yd dash.

Body Composition

A sprinter should possess minimum body fat of less than 10% of body weight. While there is no evidence comparing the performance of sprinters differing in body fat, fat has been shown to limit motor skills, efficiency (64) and flexibility (54). Since weight charts are grossly inadequate, even as an estimate of normal weight, the skinfold method should be used to determine the amount of body fat. Measurements at only two places (triceps, subscapular) are almost as reliable as the use of the more complicated methods of densitometry or the use of five to six skinfold measures (22).

Hereditary Influences

Obviously, genetic laws affect the transmission of desirable or undesirable qualities or traits for sprinting much the same as in other traits. The determination of the directions for human development are transmitted through a parent's gametes, egg and sperm in the form of gigantic molecules called deoxyribonucleic acid (DNA). DNA controls development and rules body chemistry, shape and identity. Every single cell in the body contains the same DNA molecule that the zygote contained in the first place. There is much to be discovei bout DNA molecules but it is safe to assume that, at birth, the game plan for development cannot be significantly altered. Both good and bad genes are present and will be reproduced with the daughter cells inheriting the whole genotype of the parent cell.

Although heredity deals the cards, environment plays the hand and strongly influences one's athletic outcome. In terms of inheriting the tendency to be a fast runner, Cratty (18) found that between father and son, performance on the 100-yd dash correlated moderately (.49), whereas the broad jump correlated .80. No significant father-son correlations were found with more complex gross body skills. Numerous studies of identical twins strongly suggest the advantage of being the offspring of athletic parents.

Intrinsic Speed of Muscle Contraction

Muscles do differ in ability to contract at a high rate of speed with the postural muscle: relatively slow and flexor muscles fast. The properties of skeletal muscle, which vary from individual to individual, place some limitations upon maximum sprinting speed potential. The amount of sarcoplasma is more abundant in some muscle fibers and contains pigment granules, giving it a reddish appearance (red muscle) while in others it is less abundant and muscle fibers are rather pale (white muscle). In many individuals both types of fibers are evident in every muscle. The white muscles contract faster than their slower red counterparts which possess greater capacity for endurance. In individuals where the white fibers predominate, greater speed of contraction is possible. When the red fibers dominate, less speed is possible. According to De Vries (24), it appears likely that "ultimate maximal speed capacity" is limited by the intrinsic speed of an individual's muscle tissue and by the nicety of his neuromuscular coordination patterns. Neither factor is amenable to changes as large as those affecting strength and endurance. Thus, it is obvious that heredity does place some restriction on our maximum sprinting capacity through both muscular and circulatory systems.

Recent findings of Astrand and Rodahl (2:18-19) indicate that strength training can result in the transformation of red to white muscle and a subsequent faster contraction. This information is quite supportive of weight training and other strength programs for sprinters.

Specificity of Speed

The aspect of *specificity* has been subjected to much research in recent years. General endurance and cardiovascular efficiency acquired in training for one sport (through running, for example) make only a slight contribution to performance in another sport (30). This principal is reinforced many times in observing well-trained athletes attempting to make the transition from one sport to another.

In a rather unusual approach to the well-established concept of specificity of training, Maksud (57) studied the specificity of the anticipatory heart rate response (heart rate increase during a 5-sec period immediately preceding activity in a 10 mph level treadmill run, a 200-yd sprint, and a 25-yd backstroke sprint). Anticipatory heart rate response was greater for the 25-yd backstroke following the completion of a swimming season. No significant difference was found for treadmill or track running.

Speed is also specific to body area or the muscle groups being utilized. Thus, an individual may possess high leg velocity and slow arm velocity or even be *fast* in the quadricep group in the running action and *slow* in the hamstrings. One author, for example, found that speed is 87-88% specific to the limb (72). Henry (39) reports that individual differences in the ability to execute a fast movement is 70% specific and 30% general. Gray, Start, and Walsh (33) found only slight correlations between leg speed and leg power indicating high specificity. Also, within a particular limb, speed was found to be 88-90% specific to the direction of the movement. The downward swing of the right arm and the forward kick of the right leg was also found to be specific to limbs (55). Both the type of movement being performed and the direction are then within the realms of specificity (14, 40, 72).

It is obvious that training programs designed to improve speed must involve the muscles and specific movements utilized in the sprinting action. It is also apparent that the acquisition of a high level of conditioning in one sport does not necessarily carry over to another. Sprinting is a critical, common action in most sports and necessitates special attention through sprint training programs.

Brouha (8) explains the physiological basis for the principle of specificity by identifying two facts: 1) training occurs, in part, within the muscles themselves, and 2) training is specific in terms of lactic acid production during heavy muscular work. Thus, complete training transfer, regardless of the closeness of activities, is not possible.

Sprinting Mechanics

Although any good student of kinesiology could argue the importance of proper form in acquiring high speeds of movement, there is little evidence to support an ideal form or the need to correct minor faults. While there is a so-called "commonly accepted sprinting form," its importance is theoretical in

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nature and often violated by some high caliber sprinters. This is not an argument to encourage form neglect; it is merely to point out that other factors may be more important and that research is desperately needed.

Numerous researchers have attempted to identify and associate characteristics of form with successful running. Studies and observations by Broer (6), Bunn (11), Cureton (20), Deshon and Nelson (23), Fenn (29), Hubbard (47) and Slocum and Bowerman (71) have isolated the following essentials of efficient sprint running:

1. Use of forceful push of the rear leg to minimize deceleration and increase stride length
2. High knee lift as the free swinging leg goes forward
3. Placement of the foot directly beneath the center of gravity to decrease deceleration
4. Use of a long stride.

According to Deshon and Nelson (23), attempts to increase stride may decrease the angle between a runner's leg and the surface at point of contact. The increased speed acquired from a longer stride would then be offset by a reduction in this angle of touchdown which tends to affect speed adversely. Slocum and Bowerman concur with this finding: "A simple force diagram will reveal that the farther ahead of the body the foot strikes the ground, the more acute the angle and the greater the deceleration from ground resistance" (71).

Fortney (31) conducted a cinematographical analysis of 12 boys aged 7-11. Older boys and better runners were shown to utilize greater knee flexion, bring the heel closer to the buttock as the trailing leg leaves the surface, and flex the hip and knee to a greater degree as the free limb moved forward causing a greater leg incline toward the surface.

Concerning the weight bearing area of the foot, Rogers (66) concluded that there is no significant difference between performance in the 50-yd dash and the weight bearing area of the foot.

In an ingenious attempt to analyze the *kick* action in sprinting, Akria Tsujino (76) buried a cement box with movable lid in a track to force competitors to place their feet in the center during the sprinting action. In determining the vertical and horizontal components of the movement, the step was divided into three parts: 1) braking force applied against the forward movement at impact, 2) downward pressure as the body again advanced forward, and 3) rear push or kick, neutralizing the deceleration caused in stages #1-2. An individual running 100 m in 12 sec was found to have foot/ground contact for 5 sec with 7 sec in the air. It was concluded that the forward transformation of thrust into an upward force in phase #2 keeps the body in the air for the major portion of sprinting and that sprinting is merely a series of jumps.

Nett studied foot contact with the ground among top-class athletes and concludes:

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> In the 100-meter and 200-meter runs, the ground is contracted first on the outside edge of the sole, high on the ball (joints of the little toe) . . . In the 440-meter run, which is run at a somewhat slower pace, the contact point lies a bit further back toward the heel; the foot plant is not somewhat flatter . . . even in the case of sprinters . . . the heel contacts the ground. (61)

Teeple (74) identified four factors that are significantly altered by changes in the running speed of women: stride rate, stride length, angle of leg lift and time of support.

Barlow and Cooper used not only timing devices and cinematographic techniques but also a force plate. They found that: "The fastest sprinter displayed shorter reaction times, acquired greater total block time, achieved a longer first stride, and obtained much greater horizontal and vertical components of force while minimizing breaking force during the first stride" (3).

Stride Length and Frequency

Stride rate and length determine maximum speed. For animals and men of varying sizes, maximum speed is proportional to L/L = 1 indicating that stride length from longer legs does not guarantee faster movement rates. Nor do shorter legs condemn one to slower movement rates. Short strides move more rapidly and cover as much ground as long strides. An individual's maximum speed (15-20 m of a 100-m dash) is regulated by stride length and frequency. To improve speed, an increase in one or both of these parameters must occur without a comparable reduction in the other. As Hay (36) points out, it is possible to increase speed by improving one parameter at the detriment of the other:

	Stride Length		Stride Frequency		
Original speed =	6 ft	x	3/sec	=	18 fps
New speed =	5 ft	x	4/sec	=	20 fps

The length of a stride, according to Hay (36), is composed of the sum of three separate distances:

1. The horizontal distance that his center of gravity is forward of the toe of his "takeoff" foot at the instant the latter leaves the ground (controlled mainly by the length of the legs and flexibility at the hip joint).
2. The horizontal distance that his center of gravity travels while he is in the air (controlled by the speed, angle and height of release and air resistance with release speed most important).
3. The horizontal distance that the toe of his leading foot is forward of his center of gravity at the instant he lands.

Research findings have demonstrated that stride length is predominantly a function of strength and would be more effectively improved by strengthening the muscles involved in the extension of the hip, knee and ankle joints that exert force against the ground.

Stride frequency is the sum of the time taken with ground contact and in the air. The ratio of these two times in top-class sprinting varies from approximately 2:1 during the start to between 1:1.3 and 1:1.5 when the athlete is running at maximum or near-maximum speed (36). The physiological factors that control stride frequency are not easily identified. Stride rates in sprinting are *not* limited by the ability of the nervous and muscular system to rapidly contract and relax the appropriate muscles. In fact, it has been shown that a good sprinter may execute 4½-5 strides/sec (66), children 4-7 years old may be capable of as many as 6-7 strides/sec at a much reduced length (24), and sprinters are capable of cycling rates of 5.6-7.1/sec which is considerable faster than their sprinting rates (69).

Limited research has been done dealing with stride length and frequency that is helpful in planning a sprint training strategy. Hoffman (45) studied 56 male sprinters with best 100-m times of from 10.0 to 11.4 sec including Figueroa of Cuba, Radford of England, Hary of Germany and Sime of the United States. Average stride length (including average length of four strides taken between the 50- and 60-m mark) and standing height were significantly related as were leg length (greater trochanter of the femur to the sole of the foot) and stride length. Average stride lengths of the 56 sprinters studied equaled 1.14 times height or 2.11 times leg length. An inverse relationship was uncovered between height and stride frequency and leg length and stride frequency.

Depending upon the caliber of sprinters studied, average maximum stride length has been reported as 1.14 X height, 1.17 X height ± four in, 1.24 X height, and 1.265 X height (28). The faster sprinters have the higher values.

In another investigation, Hoffman (46) studied 23 champion female sprinters from various countries with 100-m times of 11.0 - 12.4 sec. Results were very similar to the previous study. The average stride length equaled 1.15 X height and 2.16 X leg length. When matched pairs of women and men sprinters (similar height, length of leg and leg of stride) were compared, it was found that women are approximately 1 sec slower over 100-m because of lower frequencies of stride.

Kinetic Energy

According to Hill (42), the kinetic energy (KE) developed in a limb depends upon its mass and the square of its velocity, and that work done during a single movement, calculated per unit of body weight, in producing and utilizing kinetic energy in the limbs, should be the same in individuals of varying limb length and body size.

Fenn (29) demonstrated that a good sprinter generated approximately 13 hp with 5.2 hp attributed to the initial energy and 7.8 to waste in recovery. Only

2.95 hp was attributed to useful work related to propulsion. Wasteful work was the result of anti-gravity forces, wind resistance, ground contact resistance and recovery energy associated with non-propulsive limb movements.

Cureton (21) developed a velocity vs. air-resistance curve and stated that the effect of air-resistance approximates 2.8% pf (propelling force) at 30 ft/sec. Approximately .195 hp is needed to overcome air-resistance on a quiet day.

Form is considered rather unimporant as indicated by a survey of collegiate coaches of football, basketball, baseball, soccer and track and field concerning the important characteristics of a fast runner. The five highest qualities in their ranked order were (27):

1. Hereditary factors
2. Explosive power
3. Leg strength
4. Anthropometric measurements (length and size of limbs)
5. Form

Additional research is needed before accepting such a conclusion.

The Start

There are three types of starts named according to the distance between the feet in the starting blocks: the long, the medium and the bunch. The placement of the front foot on the block is approximately 14-21 in behind the starting line. The placement of the back foot is determined by the type of start used. The *elongated* start is assumed by preparing the block for the front foot and then extending the back leg so that the knee is even with the heel of the front foot. The *medium* start is assumed by placing the knee of the back leg approximately even with the toe of the front foot. The *bunch* start is assumed by placing the toe of the back foot approximately one foot behind the heel of the front foot. Obviously, space between the feet varies for the three types of starts: elongated (21-26 in), medium (16-21 in), and bunch (11-12 in). Spacing for all three starts must be determined individually after careful experimentation. The following additional guidelines are offered for determining spacing in the medium start (and its variations) which is the most common and most efficient style in use today:

1. The rear foot should be as close to the starting line as possible. Such a position increases rear knee flexion and places the muscles at an angle most conducive to the exertion of maximum force. A rear leg angle of 120° and a front angle of 90° in the set position is desirable.
2. The back should slope slightly downward toward the shoulder.
3. The lead foot should be placed approximately one foot from the line, adjusting accordingly while in the set position to assume a comfortable, balanced stance. The knee of the rear leg is now placed opposite the center of the lead foot to determine rear foot placement.

There are many variations of these three starts caused by differences in body build and style. The purpose of the use of any technique is to help obtain maximum power, body balance, and acceleration to maximum speed.

Researchers have investigated a multitude of factors affecting starting time in sprinting in terms of reacting to the gun, vacating the blocks, and attaining maximum speed. Although some conflicting reports occur, there is general agreement within ranges (3, 4, 17, 19, 25, 32, 34, 35, 38, 41, 44, 48, 52, 59, 60, 62, 63, 67, 68, 73 and 77):

General

1. Starting blocks yield faster starting and finishing times than holes.
2. A semi-standing start may be as effective as a crouch start over a distance of 10 yd for inexperienced high school sprinters. Paul Nash, South Africa's top sprinter ran 10.1 sec for 100 m using the standing start.
3. Faster sprinters possess shorter RTs, greater total block time, a longer first stride and greater horizontal and vertical components of force while minimizing breaking force during the first stride.

Reaction Time (RT) and Acceleration

1. It takes approximately 0.1 sec to respond to the gun and an additional 0.5 sec to clear the blocks.
2. Approximately 90% of maximum acceleration occurs within 15 yd with 95% velocity attained at 20 yd and full running speed at approximately 40-65 yd, depending upon the conditioning level and superiority of the sprinter.
3. RT and velocity are unaffected by making the arm either relaxed or tensed. The final one-third of the arm movement at the start is significantly faster when the prime movers of the arm are stretched. Movement time was faster with a relaxed arm.
4. RT does not appear to be related to block spacing.

Foot and Hand Spacing

1. Wide variations in distances have proved effective.
   a. Hands should be no more than 6 in ahead of the lead foot.
   b. Runners with long extremities should place their forward foot a greater distance from the lead hand.
   c. Foot spacing is governed by the length of the extremities, with foot size also a factor.
   d. Placing the front foot 10 in from the starting line was better than 19-in and 22-in spacing for junior high boys. Foot spacing failed to affect significantly the sprint start in college subjects.
   e. A 16- to 21-in distance between blocks appears to be the most effective spacing.

f. The 26-in spacing produces greater velocity in clearing the blocks; however, the advantage is lost within 10 yd.

g. Times were improved in a 10- and 30-yd dash using the medium start when the hands and lead foot were placed as close to the starting line as feasible.

h. Narrow hand spacing (8 in between thumbs) may produce faster acceleration to maximum speed. A wide hand spacing lowers the center of gravity and may cause a runner to accelerate for a longer period of time to reach the maximum height of his center of gravity.

Comparison of the Three Basic Starts (Bunch, Medium, Elongated)

1. The bunch start is more conducive to high hip elevation, improved forward trunk lean, and more rapid leg movement.
2. The bunch start allows one to clear the blocks sooner but with less velocity than from a medium stance. For shorter 2-5 yd sprints, the bunch style appears quicker; however, times may not be as fast should the distance be carried to extended yardage.
3. The medium start position is significantly faster for runs from 10-50 yd than the elongated and bunch styles. The greatest number of best runs were made from the medium start and fewest from the elongated position The largest number of slower runs were executed from the medium position. Subjects had not reached maximum speed at 40 yd through use of any style.
4. A shorter mean time was required to complete every distance from 10-50 yd using the medium start.
5. Variations in starting position seem to affect performance of the first stride more than subsequent strides. Time in covering the first 6 yd is determined by the location of the center of gravity which is controlled mainly by a shorter distance between the starting line and front block and, to a lesser degree, a shorter distance between the blocks.
6. The elongated stance produces greater velocity as the runner vacates the blocks; however, after a 10-yd distance, no advantage remains.

Force Against the Blocks

1. The pattern of forces is characteristic of the particular athlete.
2. Top class sprinters exert block force with both feet at the same time.
3. Strong rear leg action is characteristic of better starts.
4. Block force acts first in front of the center of gravity and then behind.
5. The greatest amount of force is placed on the rear leg; however, the lead leg is in contact with the block for a greater period of time and, therefore contributes more to block velocity.

6. The angle of the rear knee affects force against the rear block. At 180° the rear knee and hip extensors exert little rear block force.
7. No relationship exists between speed of charge and force exerted.
8. Total body weight and force exerted are related.
9. An inverse relationship exists between body weight and speed of the charge (-0.51).
10. Using the bunch and medium start, a significant relationship exists between forces on the front block and a 10-yd dash.
11. Using the elongated start, a significant relationship exists between block force and 10-yd dash times. No relationship was found using the bunch and medium starts.
12. Force against the blocks will vary according to body weight, experience of the subjects, knee angle, and block spacing.
13. A 20-in spread produced a total block force of 386 lb, an 11-in spread produced 346 lb.
14. In comparing block pressure with foot spacings, the elongated start provided the most powerful force: 26-in spread - 404 lb; 20-in spread - 386 lb; 11-in spread - 346 lb, and a 16-in spread - 303 lb.
15. Block force does not guarantee a rapid start and rapid acceleration which may be more closely tied to body lean, angle of the legs, and center of gravity.

Angle

1. A 96° angle was better than a 87° angle for the front knee and the 120° angle superior to the 128°-135° angle for the far knee in junior high boys.
2. Use of varied angles failed to affect significantly the sprint start in college subjects.
3. A knee angle of 180° was significantly slower than angles of 90° and 135° from 0-10 yd and 0-30 yd.
4. A rear knee joint angle of 165° (medium spacing) that elevates the hips improved 50-yd dash times.

Length of the Hold

1. RT to the gun is improved when the stimulus can be anticipated. Rhythmic digit starting in football, for example, yields faster movement times than non-rhythmic signals. It also logically follows that RT is improved when sprinters are able to anticipate the stimulus and react *with* the sound of the gun.

2. The optimum time of holding sprinters by starters is 1.5-2.0 sec. Some starters are surprisingly consistent in their "hold" time as determined by observation, allowing an anticipated movement with the sound of the gun.

The Middle Phase

There is no reduction in speed during this part of the race; however, the power used in the start is replaced by a more relaxed movement as full running speed is reached. A sprinter reaches maximum speed in approximately 6 sec and is capable of holding this pace for approximately 15 yd before some deceleration occurs. During this phase, coasting occurs through a reduction in tension and adequate striding without a fighting effort. Long, smooth striding as well as sufficient strength and explosive power aid in improving the coasting phase. Relaxation is essential after maximum speed is reached. "There are about 45 strides in a 100-yd race. The muscle groups involved in each stride undergo a lightning fast switch from contraction to relaxation. The sprinter's secret is the ability to make this switch skillfully and to maintain a relaxed style of running without decreasing the force of the drive" (79). Proper form described during the "middle phase" was extracted from the literature as described by experts in the area of sprinting.

Body Position

1. The body gradually reaches its proper running posture at 15-20 yd with maximum sprinting speed attained slightly later in the race. The body may be nearly upright or leaning as much as 25° depending upon the individual. The actual degree of lean is dependent upon: wind resistance (greater forward lean is needed to offset a headwind and almost no lean to reap the benefits of a tailwind), and, rate of acceleration (forward lean is most exaggerated when acceleration is the greatest such as at the start of a race and least noticeable when maximum speed is attained) with only a slight lean required to counter the wind resistance created by the speed of the sprinter (13). Too much lean prevents a full stride while an overly vertical trunk position diminishes forward drive.
2. The eyes are kept straight ahead, focusing on the track approximately 25 yd ahead.
3. The head is held in a natural position, the facial muscles are relaxed and the chest is firm and open to give the impression of running with the chest as a shield.

Leg Action

1. As a result of decreased body lean and increased acceleration, there is a change from power to speed in a relaxed sprint.
2. The knee moves high enough to secure maximum length of stride in and up and out motion.
3. The leg movement is always a pushing and not a pulling motion; therefore, the center of gravity must be in front of the planted foot. Correct body position will make this possible.

4. Film analysis shows that runners at all distances plant the foot on the outside edge as first contact is made with the surface. Thus, the ground is first contacted on the outside edge of the sole high on the ball of the foot (joints of the little toe). Also, with the slightest load on the foot at ground contact, a riding onto the full sole occurs as the foot is planted, causing the heel to touch the ground. Ground contact should be smooth and soft with as little shock as possible.
5. The toes are pointed straight ahead, both during the power and the recovery phase.
6. There is a resilient bounce from the balls of the feet which is produced by a final flip of the toes as the foot leaves the surface. At ground/toe contact, the knee is flexed and the ankles relaxed to permit upward spring and start of another cycle in the series of jumps characterized as sprinting. Driving time is shortened by pulling the toes upward toward the knee immediately after ground contact occurs. Also, the more weight that is placed on the driving leg, the greater the driving force against the surface.

Arm Action

1. Broom (7) indicates that the best arm action for a sprinter has the following characteristics: the movement is directly backwards and forwards from the shoulders, with the elbows close to the side. The arm acts independently of the shoulders, as though the upper arms were connected by a pin to the shoulder and free to move as on a toy doll. The angle at the elbow is slightly greater than 90° so that the hand in the backward movement travels beyond the hip. The action matches the leg action in force and range of movement. The arms actually lead the legs, and a high quality leg drive is only possible when the arm action is in tune with it.
2. The maximum range of movement of the hands is from a point near the height of the shoulder to a point out from the ilium. The hands do not swing so far that they pass behind the body. Forward arm action never continues above the shoulders nor backward more than 6-8 in beyond the hip.
3. The hands are held as naturally as possible in a half-closed manner.
4. Arm movement serves to assist the ground-reaction of the sprinter in attaining maximum upward and downward ground thrust in preparation for the next stride. Thus, arm acceleration and full cooperation of the arms with the legs are major concerns in sprinting.

Ideal stride involves the execution of 4½-5 strides/sec with stride length ranging from 7-8½ ft and optimum stride being approximately 1.17 times an individual's height, plus 4 in (28). Stride length is obviously an acquired, alterable variable that affects sprinting speed. Certainly, any increase in stride length, without a reduction in the rate of leg movement will result in improved sprinting time.

There is a significant relationship between the mean length of one cycle (one stride) and the mean angle of the leg with the ground at touch (23). A long stride should be cancelled out by a decrease in the angle between the leg and ground at contact; however, this is not the case.

Hubbard (47), in his kinesiological analysis of running, indicated that sprinting speed is improved by increasing the length of the stride and maintaining the same rate of leg movement. As stride is increased, however, strength becomes a limiting factor since this increase requires additional dynamic strength–thus, the basis for strength training involvement along with flexibility and sprinting training.

Broer analyzes running speed and sheds additional light on its improvement:

> Speed of running is increased by increasing the propulsive force and/or the length of the stride and the two are interrelated. Increased propulsive force gives more upward force which, resisting gravity, keeps the body in the air longer allowing it time to move farther, and, more forward force which makes the body move forward faster in the time allowed and thus farther before it contacts the ground. The longer stride lowers the center of gravity and to avoid superfluous vertical motion which would detract from the forward motion, the supporting knee is flexed more. This additional flexion puts the muscles of the leg into a position for more powerful drive and a longer stride. Lengthening the stride to the point where a resistive phase is introduced (the foot strikes the ground ahead of the center of gravity) reduces the speed.(6)

Thus, stride length increases are mechanically advantageous until a point is reached where a resistive phase is introduced.

The Finish

There are three basic types of finishes: straight running form, the shrug, and the lunge. Most experts feel that any change in proper running form as one approaches the finish line will detract from forward propulsion and decrease speed. Therefore, straight running form to a point several feet beyond the finish tape appears to be mechanically advantageous. Not all sprinters subscribe to this theory and contend that an advantage is gained by shrugging the shoulders, lunging or even turning as they approach the finish line.

There is no evidence to suggest a change in style as one approaches the finish line. As mentioned in Chapter 1, any sudden acceleration at the latter part of the racing distance can only occur if the runner is not at maximum speed.

As a kind of afterthought, it must be mentioned that a few athletes have used the standup rather than the conventional crouch start. Some investigators have reported faster times for sprinters using this technique. Ward's research (77) is worthy of view concerning this topic.

It is difficult to determine whether sprinters are well portrayed on Greek vases and show runners well upon their toes, knees lifted high, bodies erect, and arms swinging vigorously. These factors are also stressed by modern day coaches. Archie Hahn's book, *How to Sprint*, published in 1925, remains surprisingly accurate today and combines with the books by Lloyd Winter, *So You Want To Be a Sprinter* (new ed. 1974) and by Dintiman, *Sprinting Speed: Its Improvement in Major Sports Competition*, published in 1971, as the only three books ever written that deal entirely with sprinting.

SUMMARY AND RESEARCH NEEDS

It is impossible to describe the characteristics of champion sprinters. Individuals vary in height, weight, length of levers and anthropometric measurements with no apparent tie-in with sprinting ability. While sprinters appear to possess a high degree of flexibility and strength, conclusive evidence is unavailable at this time. Sprinters are superior to distance runners and other athletes in reaction time. Also, no circulatory, respiratory and/or metabolic advantages have been identified to date, although some exciting research is underway dealing with sub-maximal, maximal and recovery heart rates.

There is some physiological support suggesting hereditary influences on speed of movement.

The medium start with variations among individuals is the most effective over the entire racing distance. Suggested ranges for foot spacing, hand spacing, lean and knee angles have been identified for maximum results.

The champion sprinter possesses a high knee lift, long stride and forceful push off the rear leg. Mechanically sound form throughout the racing distance has been identified although styles vary from individual to individual with no proved disadvantage.

Experimental research dealing with form improvement is lacking. There is little evidence to suggest that a change to mechanically sound movement actually improves sprinting speed. The various types of finishes (straight running, shrug, or lunge) have also never been compared and choice remains entirely theoretical. Form is undoubtedly important. The question is just how important are corrections of minor deviations and is time justifiable in terms of improved speed of movement.

A comprehensive quick assessment technique for identifying individual weaknesses is desperately needed. Also, a thorough analysis and comparison of the physical characteristics of champion, average, slow sprinters and nonsprinters is needed. The importance of fat reduction, weight reduction, flexibility, strength, circulatory changes, red and white muscle properties need to be determined. Key characteristics of a sprinter have not been identified.

Hay (36) imposes additional questions that have implications for research dealing with the start: Do findings of male sprinters apply to women also? What is the optimum angle for each starting block? How should the sprinter's weight be distributed in the "set" position? What is the optimum design for starting blocks? Should the faces of the blocks be curved or flat? What materials should be used on the face of the blocks? Should the tips of the spikes or the soles of the shoes bear on the face of the blocks? Should the block be large enough to support the heel as well as the forward part of the foot? Or do all these factors have so little effect on the final outcome that they can be considered irrelevant?

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3. PHYSIOLOGICAL FACTORS AFFECTING SPEED AND ITS DEVELOPMENT

This chapter examines speed improvement occurring through physiological changes in muscle and joint tissue, circulation and the nervous system through commonly used supplementary programs (any program other than sprint training). Studies are reviewed relating to sprinting speed and explosive power, flexibility, reaction time and strength. Each is examined in these areas to determine: 1) importance of the quality in the attainment of maximum sprinting speed, 2) relationship between the quality and sprinting speed, 3) degree to which the quality can be improved, 4) best training method of improving each quality, and 5) subsequent effects of improvement upon sprinting speed.

Explosive Power and Speed

Explosive power or the ability to exert a fast, maximum force against resistance in a minimum time (amount of work per unit of time) is important to sprinters in leaving the starting blocks and in accelerating to maximum speed. Block force varies according to weight, experience, knee angle and spacing. Furthermore, high block force does not guarantee a rapid start or rapid acceleration. With proper acceleration, however, great force is advantageous.

Although it has been hypothesized that velocity of muscular contraction is restricted by the antagonistic muscles which, as the theory goes, cannot relax with the necessary speed to avoid limiting the action of the agonistic muscle. the theory is not supported by research. Numerous researchers, on the contrary, report no relationship between tests of explosive power and agonistic leg muscle strength (36, 70, 79). Clarke and Henry (15) report correlations of .11 (hip joint) and -.04 (knee joint) between Sargent jump scores and antagonistic muscle strength of the leg muscles in these areas.

Attempts to improve explosive power have centered around training programs designed to develop strength and speed, since these factors are largely responsible for the body's initiating a rapid, vigorous movement from a stationary position. Researchers are in general agreement that explosive power can be improved. Vertical jumping ability has been shown to increase significantly following six weeks use of a 3-lb ankle spat on each foot (1).

Attempting to attain maximum height on each trampoline jump for three minutes daily over a five-week period also significantly improved vertical jump scores (8). Improved explosive power may aid the propulsive force of the legs and feet against the blocks and improve acceleration to maximum speed. Additional research is needed to verify this theory.

Flexibility and Speed

In determining the importance of flexibility to speed of movement it is essential that both static flexibility (maximum degree of flexion or extension) and dynamic flexibility (flexibility of motion) be considered. *Static* flexibility has been the focus of research in the past. Measurements are taken to determine the degree to which a joint is extended or flexed and these measurements correlated with performance, or increased through training to determine subsequent effects upon running speed. *Dynamic* flexibility is touched upon by De Vries (20), who states: "How easily the joint can be moved in the middle of the range of motion – where speed is necessarily greatest - is quite another factor."

Dynamic flexibility or the amount of torque needed to move a joint through the complete range of motion at varying speeds has been found to be affected by viscosity or heavy muscle mass (one-tenth of the torque is passive movement) and, predominantly, elasticity and plasticity. Inertia and friction appeared to be insignificant factors (94). Stretching of connective tissue does not appear to affect elasticity and plasticity.

Increased flexibility is limited to certain *unalterable* factors such as the bony structure of the elbow and knee joint, excess bulk in a heavily muscled individual, and calcification. According to the findings of Ramsey and Street (68), resistance to muscle flexion is largely due to the fascial sheaths covering the muscle and the sarcolemma of the fiber. Flexibility in the elbow and knee is generally not a factor affecting sprinting speeds providing complete extension of the knee is possible. The major areas of importance to the sprinter are ankle flexion and extension, hip flexion and extension, and shoulder flexibility that allows maximum free arm movement. Limiting factors for *ankle, hip and shoulder flexibility* that can be altered with training are imposed by the soft tissues: muscle and its fascial sheaths, connective tissues (tendons, ligaments, joint capsules) and skin (20).

Specificity of Flexibility

Although conflicting evidence is reported, the majority of researchers have concluded that flexibility is specific to the various body joints (19, 35, 36, 38). Dickinson (23) states that flexibility is not only specific to the joint but also to the individual movements of the joint.

Although Sigerseth (77) uncovered bilateral flexibility tendencies among football players, other investigators (35, 38) have found high correlations between flexibility measures of the right and left body sides in the same individuals. Research also indicates that, with few exceptions, flexibility and various anthropometric measures are unrelated (49, 54):

1. Sit-and-reach flexibility and prone and supine back extension were found to be unrelated to leg length or trunk length (85).
2. Hip flexion was found to decrease significantly with increased neck size, front-to-rear (84).
3. A positive relationship has been uncovered between somatotype and static flexibility (3, 84).

Improvement of Body Flexibility

Static flexibility in the major joints can be improved in a relatively short period of time (two to three weeks) either through *static*-steady pressure applied at the extreme range of motion in a particular joint, or through *ballistic exercises* bouncing to attempt to force the body beyond the normal range of motion (21, 24, 56, 61).

Static procedures appear to be more practical and efficient (producing equal flexibility changes) and have been found to relax the stretched muscles, reduce probability of injury due to overstretching, and eliminate much of the soreness accompanying ballistic procedures.

Effects of Increased Flexibility Upon Speed.

Flexibility has long been recognized as an important aspect of training for sprinters. Morehouse and Cooper, noted physiologists, theorize by stating: "There is a maximum rate of movement of the legs in sprinting. This maximum rate is determined by the length and weight of the legs, the weight of the body, the mechanics of running, and the flexibility and strength of the muscles" (60).

It is also hypothesized that flexibility increases may result in an increased stride without a reduction in the rate of leg movement and, at the same time, result in a decreased expenditure of energy and a reduction in the resistance one must overcome while performing the running action.

> Flexibility aids in gaining a long stride in running. Great flexibility in the ankles, hips and trunks may overcome some of the disadvantages of possessing legs which are not extremely long. Short legs and inflexible joints

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are a poor combination for running performance. . . . Keeping the rate of the leg movement constant, the speed of running can be increased by lengthening the stride. (60)

Slow stretching procedures and proprioceptive neuromuscular facilitation reversal of antagonist exercises increased horizontal linear velocity of sprinting and hip joint flexibility. No change in stride length or angular velocity of the lower limb segments was noted (12).

Experiments by the author have considered flexibility training as a supplement to, rather than a replacement for, sprinting training. The mere attempt to increase body flexibility in key areas (ankle, hip flexion, hip extension, shoulder girdle) to study the subsequent effects upon running speed has been fruitless. Numerous studies of this nature have been conducted and, although flexibility is easily increased through static or ballistic exercises, no changes in running speed are noted.

Several researchers lend additional support to the value of flexibility in improving running speed. Olsen (62) indicates that the knees may be a factor in running, jumping and body maneuverability. Campbell (10) concludes that hip flexibility seems to have a positive effect on free running speed as measured by the 20-yd dash. De Vries (22) found no significant improvement in 100-yd dash times following an effective flexibility training program. Since the drive of the foot and leg against the surface is executed to full muscle extension, it would also appear that the hips should be as flexible as possible for optimum results. More refined measurement of dynamic flexibility is needed and should uncover additional information relating flexibility to running speed.

The use of flexibility training as a supplement to sprint training has been found to improve running speed. Table 1 shows the significance of changes in running speed (50-yd dash) following eight weeks of training. It is interesting to note that the group participating in both flexibility and sprint training increased significantly from the pre- to the posttest (mean increase, 0.42). Although nearly 1/10 sec difference exists between mean improvements of the flexibility/sprint training group and the group receiving only sprint training (Group II), this difference was not significant. When both flexibility and weight training were combined with sprint training (Group C), speed improvements were significantly higher than those attained by the sprint training group (24).

The physiological logic is tremendously supportive of the idea of increased speed through increased flexibility. Unfortunately, research does not always concur. In theory, sprinting speed should improve through improved range of motion, possibly through increased stride length, decreased muscle resistance, easier movement through the range of motion, and energy conservation. Lack of positive evidence in the studies cited may be due to measurement techniques. Researchers have tended to use static flexibility as the criteria when dynamic flexibility (through the range of motion) is more critical to speed. Also, flexibility training is a supplement to (not a replacement for) sprint training. Research designs that recognize this factor have uncovered positive results.

Reaction Time and Speed

Reaction time refers to the time elapse between the presentation of the stimulus and the first muscular movement or overt response. Germany's Olympic sprinter, Armin Hary, timed unofficially at 10.0 in 100 m, for example, is one of the fastest starters of all times and acquired a significant lead in the 1960 Olympics upon leaving the starting blocks. Although unique differences in Hary's starting form and American styles were uncovered, Hary undoubtedly developed superior reaction (simple) to the gun sound that has not yet been equalled in track competition.

Considerable research has been conducted to determine the value of reaction time in athletic competition. Although evidence is somewhat conflicting, some trends are evident that uncover valuable implications for athletes. One serious

TABLE 1. GROUP COMPARISONS OF RUNNING SPEED INCREASES USING CORRECTED MEANS

Group[a]	Adjusted Mean (Y)	Groups Compared	S.E. of the Difference	Diff. Between Adjusted Means	
A	6.01	A-B	0.04	0.04	NS[b]
B	5.97	A-C	0.04	0.09	NS
C	5.92	A-I	0.04	0.05	NS
I	6.06	A-II	0.04	0.36	**
II	6.37	B-C	0.04	0.05	NS
		B-I	0.04	0.09	NS
		B-II	0.04	0.40	**
		C-I	0.04	0.14	**
		C-II	0.04	0.45	**
		I-II	0.04	0.31	**

**$P < .01$

[a]A Flexibility and Sprint Training
B Weight Training and Sprint Training
C Flexibility, Weight Training and Sprint Training
I Sprint Training
II Inactive

[b]NS Difference not significant

limitation has been the tendency of researchers to measure reaction of a specific body part rather than total body reaction so vital to sprinting and performance in major sports competition. Findings are as follows:

Positive Findings (40, 46, 51, 65, 67, 88, 90, 96)

1. Reaction time (RT) and movement in time (MT) are positively related.
2. There is a significant correlation between RT and 75-yd dash time (R=.863).
3. RT and speed of an arm or leg movement are re'-ted.
4. Good sprinters possess better reaction time than poorer sprinters.
5. RT affects time variance by approximately 4% from 30-40 yd, 7% at 20 yd, 15% at 10-yd and 24% at 5-yd. Sprinters possess shorter RT than middle distance runners.
   Dash men .... .0.131 sec.
   Middle distance men .... .0.149 sec.
   Distance men .... .0.169 sec.
   RT is uninfluenced by block spacing.
6. RT is improved by exercise or warm-up unless a point of extreme fatigue is reached.
7. Varsity athletes possess better RT than intramural participants and nonathletes.
8. Grip strength and RT are related.

Negative Findings (17, 31, 41, 50, 58, 66, 76, 78, 80)

1. No relationship exists between RT and MT.
2. RT and 100-m dash time are unrelated.
3. RT and speed of an arm or leg movement are unrelated.

It is apparent that findings are conflicting; however, an analysis of studies utilizing total body reaction time, rather than just speed of a single limb movement, is more encouraging.

Improvement of Reaction Time

Reaction time can be improved with practice (5. 6, 41, 52. 72); however, it appears that the principle of specificity should be observed with practice simulating actual starting movements. Numerous studies in athletics have indicated how RT can be improved. A six-week training program consisting of four 30-min. sessions significantly improved total body RT of low fitness individuals (83). Bates (4) found that a five-week strength program significantly improved RT. Hitting reaction time was improved using a variable speed pitching machine (82). Isometric training significantly improved arm and leg RT after six weeks of training (59). Sprint starts and 25-yd dashes improved lower leg RT as did a calisthenic program (33). A six-week program (twice weekly) of sit-ups, push-ups, pull-ups, side straddle hops, and *sprint starts* increased lower leg RT by 14.63 msec (30). Genasci (28) found that total body RT improved following participation in athletic and physical education activities. Weight training has also been shown to improve RT (93).

Although some drugs may improve RT, their use in athletics is strongly discouraged and can be habit forming and harmful to health. Obviously, alcohol has an adverse effect upon RT and has been found to result in an RT reduction of 10% (.35 alcohol level in blood) and as high as 24% (1.4 alcohol level in blood).

Additional factors affecting RT are stimulus intensity and duration and the readiness state. The use of sharp, loud commands (hut, go, sound of gun) and bright colors result in faster RT than low intensity commands (13, 44, 69). The length of the preparatory period resulting in proper muscular tension and mental concentration is another key factor. Both a long period (5 sec or more) and a very short period (less than 1 sec, preventing the assumption of proper preparatory position) hinder RT. Holding the preparatory posture approximately 1-4 sec appears to be ideal for maximum RT with the tension greatest at the time of expected stimulus. Thus, anticipation of a loud signal with concentration on the motor response (leg lift, upward arm movement) produces greater muscular tension in preparation for the start.

Warm-up (formal or informal) does not appear to improve RT significantly (32, 42, 65, 75); however, no detrimental effects have been observed unless exercise is carried to a state of extreme fatigue (26, 29). There is apparently no significant difference in RT following strenuous exercise or a rest period.

The question of specificity or whether RT is specific to the body part (16, 55, 69) or operates under a condition of generality within the individual (74) remains in doubt. Additional light is shed on the value of RT in athletics by Henry (40).

> Twenty-four per cent of the total time variance at 5 yards will be due to RT, compared with 15 per cent at 10 yards, 7 per cent at 20 yards, 4 per cent at 30 yards, and less than 2 per cent at 50 yards. Furthermore, fast reactors are not fast runners. The reaction times only correlate 0.14 with 50 yard runner's times, which agrees with the results of another experiment in which the average of 60 finger press reactions was not significantly correlated (r = 0.28) with the average time on two 50-yard dashes. A third experiment also showed no correlation. Contrary to popular belief, individual differences in the reaction functions can be neglected except for very short distances, 10-15 yards at most.

Although Henry's statements argue against the importance of RT in athletics, they possess a wealth of evidence in favor of concentration on improvement of RT. The fact that RT becomes less a factor influencing movement time (MT) as

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the distance increases still fails to determine the effects of increased RT upon MT. Improved RT within the individual may significantly improve MT and running speed. The initial 15 yd of a 50-100 yd sprint are also extremely important with few athletes capable of rebounding from a poor start in championship caliber competition. A variance in total movement time of 7-24% for distances up to 20 yd is critical in athletics. Should improved RT reduce this variance, individual and team performance will also be greatly improved.

Strength and Speed

It has become apparent that the strength of the muscles involved in the sprinting action determines, to some extent, the maximum running speed of an individual. Strength appears essential to sprinting in 1) the drive from the starting blocks, 2) the leg drive against the track: it is the strength of the muscles in the hip, knee and foot and the ability to straighten these areas quickly that decides a large part of a sprinter's speed, 3) the attainment and maintenance of a long stride, 4) acceleration to maximum speed, 5) the powerful leg drive, and 6) maximum speed during the coasting phase.

Numerous studies have been conducted in the area of strength and speed; although some conflicting evidence is reported, considerable agreement is evident in certain areas. Research can be divided into four major categories:

1. Effects of increased strength upon speed of muscular contraction
2. Relationship between strength and sprinting speed
3. Effects of increased upper body and/or lower body strength upon sprinting speed
4. Effects of supplementary strength training programs upon sprinting speed

Increased Strength and Muscle Contraction

Research efforts in this area have been numerous since it had been the opinion of many coaches and physical educators in the past that weight training has a deleterious effect upon speed of movement due to increased muscle viscosity and added internal resistance. Karpovich and Zorbas (45) examined the effects of weight training upon the speed of movement of a single arm turning a crank in a frontal plane; Wilkin (87) studied this same movement while Clarke and Henry (15) concentrated on neuromotor specificity and increased speed from strength development.

Analysis of the data from these three studies revealed that: 1) weight lifters were slightly faster than Springfield College athletes; 2) weight training, over a period of one semester, had no slowing effect on speed of arm movement; 3) chronic weight lifters are not muscle bound and their speed does improve during a semester of weight training; 4) weight training did not increase the speed of movement significantly more than a semester of beginning golf or swimming; and 5) weight training can improve the speed of a simple arm movement.

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Additional support for increased speed of muscle contraction through weight training is provided by Masley (53) who concludes that six weeks of weight training significantly increased rotary arm movement speed above that of a similar group participating in volleyball. Yankosky (95) found that an 11-week weight training program improved all four movement speeds of arm and leg extension and flexion, although improvements were not significant. Whitley and Smith (86) conclude from their study that increased strength in the muscles involved in a specific movement makes it possible for an individual to execute a faster limb movement.

Brose and Hanson (9) tested the effects of a six-week period of overload training upon pitching velocity and accuracy using weighted balls and a pulley device to provide resistance in a simulated throwing position. Both programs produced significant increases in throwing velocity without impairing accuracy.

It is apparent from these studies that increased strength can improve speed of muscular contraction.

Strength and Speed Relationship

Although the early literature supported the hypothesis of independence between strength and speed of voluntary movements, evidence linking strength and speed continues to mount. It is now evident that a statistically significant relationship exists between strength and speed of movement. It is interesting to note that the majority of earlier studies showing low relationships between strength and speed used single limb movements (arm cranking, adductive arm swing, leg kick, vertical jump, wrist/arm movements, elbow flexion) as their speed measure and thus are only partially applicable to the value of strength in sprinting.

Rarick (70) obtained correlations of 0.64 and 0.61 between the time taken to cover the final 10 yd of a 30-yd sprint and the vertical jump. Harris (37) also uncovered a significant correlation of 0.59 between 40-yd dash times and the vertical jump with the use of the arms. A correlation of 0.47 was found by Gray, Start and Walsh (34) between leg speed and leg power. Although the above studies did involve valid speed measures, all were correlated with a test of explosive power which does contain an element of leg strength.

The relationship between lower extremity extensor/strength and 30-yd dash time was investigated by Ostrander (64) and found significantly related or 11-year-old boys. Willgoose (89) reports that boys with a higher strength index tended to be faster. It is also interesting to note that increasing the length of the stride requires additional dynamic strength (43) and that strength is also a function of speed and agility when running with the weight of a football uniform (71).

In a study by the author (25), 208 freshmen students were tested with a running start. Each subject was somatotyped and placed into one of five classifications:

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I Endomorphs (14 subjects): endomorphic component of 5 and over; no other component above 4

II Ectomorphs (55 subjects): ectomorphic component of 5 and over; no other component above 4

III Mesomorphs (42 subjects): mesomorphic component of 5 and over; no other component above 4

IV Endo-meso (15 subjects): mesomorphic component of 5 and over, endomorphy of 4 and above; ectomorphy below 4

V Mid-types (82 subjects): no component exceeding 4

Separate correlations were then computed within each body classification between the ratio leg strength/body weight and running speed with results shown in Table 2. It can be concluded that there is a significant relationship between the ratio leg strength/body weight and running speed.

Although the literature indicates that high scores in leg strength tend to be accompanied by fast sprinting times, a cause-effect relationship is not established. The next logical step is to examine the effects of increased leg strength in the muscles involved in the running action upon sprinting speed.

TABLE 2. CORRELATION COEFFICIENTS BETWEEN THE RATIO LEG STRENGTH/BODY WEIGHT AND RUNNING SPEED

Somatotype	N	Running Speed[a] Mean	Running Speed[a] SD	Leg Strength[b] Mean	Leg Strength[b] SD	r	Signif.
Endomorphs	14	6.98	.55	617.3	166.04	+0.60	0.01
Ectomorphs	55	6.19	.41	550.0	146.0	+0.62	0.01
Mesomorphs	42	6.12	.42	584.6	169.0	+0.71	0.01
Endo-mesomorphs	15	6.40	.49	601.2	161.3	+0.64	0.01
Mid-types	82	6.22	.40	561.9	138.4	+0.47	0.01

[a]50-yd dash time to the nearest tenth of a second

[b]Leg strength in pounds

Effects of Increased Strength upon Running Speed

A rapidly contracting muscle consumes most of its total energy in performing the contraction, leaving little available energy for the application of the external force. Optimum speed, unlike maximum speed, allows reserve energy for propelling the body forward as well as for muscle contraction. Kusinitz provides a practical example of this principle:

> During extremely rapid contractions, maximum energy is not applied to the levers to which the muscles are connected. This results in a loss of

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> running speed since energy wasted in the contractions is not available to the levers. This is why coaches try to teach their athletes to perform at optimum speed. This is the point at which the greatest force can be exerted with a minimum of energy loss (due to maximum speed of muscular contractions). Ideally, the greatest speed, accompanied by the greatest possible application of force, is the goal of the athletic coach. (47)

Kusinitz continues in establishing the importance of strength in sprinting indicating that with greater strength, increased tension is available at optimum speed for the rapid, forward sprinting movement of the body Thus, lower leg strength increases provide the physiological means for improved sprinting speed.

Researchers have directed their efforts toward the effects of increased upper body and/or lower body strength (usually through weight training) upon sprinting speed. One serious limitation of these studies has been the trend to consider weight training as a replacement for, rather than a supplement to, actual sprint training. This trend has seriously obscured the true value of strength training programs in improving sprinting speed.

Positive Findings:

To determine the effect of systematic weight training on power, strength and endurance, Capen (11) collected data from subjects in a weight training class at the University of Tennessee and a conditioning class at the same university. All subjects were tested at the onset of the experiment in the Sargent jump standing, Sargent jump running standing broad jump, 8-lb shot put from a stand, 12-lb shot put from a stand, and a 60-yd dash. The weight training group then engaged in a semester of systematic exercises while the conditioning group performed special exercises. An analysis of posttest scores revealed a significant improvement in both speed measures 300-yd run and the 60-yd dash. It was concluded that weight training, as used in this experiment, improved running speed and did not result in muscular tightness or decreased speed of muscular contraction.

Chui (14) conducted a similar study to determine the effects of systematic weight training on power as related to jumping, the shot put and sprinting the 60-yd dash. Improvement in running speed was only slight; however, it was concluded that there is a possibility that running speed can be aided through systematic weight training. Fishbain (27) placed 12 students in an experimental and a control group to determine the effect of weight training upon performance in the 35-yd dash, standing broad jump and 20-ft rope climb. The experimental group engaged in a nine-week weight training program while the control group was involved only in the regular physical education program. The experimental group increased significantly more than the control group in the 35-yd dash and broad jump.

O'Shea (63) used an eight-week training program of heavy resistance and low repetitions (4-5) to increase dynamic strength to determine subsequent effects on the 400-m run. Two additional groups trained with 9-10 and 14-15 repetitions with all three groups using four sets for the bench press, seated dumbbell curl and squat. All three groups improved significantly in both strength and the 400-m dash (4.4-sec mean improvement).

Barnes (2) equated two groups of boys (grade 9) on 100-yd dash times and randomly assigned subjects to a control and experimental group. One group received 14 weeks of physical education involving basketball, tumbling, volleyball and dodge ball while the other group spent equal time in progressive weight training using three sets of eight repetitions in half-squats, curls and full knee bends. Both groups ran weekly two 100-yd dashes for time with 15-min rest intervals between trials. The weight training group increased significantly from the pretest (13.4) to the posttest (12.7) showing a mean improvement of 0.7 of a second. In the control group, one subject ran slower and six showed no improvement.

Masley (53) also uncovered larger improvements in both speed and endurance for subjects involved in a weight training program than those participating in volleyball.

Negative Findings:

Results, however, are not all as encouraging as those previously cited. Kusinitz and Keeney (48), for example, conclude from their study of the effect of weight training on the health and fitness of adolescent boys that weight training merely had no deleterious effect upon speed of movement, agility and flexibility. Obviously, researchers and coaches in the past suspected that weight training adversely affects running speed. Hellixon (39) randomly assigned 24 subjects to a control and experimental group in an effort to determine the effects of near-maximum weights on the running and jumping ability of first-year high school track performers. An experimental group received weight training five days weekly for six weeks while a control group remained idle. No significant difference was found between either group on the measures, vertical jump, 100-yd dash, running broad jump, and 1-mi run.

Woodall (92) tested the effects of increased strength in the arms and upper body upon running speed. Twenty-four subjects were placed in an experimental group and control group on the basis of their 100-yd dash times. After a six-week period of weight training administered to the experimental group, all subjects were retested in the 100-yd dash. No significant difference was noticed between the 100-yd dash times of the two groups. Cummings (18) tested the hypothesis that increased hip flexor strength would improve running speed. Pre- and posttest 100-yd dash times were recorded eliminating reaction time, impulsion and acceleration from a motionless position. The experimental group performed isotonic exercises thrice weekly to improve hip flexor strength. No significant improvements were noted in running speed. In a similar design Plumb

(68) reports no significant improvement (0.4 sec) in sprinting speed following a nine-week weight training program.

Blucker (7) reports that significant leg strength increases failed to improve running speed significantly. Negative findings were uncovered by Winningham (91) in his study of the effects of training with ankle weights on running speed. Training with 2- and 5-lb weights was found to hinder 100-yd dash times. Rarick (70) infers from his study that strength beyond a certain optimum is not of much importance in speed events. Meisel (57) and Campbell (10) also report negative findings. Meisel revealed that an 18-session progressive resistance program increased leg strength; however, it significantly reduced free running speed. Campbell indicates that increased leg strength appears to have a slight slowing effect on free running speed.

It should be pointed out that the manner in which strength was developed through weight training (control of variables such as weight, speed of contraction, repetitions, sets, rest interval, muscle involvement) determines the degree to which sprinting speed is favorably or adversely affected. A program involving heavy weight, slow contractions and few repetitions may be ideal for strength improvement but it can hardly be expected to improve sprinting speed.

Supplementary Strength Training Programs and Speed

In one of the few studies that considered strength and flexibility training as supplements to actual sprint training, 145 subjects were randomly assigned for an eight-week period to one of five training groups: 1) flexibility and sprint training, 2) weight training and sprint training, 3) flexibility, weight training and sprint training, 4) sprint training and 5) inactivity. The study was done to determine whether a flexibility training program (designed to increase flexibility in the major joints), a weight training program (designed to increase leg strength), and the combination of both training programs would affect running speed when used as supplements to the conventional method of training sprinters. All 145 subjects were tested for running speed as measured by the 50-yd dash with a running start, body flexibility as measured by the Cureton Flexibility Test, and leg strength as measured by the leg dynomometer with use of the belt. Upon completion of the eight-week training period, each subject was retested in these same areas. The two groups that received flexibility training increased significantly in each of the four flexibility measures. All groups, except the inactive, increased significantly in leg strength and running speed. Analysis of covariance was computed to determine whether the training programs produced significantly different improvements in each of the variables. The Newman-Keuls Multiple Range Test was utilized to compare all possible combinations with the major conclusions listed below:

1. The flexibility training program, used as a supplement to sprint training, did not improve sprinting speed significantly more than only the sprint training program.

2. The weight training program, used as a supplement to sprint training, did not increase sprinting speed significantly more than the sprint training program; however, a difference in adjusted means of only 0.01 of a second prevented significance at the .05 level.
3. The use of both flexibility and weight training, as supplements to sprint training, increased sprinting speed significantly more than the sprint training program (24).

Sweeting (81) used a similar design to test the combinations of running, weight training and weight training/running upon sprinting speed as measured by a 30-yd dash. Analysis of variance revealed that systematic running increases sprinting speed significantly more than a weight training program involving equal training time, and is as effective as the combination programs of running and weight training. Weight training alone, as indicated in studies cited previously, failed to improve 30-yd dash times significantly more than no training at all.

Schultz (73) tested the effectiveness of repetitive sprinting and weight training in improving 60-yd dash times. Repetitive sprinting alone resulted in a mean improvement of 0.31 of a second while the combination of both repetitive sprinting and weight training produced a mean improvement of 0.33 of a second.

Kusinitz (47) also examined the effects of supplementary weight training on running speed (50-yd dash, 60-yd dash, 300-yd shuttle run). The experimental group participated in weight training and running three times weekly and running only on two additional days while a control group participated only in a daily running program five times weekly. It was concluded that weight training and running are more effective in improving both strength and running speed than running alone. The amount of speed changes due to progressive weight training and running was not significantly related to the amount of changes in strength.

When weight training is used as a supplement to sprint training, results are encouraging. It is hypothesized that much greater speed improvements will be uncovered when weight training programs are used in experimental work control training variables in a manner most conducive to the development of sprinting speed as described in Chapter 4.

SUMMARY AND RESEARCH NEEDS

Supplementary training programs of strength/power, flexibility and reaction time are essential to the development of maximum speed potential. These programs should be used in conjunction with systematic, individualized sprint training. The principle of specificity should also be followed in tailoring each supplementary program to individual needs, designing exercises, and in variable control. Warm-up appears to have little effect, beneficial or detrimental, upon sprinting performance. There is enough evidence to suggest that a formal warm-up routine, designed to elevate body temperature 2° F, could benefit some individuals when used prior to a sprinting effort.

There is a need for future researchers investigating supplementary programs to measure dynamic strength and flexibility as opposed to static movements. There is also a need to determine the effects of new methods of improving explosive power (hopping and jumping exercises; high speed, heavy load weight training; skipping with weights; optimal overload using 8-10 oz ankle spats, maximum effort exercises) upon block force, starting time, stride rate, stride length and sprinting speed.

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4. TRAINING THE SPRINTER

The majority of needed research lies in the area of training the sprinter. In fact, so-called supplementary programs (strength/explosive power, flexibility and reaction time training) have received more attention from researchers than sprint training programs. This chapter attempts to analyze important research in miscellaneous areas that directly affect sprinting speed, supplementary training programs and, finally, the critical area of sprint training programs which includes both sprint-resisted and sprint-assisted training.

ENVIRONMENTAL CONDITIONS

Deviations in sprinting speed because of extreme heat and humidity do occur; however, there is no evidence to clearly separate psychological and physiological causes.

Wind Velocity

According to Hill (38), external work done in overcoming air resistance is proportional to the square of the linear dimensions of the surface area. He therefore concludes that wind resistance should be the same regardless of body size. Cureton (16) indicates that air resistance requires approximately 2.8% of propelling force at a speed of 30 ft/sec requiring .195 hp on a quiet day. An arching wind of 1-6 m/s produced strange results for college sprinters. Mean times at 1 and 2 m/s were faster than at no wind; however, assisting wind of 3, 4, 5 and 6 m/s appeared to retard 50-m dash times (65).

ERGOGENIC AIDS AND SPEED

An attempt to uncover ergogenic aids that increase work capacity, delay fatigue, expedite recovery and improve sprinting speed without harming health or causing physiological and psychological dependence is a difficult task. Yet, it is common knowledge that athletes in track and field do occasionally resort to various forms of dangerous aids. An aid of any type that improves performance and is not dangerous to health must be considered a valuable supplement to athletics. However, such aids are not easily discovered.

The literature is replete with studies concerning the effects of various aids upon athletic performance. The following is a summary of findings as viewed by four leading texts in physiology of exercise (2, 20, 26, 42).

1. *Salt supplements* only assist in utilizing normal energy output and do not aid performance. Increased salt intake will decrease the incidence of muscular cramps and premature fatigue and reduce the probability of heat stroke, cramps or exhaustion for individuals who lose more salt through perspiration than is consumed.

2. *Alkalies* would appear to aid performance by reducing elevated blood acid accumulation occurring during exercise; however, neither performance nor sprinting speed is affected.

3. *Benzedrine* is a dangerous drug capable of producing addiction, insomnia and circulatory collapse. Its use in athletics as a means of removing inhibitory mechanisms is highly undesirable and unethical. Its effect upon improving sprinting speed (not an endurance activity) is questionable with no significant improvement evident.

4. *Cane sugar* (two to three lumps) or dextrose tablets have been shown to improve times in long-distance races significantly; however, no appreciable effect in short sprints is noted when psychological effects are controlled through the use of placebo cubes.

5. *Ultraviolet rays* have been shown to improve sprinting speed, physical fitness and cardiovascular stress although the exact physiological basis is not well understood.

6. *Cigarette smoking* decreases the ability of the lung to take in and utilize oxygen, reduces the oxygen-carrying capacity of the blood due to carbon monoxide absorption, produces digestive disturbances and stress in habitual smokers, irritates the nervous system in young habitual smokers, and irritates the membranes of the throat and lungs causing a cigarette cough and greater susceptibility to infection. Performance is decreased in endurance-type activities. For some individuals, speed is also adversely affected.

7. *Vitamins,* administered in excess, do not appear to improve speed or athletic performance; however, vitamin deficiency (Vitamin B_1 and C) does hinder performance. Vitamin B_1 deficiency is common, and a supplement should be used to increase the fitness of individuals lacking in Vitamin B_1 (thiamine, found in unmilled cereal, grain germ, bran oats, bread, flour and macaroni and used for the oxidation of carbohydrates)
8. *Caffeine* taken in various forms (tea, coffee, cola-nuts, cola) does not affect sprint running.
9. *Hormones* and other steroids appear to elevate physical fitness and cause weight gain; they do not significantly affect speed.
10. *Oxygen breathing* just prior to a short sprint appears to aid performance. Sprinting speed may also be aided by forced breathing of natural air or oxygen inhalation to enrich the lungs with oxygen prior to the race.
11. *Cocaine* has been shown to expedite recovery and improve endurance; however, it is a dangerous drug capable of causing addiction and does not affect sprinting speed.
12. *Special foods* such as fruit juices, gelatin and wheat germ oil do not affect sprinting speed.
13. *Phosphates* (double the daily intake) appear to improve work capacity and endurance and expedite recovery following exercise; however, there is no evidence of improved speed.
14. *Coramine and Metrazol* have no value in improving running speed.
15. *Gylcine and niacin* administered together have no affect upon sprinting speed.

WARM-UP

The physiological logic supporting the value of warm-up for improved sprinting speed is overwhelmingly favorable. Since muscle contractions are dependent upon temperature (increased muscle temperature improves work capacity) and exercise increases muscle temperature, it is assumed that warm-up is necessary in athletics for improved performance and reduced incidence of injury. Additional physiologically-based findings provide further support (17, 57, 69, 76):

1. An exercised knee joint contains larger amounts of synovial fluid which should contribute to more efficient movement and lack of stiffness.
2. Maximal oxygen uptake is higher following warm-up with the O_2 requirements for exercise also reduced. Unfortunately, VO_2 is not a limiting factor in sprint events.
3. Pulmonary resistance to blood flow is reduced and internal viscose resistance of joints and muscles decreased.

4. Elevated muscle temperature dilates the capillaries of the tissue and increases blood flow.
5. Elevated temperature increases metabolic rate at approximately 160% per 10°F rise and should improve a muscle's capability of conducting chemical activity.
6. Speed of muscle contraction is set by muscular and neurological control. The nervous system is basically unaffected by warm-up with the speed of an impulse stable unless affected by drugs, illness or fatigue. The muscular system *is* affected and, as heat is produced by the contractile process, relaxation of fibers, and fiber recovery, muscle contractile speed is improved by lowering the viscous resistance inside the muscle cell.

Unfortunately, the above logic is not fully supported by practical research. A review of 38 studies reveals conflicting evidence in practically every area of investigation. In the area of sprinting performance, findings are equally conflicting. The only consistency appears to lie in the finding that lack of warm-up does not increase the probability of injury (49, 76).

Conflicting evidence appears to be a result of several factors inherent in experimental design with results varying according to 1) type and length of warm-up, 2) environmental temperature, 3) control of psychological variables and 4) type of activity. Glidewell (32) brings out another important aspect indicating that warm-up is an individual matter with some subjects exhibiting consistently better performance with a certain type of warm-up. Another key factor was uncovered by Miller (56) who interviewed various athletes concerning the value of warm-up. Every athlete interviewed felt that by warming up better performance resulted. A study by Smith and Bozymowski (71) indicated that individuals with a favorable attitude toward warm-up had significantly better times on an obstacle race with warm-up than without, while those possessing unfavorable attitudes failed to improve with warm-up.

Still another area of discrepancy among researchers is the failure to determine whether body temperature was even elevated through a specific warm-up technique. Most studies did not use core temperature (oral or rectal measurement with the latter more accurate) or muscle temperature (measured by isolating the muscle and injecting a thermo-needle). A minimum of 2° (rectal) is recommended by De Vries (22) before warm-up is considered sufficient. Temperature is easily elevated to this point through muscular activity (1, 49, 68) and will slowly reside with cessation of activity with muscle temperature dropping about 2.5° C in 10 min and core temperature not falling back to normal until 30 min or so of inactivity, depending upon environmental conditions (68). In studies where warm-up was continued long enough to elevate rectal temperature or where rectal temperature was accurately determined as having risen, results tend to be favorable.

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Types of Warm-up

The following categories of warm-up methods encompass the majority of procedures in use today:

1. Formal – Utilizing the skill or act that will be used in competition.
2. Informal – General warm-up involving calisthenics or other means of preparing the entire body for activity.
3. Passive – Heat applied to various body parts in numerous forms such as hot showers, baths, massage, electric blankets, diathermy, sweat box, auto heater. No muscular activity.
4. Overload – Simulating the activity for which warm-up is being used by increasing the load or resistance such as use of weighted boots prior to a 100-yd dash or two bats prior to hitting in baseball.

Each of the above methods has been found by some researchers to improve performance although conflicting evidence is reported. Even general heating to increase rectal and muscle temperature through various means (artificially or by vigorous exercise) has been shown to improve performance (11, 12). Hill (38) takes a stronger stand on the importance of increasing body temperature, indicating that muscle contraction in animals is quickened approximately 20% by elevating body temperature 2° C and that such increases are possible in sprinters through the use of diathermy. Such an increase, it is suggested, may then make an 8-sec record 100-yd dash possible. Local heating of the involved body part only, however, induces early fatigue and decreases work capacity (14, 34).

Effects of Warm-up Upon Sprinting

Numerous investigators (6, 45, 69) have reported that warm-up significantly improves running speed while others report no such cause-effect relationship (10, 33, 39, 48, 72). One hundred-yard dash times have been reduced as much as .94 sec following intense formal warm-up. The previously mentioned study by Hill also suggests that running speed can be improved through the use of artificial heat. Speed of leg movement (one- and two-foot tapping and leg circling) has been found to improve significantly following high intensity informal warm-up (52). McWatt (53) found that the 12th and 13th practice starts yielded the fastest 15-yd dash times with an improvement of 0.2 of a second noted over the early starts in the subject field.

Conversely, Hutterly (40) found no significant difference in 440-yd dash times using various rest intervals (1 min, 4 min and 10 min) following formal warm-up. Thus, a 10-min cooling-off period had no ill effects upon speed, which may either support the retention of warm-up effects or the lack of need for warm-up prior to 440-yd dash competition. Mathews and Snyder (48) also report no significant effects on 440-yd dash time.

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It is interesting to note that no one has indicated that warm-up is detrimental to sprinting speed. Since sprinting involves large muscle groups in vigorous contraction, it is suggested that formal warm-up be utilized (15-30 min) to cause perspiration and involve slowly increasing accelerated repetitions under the racing distance until several repetitions at maximum speed can be performed without undue muscular strain. Since research indicates a marked increase in muscle temperature after 5-min of warm-up, which continues to rise for 25-30 min with test times recorded after a 25-min warm-up period (20), this length of time is recommended for the fairly well-conditioned athlete.

Injury Prevention

> The muscles most frequently torn during strenuous activity that has not been preceded by a warming-up period are the antagonists to the strong contracting muscles. These *cold* antagonistic muscles relax slowly and incompletely when the agonists contract and thus retard free movement and accurate coordination At the same time the force of contraction of the agonists and the momentum of the moving part exert a terrific strain on the underlying antagonists, with consequent tearing of the muscle fibers or their tendinous attachments. (57)

Although the preceding statement is generally accepted, there is only limited scientific evidence supporting the value of warm-up in injury prevention. De Vries (19) reports a higher incidence of muscle soreness among college males when the 100-yd dash was not preceded by warm-up. Only one study (76) deals with sprinters and a 60-yd dash with and without warm-up.* No significant difference in the incidence of hamstring injury (with warm-up 7, without warm-up 5) was found even though it appears that the ability of the hamstring muscles to extend on the forward stride of the sprinter reduces the possibility of injury to these posterior muscles. Although other researchers have reported insignificant differences in incidence of injury without warm-up (47, 73), it appears that warm-up is essential preceding large muscle activity of a vigorous nature such as sprinting. Its true value may be a personal matter which must be determined by each individual athlete.

SUPPLEMENTARY TRAINING PROGRAMS

There is evidence to suggest that strength/explosive power training, flexibility training and reaction time training, used as supplements to actual sprint training, will improve sprinting speed. An attempt is made here to identify specific training routines and control of variables that have been effective in meeting the objective of improved sprinting speed.

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Order of Use

The placement of supplementary training programs into a practice schedule is critical if maximum results are to be obtained. Our knowledge of the immediate physiological changes brought about by various training programs allows a logical placement (22):

Supplementary Program	Order in a Practice	Rationale
Flexibility or stretching exercises	1	Improves range of motion, provides a warm-up effect and decreases resistance through the range of motion.
Sprint training or sprint-assisted training, and anaerobic training RT training	2-4	Rapid leg rates and a long stride are only possible when the muscles are free from fatigue lactates. At the close of a practice session, fatigue products inhibit muscle contraction and prevent maximum stride rate and length.
Strength/explosive power training		A 36-48 hr period of recovery is necessary following such a program. Earlier placement would reduce the effectiveness of all other supplementary programs and sprint training programs.

Weight Training Exercises

Weight training exercises have constituted the most successful supplementary program in elevating the strength of muscles involved in sprinting action and, ultimately, sprinting speed. Programs used by researchers are generally based on the following principles:

1. Exercises should be chosen that simulate actual sprinting form and involve similar muscle action.
2. Weight training should be used as a supplement to actual sprint training and follow the sprint training workout thrice weekly.
3. If increased speed of muscle contraction is the desired outcome, exercises should be performed explosively for each repetition.
4. Rather heavy weights (1-3 RM) are needed to develop high levels of strength and explosive power to aid the transformation of red to white muscle and a subsequent faster contraction.
5. Exercises should be performed in an order that alternates muscle groups, limits changing of weights, and places the iron boot and dumbbell exercises together.

6. Arm exercises should be increased 5-10 lb and leg exercises 10-20 lb when upper limits are attained.
7. The rest interval between sets and exercises is important to the development of cardiovascular/respiratory endurance and reduced workout time.
8. Hamstring stretching exercises (toe touching, sit-ups, hurdle exercise) should follow each workout to prevent any muscle shortening.

Table 1 shows most weight training exercises used by past researchers and the variable control that has been most effective in providing strength increases and subsequent increases in sprinting short distances when used as a supplement to sprint training. The variable control shown is in keeping with the basic principles discussed previously. Not all researchers have used the same variable control. By far the most common variable has been three sets of 8-12 repetitions, use of the 8 or 10 RM, absence of any of the competitive lifts, use of general exercises without concern for those involving the muscles of the sprinting action, and little control over the speed of contraction or rest interval between each set and exercise (4, 15, 23, 35, 64). Still other researchers have emphasized only upper torso exercises to determine their effect upon sprinting short distances (77). O'Shea (64) is one of the few researchers who has used heavy resistance and low repetitions representing the common approach utilized by champion sprinters of today.

Reaction Time Training

Reaction time training involves high speed starting practice with the gun and should occur in the absence of fatigue to simulate competitive conditions. It is doubtful that other unrelated reaction time drills would be of any value unless such movements simulated actual sprinting form (first arm movement forward, propulsive force of legs against the blocks, etc.). Henry (36) indicates that a sprinter requires approximately 0.10 sec to respond to a signal and 0.5 sec to leave the blocks after the stimulus. Even such a small fraction of time is critical to sprinting. Nakamura (60) found that competition or use of the start in actual races caused only slight improvement in RT for 10 subjects. McConnell (43) found no significant improvement in times required to cover 10 yd following a training period for 12 experienced sprinters. The fastest RT also did not necessarily produce the fastest start.

Additional experimentation is also needed to determine the yield from concentration upon the sound of the gun (sensory set) or the first muscular movement forward (motor set). "Set," in sprinting, refers to the direction of the subject's attention prior to an anticipated movement. Although "motor set" is commonly accepted as yielding better RT, there is no research support. In fact, Henry (36) found that college-age men and women react 2.6% slower and move

TABLE 1. BASIC WEIGHT TRAINING PROGRAM FOR SPRINTERS

Exercises	Repetitions	Sets	Starting Weight	Speed of Contraction	Interval[a] Min Sec
Basic Program:					
Two-handed press	3-5	3	3 RM	Rapid	2 to 30
Squat (¾, ½)	3-5	3	3 RM	Rapid	2 to 30
Rhythm lift	Maximum	2	Squat Wt	Rapid	2 to 30
Two-handed clean and jerk	3-5	3	3 RM	Rapid	2 to 30
Upright rowing	6-9	2	6 RM	Rapid	2 to 30
Sprint-arm exercise	6-9	3	5 lb	Rapid	2 to 30
Two-handed snatch	2-5	3	3 RM	Rapid	2 to 30
Knee flexor	2-5	3	3 RM	Rapid	2 to 30
Modified hip flexor	3 8	3	6 RM	Rapid	2 to 30
Hamstring stretching[b]	15-25	2	Body only	Slow, static	0-30
Alternate I (Lower Torso Concentration)					
Bench press	3-5	3	3 RM	Rapid	2 to 30
Squat walk	6-9 steps	3	6 RM	Rapid	2 to 30
Heel raise	6-9	3	6 RM	Rapid	2 to 30
Straddle lift	3-5	3	3 RM	Rapid	2 to 30
Hip flexor	3-5	3	3 RM	Rapid	2 to 30
Supine leg lift	3-5	3	3 RM	Rapid	2 to 30
Leg abductor	3-5	3	3 RM	Rapid	2 to 30
Balance shoot	6-9	3	6 RM	Rapid	2 to 30
Hamstring stretching	15-25	2	Body only	Slow, static	2 to 30
Alternate II (Lower Torso Concentration)					
Pull-over (Straight)	6-9	3	6 RM	Rapid	2 to 30
Squat jump	6-9	3	6 RM	Rapid	2 to 30
Modified leg lift	3-5	3	3 RM	Rapid	2 to 30
One-legged squat	3-5	3	3 RM	Rapid	2 to 30
Knee extensor	3-5	3	3 RM	Rapid	2 to 30
Knee curl	3-5	3	3 RM	Rapid	2 to 30
Quadriceps exercise	3-5	3	3 RM	Rapid	2 to 30
Modified leg lift	3-5	3	3 RM	Rapid	2 to 30
Hamstring stretching	15-25	2	Body only	Slow, static	0 to 30

[a]Subjects slowly decrease the rest interval between repetitions and sets from 2 min to 30 sec over a period of workouts.

[b]Several hamstring stretching exercises, using static procedures, should follow each workout.

2.1% slower when using the motor set, compared with the sensory set. On the positive side, those subjects who were found to have a natural preference for the motor set did perform better with this approach.

Static Flexibility Exercises

Static flexibility exercises have been shown to significantly improve body flexibility in a relatively short time. Several studies (23, 50, 62) used the basic exercises suggested by De Vries (21) with variable control similar to that shown in Table 2 in an attempt to determine the effects of increased flexibility upon sprinting speed. In each exercise, subjects applied as much force as possible, in a position of maximum flexion or extension, in an attempt to go beyond the maximum range of motion. One method is shown in Table 3. The position of maximum flexibility is held for 30 sec in initial workout, working up to 1 min by the fourth workout and 2 min, 15 sec by the final testing day eight weeks later (23).

TABLE 2. STATIC FLEXIBILITY EXERCISES

Exercise	Description
1. Upper trunk stretcher	Subject lies on his stomach with both legs extended. Arms are extended, with the pelvis on the floor. Position is held at maximum extension with the pelvis remaining flat at all times.
2. Lower trunk stretcher	Subject lies on his stomach with both knees flexed toward his buttocks. Arms reach back and grasp both ankles with the hands. Subject pulls as hard as possible on the ankles, raising both the upper and lower torso. Position is held at maximum extension.
3. Lower back stretcher	Subject sits on the floor with knees extended and flat and the toes pointed. Subject bends at the trunk and grasps the outer borders of the feet, pulling the trunk downward without flexing the knees. Position is held at maximum flexion.
4. Upper back stretcher	Subject lies on his back with both arms extended to his side. Extended legs are raised back over the head. Hands and arms are flat and knees extended throughout the exercise. Toes are rested on the surface behind the head.
5. Trunk twister	Subject sits on the floor with one leg overlapping the other. Ankle is grasped with one hand and the thigh with the other. Trunk is twisted by turning the head in the direction of the trunk. Repeat to other side.
6. Gastrocnenius stretcher	Subject stands erect with feet 3 to 4 ft from a wall. Body is kept straight with feet parallel and heels on the floor. Subject lowers the body toward the wall and maintains this position without raising his heels.
7. Toe pointer	Subject sits on both feet with the toes and ankles extended backward. Weight is shifted backward and knees are raised from the floor. Weight is balanced with both hands on the surface just behind the hips.
8. Shoulder stretcher	Subject stands erect and brings the right hand to the upper back from above. Left hand is also brought to the upper back from below and the fingers of the two hands are joined. Subject pulls as hard as possible for the time allowed. Repeat to the other side.

TABLE 3. VARIABLE CONTROL FOR STATIC FLEXIBILITY EXERCISES

Week	Time* Workout 1	Rest	Time Workout 2	Rest	Time Workout 3	Rest
First	0:30	1:00	0:40	1:00	0:50	1:00
Second	1:00	0:55	1:00	0:55	1:00	0:55
Third	1:00	0:50	1:00	0:50	1:00	0:50
Fourth	1:05	0:45	1:10	0:45	1:15	0:45
Fifth	1:20	0:35	1:25	0:35	1:30	0:35
Sixth	1:35	0:25	1:40	0:25	1:45	0:25
Seventh	1:50	0:15	1:55	0:15	2:00	0:15
Eighth	2:05	0:05	2:10	0:05	2:15	0:05

*Time in seconds at which maximum extension or flexion was held for each exercise.

Sprint-Assisted Training

In the past, the rate of stride frequency per second has been considered an unalterable, inherent quality. Research has uncovered evidence to the contrary. Slater-Hammel (70), for example, found that higher rates of leg alternation were possible in cycling (5.5-7.1/sec) than in sprinting (3.10 – 4.85). Children are also capable of faster steps than mature athletes; stride increases and stride rate decreases as an individual grows (26). The three sprint-assisted programs discussed below attempt to increase stride frequency rate and length through decreased internal and external (wind) resistance, carry-over to flat surface and unaided sprinting:

1. Downhill running
2. Towing
3. Treadmill running

Unfortunately, researchers have made no attempt to isolate the exact contribution to stride frequency rate and length to improved speed in any study.

Downhill Running

The value of downhill running is questioned by Broom (8), honorary senior coach and leading English sprint coaching authority, who states that a speedier rate of leg movement in downhill running is imaginary. He continues in his argument indicating that a greater body lean results in the driving foot contacting the ground further under the body than desirable, thereby reducing stride length and the time available for the foot to apply force against the track. Thus, he feels that although the feet contact the ground more frequently, the duration and efficiency of their drive are lessened and a slowing effect occurs. This criticism of downhill running may be directed at the use of great inclines which is an undesirable practice. In controlled downhill running, research has shown that the slope should never exceed 2.6° (55).

There is evidence supporting the use of a combined downhill-uphill surface. European countries use such an approach to train sprinters. In one experiment cited by Milakov and Cox (55), a group training on downhill, uphill and flat surfaces improved sprinting speed significantly more than groups participating on only one type of surface. Positive work (uphill) expends approximately twice as much energy as negative work (downhill running). Six percent elevation on a treadmill causes an increase in heart rate, VO_2, and energy costs over that of flat surface running. A 6% decline causes a decrease in all three areas over flat surface running (2).

Towing

The most effective form of towing is performed with a *pacing machine* consisting of a tow bar and handle attached to the rear bumper of an automobile. Speeds faster than an 8.0 sec. 100-yd dash pace are possible using this apparatus due to the pull and limited wind resistance. Sandwick (66) cites cases of sprinters reducing average times from 10.5 to 9.9 sec after five weeks of steady use. After several years of use by Sandwick, a scientifically sound program has been developed in regard to towing speed, repetitions, proper form, tow car operation, reducing injury and efficient use of the apparatus.

Towing speed is dependent upon unaided 50-yd dash times with a running start with a subject towed ½ sec faster than his times in this test. Towing speeds increase as the subject improves his 50-yd dash time. Table 4 shows proper tow car speeds and corresponding total 100-yd dash and estimated 50-yd dash times (final 50 yds of the 100-yd dash). Thus, in this alternate method of determining 50-yd dash times, it is assumed that the last half of the 100-yd dash is covered faster than the first half. An individual who runs 100 yd in 11.0 sec, then is estimated as having covered the final 50 yd in 5 sec. One-half second less than this speed, or 4.5 sec, is then used as the towing pace.

TABLE 4. UNAIDED AND ADJUSTED TOWING SPEEDS

100-yd Dash Times	Unaided First 50 yd	Sprinter Last 50 yd	Suggested 50-yd Time with Machine	Equivalent Tow Car Speed mph
Total Time				
13.0	7.0	6.0	5.5	18.6
12.0	6.5	5.5	5.0	20.5
11.0	6.0	5.0	4.5	22.7
10.0	5.5	4.5	4.0	25.6
9.0	5.0	4.0	3.5	29.2

Source: Charles M. Sandwick, Jr., Pacing machine, *Athletic Journal* 47: 1967, 36-38. Used by permission.

Repetitions involve a maximum distance of 50 yd and are preceded by thorough warm-up consisting of jogging-sprinting and flexibility exercises. Four to six repetitions interrupted by a walk for complete recovery are used in preliminary workouts and systematically increased to eight runs by the fourth or fifth session. Two to three workouts weekly are suggested. Runners accelerate gradually for the first 40 yd while holding the handles, reaching the desired speed at the first timing marker (flag) and continuing at that pace for 50 yd.

Running form is examined carefully in early runs at slower speeds emphasizing a position close to the handles, a comfortable grip on the bars, proper toe-ground contact, proper shoulder and head alignment, and form commensurate with unaided sprinting.

Tow car operation requires practice and use of a 100-yd stretch of smooth, firm surface such as macadam, level grass area or cinder track. The car is accelerated gradually for the first 50 yd, reaching desired speeds at the first flag and holding that speed constant for the next 50 yd. The card is driven in low gear with no shifting allowed and gradually decelerated at the finish line (without using the brakes) by the drag of the engine.

The probability of injury using the pacer is low. Warm weather and adequate warm-up offer insurance against muscle injury. With proper tow car operation, trial runs at a slow pace, and careful choice of firm, unobstructed surfaces, spills are eliminated. Unless the pacer is used following heavy rains, there is also no track damage.

Efficient use of the pacer occurs when two are mounted on one vehicle to permit running in pairs. Proper arm movement is not possible since both hands are needed to grip the bars.

Conflicting evidence is reported by Stenerson (75) in his study comparing the effects of towing, pacing and normal training upon 50-yd dash times. None of the training programs produced significant improvement in 50-yd dash times, nor were significant changes noted in stride length or stride rate although these measures were not determined through cinematographical analysis. Towing was performed by an auto in a manner described by Sandwick. Pacing involved the auto moving at a pace slightly in front of and faster than the sprinter.

Lawrence and Hensley's study (44), using towing, demonstrated some improvement in times from 880-10,000 m; however, no attempt was made to improve sprinting performance.

Treadmill Running

In the Virginia Commonwealth University Laboratory, the A. R. Young High Speed Treadmill (0-26.5 mph and sub 8.0 sec, 100-yd dash) is used to improve stride length, stride frequency rate, form, anaerobic capacity and sprinting speed. Cinematography and a high speed camera identify differences in stride length and frequency rate at various speeds in both treadmill and unaided flat surface sprinting. Form is corrected by an expert standing on a stool facing and looking slightly downward at the subject during moderate and high speed sprinting. The information that follows is an outgrowth of numerous studies conducted at the Virginia Commonwealth University Human Performance Laboratory (27).

The theory is that treadmill running, designed to gradually force an individual's stride rate beyond that capable in unaided running, will lead to improved speed on a flat surface. It has been shown that daily use of a bicycle ergometer that forced a more rapid rate of leg movement than possible without the aid of a motor, carried over to increased revolutions without motor assistance. Thus, the rate of leg movement in riding a bicycle was improved through forced techniques.

The following guidelines governing use of high speed treadmill training programs were developed at the Virginia Commonwealth University laboratory:

1. Runners should use a standard warm-up procedure prior to entry on the treadmill:

   Running in Place:

   1/2 speed (low knee lift) – 2 repetitions of 30 sec each
   1/2 speed (high knee lift) – 2 repetitions of 30 sec each
   3/4 speed (high knee lift) – 2 repetitions of 15 sec each
   7/8 speed (high knee lift) – 2 repetitions of 8-10 sec each
   Maximum speed (high knee lift) – 2 repetitions of 5-8 sec each

2. A belt attached to the support rails that allows free arm movement, balance and safety is needed for all high speed work.
3. One spotter on each side of the treadmill will ensure safety should a runner slip or stumble.
4. A one-week acclimation period is needed to allow sprinters to adjust to treadmill sprinting.
5. Since the treadbelt accelerates slowly and would introduce a fatigue factor if sprinters are required to jog at a slow pace and continue running until higher speeds are reached, treadbelt speeds should be pre-set prior to entry. After a short acclimation period, entry at high speeds will be performed smoothly by all runners.

A sample program is shown on page 63. Remember that sprinters should be in an almost fully recovered state prior to each sprint since the objective is to improve the rate of leg movement per second and not to improve conditioning levels. A large wall clock (pool lap timer) can be used by sprinters in timing their repetitions.

Leg muscles will contract faster than ever before. To avoid injury under these conditions, both the warm-up and the acclimation period that slowly progress to maximum and beyond-maximum speeds are important.

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Sample Treadmill Program

Maximum Speed	1.5-2 mph Beyond Maximum Speed II	Support Running at Near-Maximum Treadbelt Speed III
Subjects tested weekly to determine maximum speed	Speed adjusted 1.5-2 mph above maximum sneed for that week	Treadbelt speed adjusted at maximum speed with which balance could be attained (24-26.5 mph)
1-3 repetitions for 3-5 sec given at maximum speed daily	2-6 repetitions for 3-5 sec daily	2-5 repetitions for 3-5 daily
Free arm movement allowed with subjects in the belt	Free arm movement allowed with subjects in the belt	Free arm movement not permitted. Subjects to grasp both rails, maintain grip and concentrate only on leg movement and keep pace with the treadbelt.

Proper running form is taught during trial runs at slower speeds to allow the runner to adapt to treadmill use. Periodic pre- and posttesting in a 50-yd dash with a running start or the competitive 100-yd dash are used to determine carry-over to unaided flat surface running.

Treadmill sprint training is not without its special problems. The treadbelt movement and sprinting form produce a slowing effect; however, aiding factors predominate and allow a faster rate of leg movement per second for most individuals even without training.

The aid and hindering factors and an explanation of why faster rates of speed occur in treadmill sprinting are listed below:

+ Factors Aiding		– Factors Hindering
Braking effect each time lead foot touches treadbelt – belt speed slowed at this point to obscure speedometer reading	Less time on weight-bearing foot	Limited push-off possible from weight-bearing foot
	Motorized belt forces a faster pace	

No wind resistance	Stride length increased	Form alternation required that affects positive transfer to unaided flat surface sprinting
No unfavorable environmental conditions – temperature, inclement weather		Challenging – pre-knowledge of belt speed
Energy conservation – steady, unaltered pace, less knee lift, no acceleration – accelerate fast or else. . .		Form improvement possible – dialogue between coach and sprinter, immediate correction, high speed filming

The braking effect has been found to be greater in initial stages of treadmill running and tends to be eliminated as acclimation occurs and form instruction is given. At high speeds beyond one's maximum speed (in early use of treadmill) the braking effect almost reduces treadbelt speed to a sprinter's maximum speed. With continued training, this point is easily overcome.

Obviously, treadmill running is smoother and provides a feeling of complete mastery with little effort. Since it is an aided device, the total effort appears less although research indicates that oxygen uptake and energy expenditure are similar in treadmill and unaided running. The fact remains that form is altered, environment plays little influence, and a motorized belt assists one to contract and relax the muscles involved in sprinting faster than any other mode of training. It is also a quiet, safe, problem-free instrument.

There are still additional problems affecting treadmill sprinting. It is extremely difficult to determine treadbelt speed. Accurate readings are possible up to 23 mph without a subject; however, the speed adaptor kit permits speeds of 26 mph and a "surface speed indicator" is needed for accurate readings at extreme speeds. Treadbelt speeds cannot be accurately gauged by speedometer readings while a subject is sprinting. There is always a difference between treadbelt speed with and without a subject. In the Human Performance Laboratory of Virginia Commonwealth University a highly accurate surface speed indicator (less than .001% error) was used to determine treadbelt speed variations with sprinters (159 lb, and 197 lb) and without sprinters (Table 5). Several findings are important to future researchers:

1. A heavier runner has a greater braking effect on the treadbelt than a lighter runner.
2. The percent of braking increases as treadbelt speed increases for both light and heavy subjects.

3. At speeds in which the sprinter is being supported by the belt and is unable to maintain belt speed, onl, a normal, expected braking occurs. It was originally anticipated that as treadbelt speed exceeded a sprinter's maximum speed, the lead foot would merely reduce belt speed accordingly and not force a runner beyond his unaided capacity.
4. The maximum treadbelt speed without a runner on the A.R. Young Treadmill with Speed Adaptor Kit was 24.77 mph. Maximum be . speed with a 159 lb runner was 23.30 mph and with a 197 lb runner, 23.13 mph.

Both subjects in the study were capable of maintaining treadbelt speed without belt assistance (belt was fastened but not aiding) at all speeds except maximum belt speed of 2,180 FPM. In addition, treadbelt speeds were measured before and immediately after each run at the six speeds to determine whether a repetition had any permanent effect upon treadbelt speed. Less than .002% variance was found, indicating that treadbelt speeds returned to the previous speed without a runner following each repetition.

TABLE 5. TREADBELT SPEEDS WITH AND WITHOUT A SUBJECT

WITHOUT SUBJECT			WITH SUBJECT			DIFFERENCE			
100-Yd Time	MPH[a]	FPM[b]	100-Yd Time	MPH	FPM	100-Yd Time	MPH	FPM	Per-cent
159-lb Subject									
20.36	10.04	884	20.83	9.81	864	0.47	0.23	20	.022
13.61	15.02	1,322	13.99	14.61	1,286	0.38	0.41	36	.027
10.80	18.93	1,666	11.20	18.26	1,607	0.40	0.67	59	.035
9.74	21.07	1,853	10.10	20.14	1,773	0.36	0.93	80	.043
9.29	22.00	1,936	9.68	21.12	1,859	0.39	0.88	77	.039
8.25	24.77	2,180	8.82	23.30	2,040	0.57	1.47	140	.064
197-lb Subject									
20.36	10.04	884	20.90	9.78	861	0.54	0.26	23	.026
13.61	15.02	1,322	14.13	14.46	1,273	0.52	0.56	49	.037
10.80	18.93	1,666	11.15	18.23	1,605	0.35	0.60	61	.036
9.74	21.07	1,853	10.26	19.93	1,754	0.52	1.14	93	.050
9.29	22.00	1,936	9.81	20.84	1,834	0.52	1.16	102	.052
8.25	24.77	2,180	8.86	23.13	2,030	0.61	1.64	150	.068

[a] Miles per hour

[b] Feet per minute

A study was undertaken in the Virginia Commonwealth University laboratory (24) to determine the effects of high speed treadmill training upon sprinting speed. Eight male undergraduate students were divided into two groups using

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matched pairs on the basis of pretest 20-yd dash time (running start), age, height and weight. The experimental group engaged in an eight-week training program, three times weekly, consisting of weight training and conventional sprint training. Treadmill running consisted of sprinting at maximum speed, at 1.5 to 2.0 mph above-maximum speed, and at near-maximum treadbelt speed (up to 26.5 mph) for the prescribed number of repetitions while supported in a suspended harness that permitted free arm movement. Pre- and posttest means were compared within each group to determine whether statistically significant improvement occurred in the 20-yd dash with a running start. The experimental group improved significantly from the pre- to the posttest while the control group failed to do so.

There is a need for additional research testing several treadmill sprinting programs and their effects upon flat surface, unaided stride rate, stride length and sprinting speed.

Sprint-Resisted Training

Sprint-resisted programs attempt to simulate the sprinting action while placing the body under an increased work load through use of 1) incline running or 2) weighted clothing. Both programs strive for improved strength in the muscles involved in the running action as a means of improving sprinting speed. It is impossible to maintain normal stride length or rate while performing under increased resistance (26). Thus, such training is used only in conjunction with regular sprint training on flat surfaces.

Incline Running

Opponents of incline running contend that it will shorten stride length and subsequently hinder sprinting speed. Advocates of uphill training counter by stating that since this method is combined with flat surface training, flexibility exercises and stride training, it will not decrease stride length and can improve sprinting speed through improved strength. As indicated previously, the combined use of uphill-downhill-flat surface training appears to produce the most favorable results providing the uphill slope is no more than 3.4° from the horizontal (55).

Weighted Clothing

The use of ankle spats, heavy shoes, chest vests and other items weighing 2½ to 25 lb as a means of improving sprinting speed must be evaluated from two approaches: 1) the immediate aftereffects of this increased resistance upon sprinting speed and 2) the long-range effects upon strength and sprinting speed.

The *immediate aftereffects* involve the practice of training with weighted clothing for a period of 15-30 min and then removing these items just before competition to provide the initial feeling of lightfootedness. Using one bat after swinging three or using a weighted doughnut or removing football gear, ankle spats, and heavy shoes provides this feeling. The important point is whether removal of this resistance results in improved performance. The following summary indicates conflicting findings of past researchers (58, 61, 63):

1. Speed of throwing a baseball significantly increased, without hindering accuracy, following throws with a heavier ball.
2. Speed of swinging a bat increased significantly following the use of a heavier object.
3. Use of a weighted vest prior to removal and testing in the vertical jump did not improve performance.
4. Preliminary use of a 16-lb shot reduced performance in the 12-lb shot.
5. Elbow flexion speed did not increase significantly following use of the three levels of overload.
6. Neither foul shooting nor speed of riding a bicycle ergometer was affected by overload procedures.

This method has not been tested adequately for the improvement of sprinting speed.

Long-range use of weighted clothing is concerned with strength development and the subsequent effects upon sprinting speed. Additional research is needed to evaluate properly the long-term effects upon sprinting speed. One study (7) reported that training with ankle weights actually hindered the 100-yd dash times of women.

Mihalovics (54) investigated the effects of artificial drag (pulling a 15-lb steel platform attached to the waist by a webb belt) and training belt upon hip hyperextensor strength and 220-yd dash times. Both programs failed to significantly improve hip hyperextensor strength or 220-yd dash times.

Gibson (31) compared the effectiveness of a sprint training program consisting of three all-out 100-yd sprints daily with no ankle weights and with a 1½-lb ankle weight. Both the group without ankle weights and the group with weights improved significantly more than the inactive control group; however, neither approach was more effective than the other.

SPRINT TRAINING PROGRAMS

The most important exercise for speed development is the actual act of sprinting. Jarver (41) indicates that sprint training improves speed by reducing components to a rational pattern of overall action and alleviating internal muscular viscosity or resistance. Unfortunately, there is no magic program or routine guaranteed to produce maximum results by carrying each individual to his unknown limit of sprinting speed potential. It seems more likely that best results are attained through use of several different programs with the degree of emphasis depending upon available time and individual strengths and weaknesses.

The following section discusses the basic principles of anaerobic training, common programs in use today, those used by researchers, and a model program suggested for researchers of the future.

Anaerobic Metabolism

Energy Sources

A muscle is merely a machine for converting chemical into mechanical energy. Energy-rich organic phosphate derivatives provide the immediate source of this energy and intermediary metabolism of carbohydrate and lipids the ultimate source. The compound of phosphocreatine in the muscle provides an energy-rich phosphate for muscle contraction. Some ATP (adenosinetriphosphate) transfers its phosphate to creatine during rest which establishes adequate phosphocreatine stores. Blood glucose enters cells and is degraded to pyruvic acid through a series of chemical reactions. With sufficient 0_2 present (aerobic work), pyruvic acid enters the citric acid cycle and is metabolized to CO_2 and H_2 (aerobic glycolysis) releasing sufficient energy to form large quantities of ATP from ADP (adenosinediphosphate). When oxygen supplies are insufficient (anaerobic work), pyruvic acid formed from glucose is reduced to lactic acid. This process (anaeronic glycolysis) only occurs in the absence of oxygen to produce small quantities of energy-rich phosphate bonds to allow muscle contraction to continue (2). It is difficult to determine the exact point of entry of anaerobic mechanisms for each individual. The findings of Margaria, Edwards and Dill (46) indicate that no excess lactate is evident in the blood until the work rate reaches two-third of the maximum metabolic rate.

According to Astrand and Rodahl (2), this breakdown of glycogen into lactic acid releases approximately 55 kcal for each 6-carbon unit (glucose molecule) glycolized. One molecule of ATP is required for this reaction and, of the total of four ATP molecules formed, the net gain will be three molecules of ATP. Available energy from ATP and creatine phosphate is limited. In sprinting, when energy demands may exceed 50 kcal/min, the breakdown of total ATP would cover about a 1-sec effort and a generation of ATP from the breakdown of creatine phosphate another few seconds. This may explain the fact that maximum speed can only be maintained for a few seconds in a 100-m dash. Rapid energy from anaerobic sources is depleted from exhaustion of creatine phosphate, and, eventually of ATP. This physiological limitation may also account for the fact that highly conditioned sprinters can continue maximum effort from the starting blocks for no more than 8 sec before slowing occurs.

Anaerobic metabolism comes into action at the onset of any type of exercise as an immediate source of energy until circulatory and respiratory adjustments occur (light to moderately heavy work) and in supplying quick energy for strenuous work when the aerobic mechanisms cannot keep pace. Sprinting

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always occurs in the absence of oxygen, a condition under which skeletal muscles can function for only a short time through anaerobic metabolism. The intensity and duration of sprinting is such that the respiratory and circulatory system have no time to adapt. It is this anaerobic capacity, then, that governs the sprinter's onset of slowing late in the race, length of time maximum speed can be held and the percentage of slowing. Highly conditioned sprinters will hold maximum speed for a longer period of time and distance and suffer only minimal slowing (less than 5%).

The amount of quick energy available depends upon factors such as training or oxygen debt tolerance level, age (highest at age 20-25, decreasing slowly thereafter) and nutrition (20).

Anaerobic Training

With training, higher levels of blood lactate concentration following maximal effort can be tolerated. The well-trained individual achieves a higher concentration of lactic acid and a lower pH than an untrained individual. Both physiological and psychological tolerance improvement appear to contribute to this adaptation. Anaerobic training for the sprinter must be deducted from the preceding physiological discussion of anaerobic capacity since high-energy phosphates compounds control sprinting events. The following guidelines are offered (2, 5, 9, 22, 25, 29, 51, 59, 74):

1. Sprinting (100- and 200-m dash) is 90-95% anaerobic and training should reflect this percentage. Aerobic training should occupy only a small portion of a sprinter's training regime. The availability of additional oxygen is of no value to a sprinter. It is impossible for the respiratory system to utilize atmosphere oxygen once the gun is fired. Therefore, the improvement of VO_2 can in no way improve performance. In fact, sprinting a 100-m dash requires approximately 11 (liters) or more of oxygen. It is mathematically impossible to borrow 11 l from the 2.70 or so available in body reserves. As a result, "oxygen debt" occurs and the quick energy stores must enter if muscle contraction is to continue.

   Aerobic training also has no effect upon lactic acid tolerance, stride or stride rate.

2. There is evidence that maximum heart rates (HR) are not reached in a 100-m or 200-m dash. Training to improve maximum HR will therefore be of little value since this is not a restrictive factor. Mean maximal HR of 129 beats/min. for 70 experiments of 19 men is reported following a 100-m dash. Data were collected without telementry and HRs are undoubtedly low since the HR of a highly trained athlete reaches its physiological maximum 5-8 sec after the onset of work. In cycling, maximal HRs were reached between the first and second min at 2,700 - 3,000 kilopondmeters/min.

3. An individual should avoid training anaerobically and aerobically at the same time. Two ½-hr sessions of aeronic training weekly are sufficient for sprinters.
4. Maximum work of short duration (up to 10-15 sec) should be used.
5. Rest periods following each maximum effort should endure for a few minutes. Shorter rest periods may result in a major mobilization of glycogenesis.
6. The principle of specificity should be followed. Training occurs, in part, within the muscles themselves, and training is specific in terms of lactic acid production during heavy muscular work. Thus, complete training transfer, regardless of the closeness of activities, is not possible. Maximum work for sprinters must involve all-out sprints.
7. A 1-min maximum effort, followed by 4-5 min rest before repeating the effort, can produce lactic acid concentrations in the blood greater than 20 mmoles/l and an arterial pH of 7.0 or lower. Repetitive 400-m runs in less than 60 sec, followed by a 4-5 min rest period are an effective technique for sprinters.
8. Sprinting at maximum speed should occur early in the workout before fatigue is present as a means of improving stride length and rate. Training to improve anaerobic endurance should occur at the close of the workout.
9. The decisive factor in lactic acid concentration is the length of the work period. At maximum speed, distances closer to 400 m will produce the highest lactic acid concentration. Recovery time and the relationship between the rest interval and work are secondary.

Common Sprint Training Programs

There are three basic sprint training programs in use today: 1) acceleration sprints, 2) hollow sprint and 3) interval sprint training. Considerable similarity exists among the three programs and each appears to have evolved from the knowledge of anaerobic energy supply. There is no research to suggest that one program is superior to the other.

Acceleration Sprints

Acceleration sprinting involves a gradual increase from a jog to a striding pace to a maximum effort sprint. A 1-1 ratio of sprinting distance and recovery walk is used. An athlete may jog 50 yd, stride 50, sprint 50, and terminate that repetition with a 50-yd walk. The walk or slow job should allow near-complete recovery prior to performance of the next repetition. This jog-stride-sprint-recovery cycle tends to develop strength and speed and reduce the probability of muscle injuries in cold weather through a gradual increase to maximum sprinting effort (32).

The above-stated 50-yd cycle is an example of early season training with the exact number of repetitions depending upon conditioning levels. As the degree of conditioning increases, the distance is lengthened with late season acceleration sprints reaching segments of 120 yd. Distances beyond 120 yd make near-complete recovery extremely difficult.

Dieter Berben (5) describes a routine similar to acceleration sprints involving a series of four 50-yd sprints at near maximum speed (6-7 sec) per 440-yd lap, jogging for 10-12 sec after each sprint and completing the 440-yd run in 64-76 sec. According to Berben, New Zealand athletes have performed as many as 50 sprints (12½ x 440) with little reduction in speed on any of the repetitions. As the repetition distance approaches and exceeds 120 yd, anaerobic endurance or oxygen debt tolerance is improved.

Hollow Sprints

Hollow sprints as described by Fred Wilt (30) involve use of two sprints interrupted by a *hollow* period of recovery such as walking or jogging. One repetition might include a 60-yd sprint, 60-yd jog, 60-yd sprint, and a 60-yd walk for recovery. Similar segments of 120, 150 and 220 yd might be employed.

Interval Sprint Training

Interval training was derived from Fartlek running (speed play) and has, since the early 1950s, become a popular approach to the training of middle-distance runner, long-distance runners and sprinters. Such an approach has great application to the training of sprinters when variables are altered to meet the training objective of improved speed over a short distance.

Interval sprint training differs from that used for training middle- and long-distance runners. A faster pace (9/10 - maximum) and shorter distances (no greater than 440 yd) are used, with even shorter distances (under 120 yd) forming the foundation of speed work and the longer distances serving to develop anaerobic speed endurance. Speed and anaerobic endurance are improved by manipulating the repetition distance, speed and recovery action and length. In general, interval sprint training uses a 1-1 ratio of repetition distance (40-440 yd) and recovery distance (consuming two to three times more time).

The variables that must be carefully regulated for optimum results are: 1) frequency of training sessions, 2) length of the work period, 3) intensity of the work period, 4) length of the rest interval and 5) intensity of the rest interval.

The *frequency of training sessions* is critical to elevated functioning levels. Most athletes train on a daily basis using one to two days of rest at the end of the week (not on two successive days) or just prior to competition during the in-season period. Daily training that alternates strenuous sessions and light sessions ensures proper recovery and application of basic exercise principles.

The *length and intensity of the work period* is an individual matter. There is no magic formula for determining the number and length of training repetitions. It is not unreasonable, however, for an athlete to complete 15-50 repetitions of various distances, interspersed with walk-jog recovery. Repetition distances of from 50-440 yd are recommended, with shorter distances generally performed after near-complete recovery to allow maximum speed on each repetition and longer distances performed with some hindering fatigue products still remaining in the body to prevent attainment of maximum speed.

The intensity of training (work per unit of time) is much more important than the duration of the workout. Heusner (37) indicates that when a performance plateau is reached, improvement occurs only by increasing the quality or intensity of work and holding constant the length of the session. Improvement is *not* noted when the intensity variable is held constant and the length of the workout is increased. Use of much low intensity aerobic work involving continuous running of 10 min or more is of questionable value to sprinters since the work rate does not approach that to be used in competition. The findings of Christenson, Madman and Saltin (13) indicate that the length of the work period is the decisive factor in lactic acid concentration and anaerobic development.

Exercise heart rate can also be used to determine proper distance. An HR above 180 per min, for example, has been shown to represent a point when the heart can no longer fill or empty completely. Thus, it does not benefit the athlete to continue the exercise (3, 28). Although pulse rate recovery is a valuable aid in training distance runners and in interval training using longer repetition distances, its place and value in the training of sprinters are questionable.

The *length and intensity of the rest interval* must be carefully controlled. It is during the rest interval that the heart adapts to the stress of exercise. At the point of near-exhaustion, stroke volume falls and the heart is no longer able to supply active muscles efficiently. When exercise terminates, stroke volume is elevated beyond that of the initial functioning level and remains at this state for about 30 sec. This increase assists the heart in adapting to exercise stress. Although complete recovery of the entire body does not occur during the rest interval, partial return to pre-exercise functioning levels does occur. The rest or recovery interval between repetitions allows the athlete to perform many times more total exercise volume of high intensity than would normally be possible. The rebuilding process then reacts to an intensified workout over an extended period of time as destroyed muscle constituents are replaced, following many hours of rest, to a higher level, somewhat proportional to the exercise effort, to elevate the body beyond the pre-exercise functioning level.

Thus, the rest interval is vital to progressively increased performance and must be controlled systematically and carefully. Although an athlete can recover sufficiently to complete a second repetition after a relatively short time, 2 hr or more are necessary for complete recovery. It is the control of the rest interval between repetitions that develops anaerobic endurance and oxygen debt tolerance.

In early training, a longer rest interval is required and reduced as the athlete is able to complete four to six repetitions of the work interval at desired speeds. Heusner (37) suggests a rest/work ratio of 1-1 between the repetition distance and the recovery walk or jog distance although it should take two to three times longer to cover this distance during the walk or jog rest interval. For pure speed work, where repetitions should be executed at maximum speed, a slow jogging interval should be used and full recovery attained prior to completing the next repetition.

A wide variation in the control of variables is possible in interval training, as shown in Table 6 (29).

TABLE 6. INTERVAL TRAINING VARIABLE CONTROL

Repetition Distance	Speed	Number of Repetitions	Recovery Interval	Action During Recovery
1. One distance only fixed	Increasing	Constant	Constant	Walk
2. One distance only - fixed	Constant	Increasing	Constant	Jog
3. One distance only - fixed	Constant	Constant	Decreasing	Rest
4. Many distances - fixed	Increasing	Fixed	Constant	Jog

Source: Michael G. Down, An appraisal of interval training, *Track Technique*, 1965, 19:595. Used by permission.

Interval training for sprinters usually involves one or more fixed distances, a constant maximum speed, increasing number of repetitions, and a decreasing recovery interval involving either a walk or jog.

Programs of Researchers

Past researchers have used wide varieties of sprint training programs ranging from careful control of all necessary variables to very limited control.

Day (18) supplemented a weight training program with repetition sprinting (Group I), interspersed sprinting (Group II), and stair running (Group III) and found no difference among any of these groups or a control group receiving only weight training in 30-yd dash times.

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Dintiman (23) used distances of 25-400 yd, decreasing rest intervals and increasing repetitions in a 24-workout program in his study of the effects of various training programs upon running speed. The first and eighth weeks of training are shown in Table 7. The program significantly improved 50-yd dash times following the eight-week training period.

Schultz (67) varied the distance, recuperation time and number of repetitions per session in two workouts weekly for 16 weeks. Early sessions involved six repetitions of 60-yd runs at 5:00-min intervals or nine repetitions of 40-yd runs

TABLE 7. SPRINT TRAINING PROGRAM

Workout	Distance	Speed	Repetition	Interval	Action
First Week					
1.	400	1/4	1	5:00	Walk
	400 Circulators	1/4 1/2 Pass	1	5:00	Walk
	800	1/2	1	7:00	Walk
2.	800	1/4	1	7:00	Walk
	400 Circulators	1/4 1/2 Pass	2	5:00	Walk
	75	3/4	2	5:00	Walk
3.	800	1/4	1	6:00	Walk
	800 Circulators	1/4 3/4 Pass	1	5:00	Walk
	75	3/4	4	4:30	Walk
Eighth Week					
22.	800	1/2-9/10	2	0:30	Jog
	25	Maximum	18	0:45	Jog
	Sector	Maximum	3	1:15	Jog
	150			1:15	
	125			1:00	
	100			0:45	
	75			0:30	
	300	Maximum	1	0:30	Jog
23.	800	1/2-9/10	1	0:30	Jog
	25	Maximum	4	0:30	Jog
	150	3/4-9/10	4	1:00	Jog
24.	800	250-1/4 400-1/2 100-3/4 50-9/10	1	3:00	Walk
	25	3/4-9/10	2-4	2:00	Walk
	Final Speed Test				

Note: The specific distance covered is given in yards, whereas the interval time is given in minutes.

with 3:30-min intervals. Sixty-yard dash times were significantly improved. Gibson (31) used three all-out sprints of 100-yd daily for 22 days. No significant improvement was noted in 85-yd dash times (with a flying start).

Model Sprint Training Program

The sprint training programs shown in Tables 8 and 9 are used by two leading track coaches and may be helpful to future researchers.

TABLE 8. SPRINTING TRAINING PROGRAM

Workout	Distance	Speed	Repetitions	Interval	Action During Rest Interval
Competitive Season:					
1	80 yd	100%	4-6	5-7 min	Walk
	150 yd	85%	1-2	10-12 min	Walk
2	110 yd	100%	4-6	8-10 min	Walk
	Starts on turn from 220 stagger				
	330	100%	1-2	15-20 min	Walk
3	160 yd	100%	1	Complete	Walk
	80 yd	100%	1	Recovery	Walk
	90 yd	100%	1		
	100 yd	100%	1		
	110 yd	100%	1		
	120 yd	100%	1		
4	60 yd Starts	100%	6-8	Complete	Walk
5	Easy stretching, calisthenics, relaxed running from 50-150 on grass				
Post-Season:					
1	150-220 uphill	75%	8-10	150-220	Walk
2	4-6 mi	Steady jog with no stopping			
3	30, 40, 50, 60, 50, 40, 30 sec on grass	75%	6	Near-complete Recovery	Jog-Walk
4	220 differential running, 1st 220 stride 2nd 220 stride	50-85%	4	220	Walk
5	4-6 mi	Steady job with no stopping			
Pre-Season:					
1	550 yd	Best 440 time +15-20 sec	2-3	8-10 min	Walk

2	4-6 mi	Slow jog mixed with sharp pickups of 50-300 yd Number of repetitions and rest interval up to the athlete			
3	330	Best effort + 3-5 sec	3-5	550 6-8 min	Walk
4	150	Best effort + 2-3 sec	6-8	150 4-6 min	Walk
5	110	Maximum with Relaxation		110 2-5 min	Walk

Prepared by Glenn Hayes, track coach, Virginia Polytechnic Institute

TABLE 9. COMPETITIVE SEASON SPRINT TRAINING PROGRAM

Workout	Distance	Speed	Repetitions	Comments
March:				
1	15-min warm-up, 3/4 windsprint warm-up form training			
	Starts	100%	5-10	
	300-yd run	3/4	1	
2	Same warm-up as above			
	Starts for time over 50, 40, 30 yd	100%	2 each	
	220 yd	Varied[c]	5	
	440 yd	100%	1	
3	Same warm-up as above			
	60-yd time trials	100%	2	
	300 yd, or	100%	2	15-min rest interval
	352 yd if on mile relay team	100%	2	15-min rest interval
4	Same warm-up as above			
	Starts	100%	4-6	
	Finishes - tape breaking from 20 yd	100%		
	Play day followed by baton work and 3 X 110 relay			
April:				
1	15-min warm-up, stretching, windsprint warm-up, form work			
	Gun starts	100%	6-8	
	Long windsprints - 6-8 laps			Walk or jog between
	Baton work or pickups			
2	Same warm-up as above			
	Starts for time over 20, 30, 40 yd	100%	1 each	
	220-yd run or	Varied[c]	4	
	220-yd	Stepdown	3	Walk or jog between
	440-yd windsprint		1	Slow, medium, fast over third of distance

3	Same warm-up as above			
	60-yd runs for time	100%	2	10-min rest interval
	160-yd run	100%	1	15-min rest interval
	300-yd run	100%	1	
	Baton work or pickups			
4	Same warm-up as above			
	Starts	100%	3-4	
	Tape breaking, play day, baton work			
May:				
1	Warm-up, stretching, windsprint warm-up, form work			
	Starts	100%	3-4	
	Long windsprints 6 laps or 1 X 300			
	Baton work or pickups			
2	Same warm-up as above			
	Starts for time stressing relaxation at 30, 40, 50 yd	100%	1	
	220-yd pickups[b]	Pickup and gather from 20 yd out	3	
3	Same warm-up as above			
	Starts	100%	2-3	
	50- and 80-yd time trial	100%	2 each	
	Baton passing and relay work			
4	Same warm-up as above			
	Starts	100%	4-6	
	Tap breaking from 20 yd out	100%		
	Baton work, play day, pickups			
June:				
1	Warm-up, stretching, windsprint warm-up, form work			
	Starts (optional)			
	Long windsprints on grass[a]	Windsprints	6	
2	Same warm-up as above			
	Starts	100%	5-10	
	220's	100%	2-3	
	Baton work			
3	Same warm-up as above			
	50-yd run for time	100%	2	
	150-yd run for time		1	
	Relay work for sprint relay team			

a – Three windsprints, a slow one, a medium one and a fast one

b - Out fast, float, kick

c - Each successive 220 is one second faster. Strive for 25-24-23.

Summarized from *So You Want To Be A Sprinter* (1956) by Lloyd C. Bud Winter, Fearon Publishers, 2165 Park Blvd., Palo Alto, California 94306. Used by permission.

Sprint training programs vary considerably from athlete to athlete and coach to coach. Flexibility and individuality appear to be important ingredients. Some of the specific common and unique features of the pre-competitive and competitive training regimes of champion sprinters are listed below.

Factors common to each program:

1. A supplementary weight training program following the sprint training workout at least thrice weekly
2. A warm-up consisting of 15-40 min of slow jogging and flexibility or stretching exercises
3. A rest day or extremely light workout (form training, light jogging) one day prior to competition
4. Form training, including starts
5. A warmdown jogging period at the close of each workout
6. One workout daily from 60-120 min
7. A walking or jogging rest interval between repetitions involving a distance similar to the repetition distance

Unique features of individual programs:

1. 6-8 repetitions X 30 m of sprinting or jumping steps (Hary)
2. Use of 2½ lb ankle weights during the fall for cross-country and stadium step running (Morrow)

Complimentary sports used for variety:

1. Handball (Hary)
2. Medicine Ball Throwing (Hary)

TABLE 10. SAMPLE PROGRAMS OF CHAMPION SPRINTERS

Repetitions, Speed, and Rest Interval Include:

1. Budd (Best marks: 220 yd 20.2, 200 m 20.7, 100 m 10.2, 100 yd 9.2)

20 X 220 yd in 28-31 sec with 220 walking intervals
10 X 440 in 72 sec with jogging intervals
5 X 660 in 1:42 with 660-yd walking intervals
2-4 X 293 yd in 35 sec with 3-5 min walking interval
4 X 300 yd in 31-32.5 with 10-15 min walking intervals
666 yd in 1:25 1:32 with 5-11 min walking intervals

2. Hary (Best marks. 100 m 10.0, 200 m 20.9)

   10-15 X 30-40 m pick-up sprints with 1 min walking intervals
   8-10 X 80-100 m pick-up sprints with 10-15 walking intervals
   200 m, 300 m, 400 m and 200 m runs at any speed with walking intervals
   6-8 X 120 m in 12 sec with walking intervals
   6 X 150 m in 12.5 sec with walking intervals
   1-4 X 200 m in 25-26 sec with 200 m walking interval
   Fartlek Training

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3. Norton (Best marks: 220 yd 20.2, 200 m 20.6, 100 m 10.1, 100 yd 9.3)

   10 X 110 yd with 110 yd walking interval; 15 sec 110 yd runs, reducing 1 sec each month until four weeks before competition
   440 yd runs (alternatively sprint and jog 15 yd sectors)
   Starts: 2 X 20, 2 X 30, 2 X 40
   5 X 220 yd at 32 sec reducing 2 sec monthly until four weeks before competition 220 yd walking interval
   5 X 55, 5 X 110, 5 X 50 with walking interval of equal distances
   3 X 300 at 3/4 speed, sprinting the finish

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4. Morrow (Best marks: 220 yd 20.4, 200 m 20.6, 100 m 10.2, 100 yd 9.3)

   6-8 X 220 in 26-28 sec with a 220 yd walking interval
   3-5 X 110 pickup sprints on grass with 110 yd walking interval
   5-10 30-50 yd sprints from blocks at 1/2 to 3/4 speed
   4 X 220 on curve in 24-26 sec with 220 yd walking interval
   2 X 300 in 33-35 sec with 5 min walking intervals
   440 in 58 sec, 300 in 34 sec, 220 in 25 sec, and 110 in 11.5 sec with a 440 yd jogging interval
   6-8 220 in 24-26 with a 220 yd walking interval
   10-12 X 80 yd pickup sprints at 1/2 to 3/4 effort with 80-100 yd walking interval

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Summarized from *Track Technique: The Journal of Technical Track and Field Athletics*, No. 1, 4, 7. Used by Permission.

SUMMARY AND RESEARCH NEEDS

It is obvious that for maximum improvement of sprinting speed a number of specialized training programs must be used. Sprinting speed is improved through: 1) an increase in the length of the stride, 2) an increase in the rate and efficiency of leg movement per second, 3) improved starting ability and acceleration to maintain speed and 4) improved anaerobic capacity. The articulation of the following basic programs is needed for maximum results: explosive power and strength training, flexibility training, form and stride training, reaction time training and sprint training/sprint-assisted training. The specific objectives of each program, leading to improvement in the four previously stated areas, are indicated in Figure 1.

There is also evidence to suggest that ergogenic aids have little or no effect upon performance in sprint events and that warm-up or lack of warm-up may be a matter of personal preference that affects individuals differently.

"Shotgun blasts at midnight" best describe the hunting tactics of past researchers dealing with the training of sprinters. There is a dire need at this time to *stop and analyze* all factors that may affect speed of movement and systematically test theories within these areas. It is of little help to test arbitrarily the effects of different programs upon sprinting speed without careful isolation of all variables and positive and negative factors.

In addition, there is a need to develop and test new anaerobic training programs as well as supplementary programs with numerous combinations of variable control (repetitions, sets, weight, rest interval, speed, distance). These programs should be analyzed for their effect upon sprinting speed, starting speed, RT, stride length, stride rate, slowing and hold distance in the 100- and 200-m dash, and acceleration.

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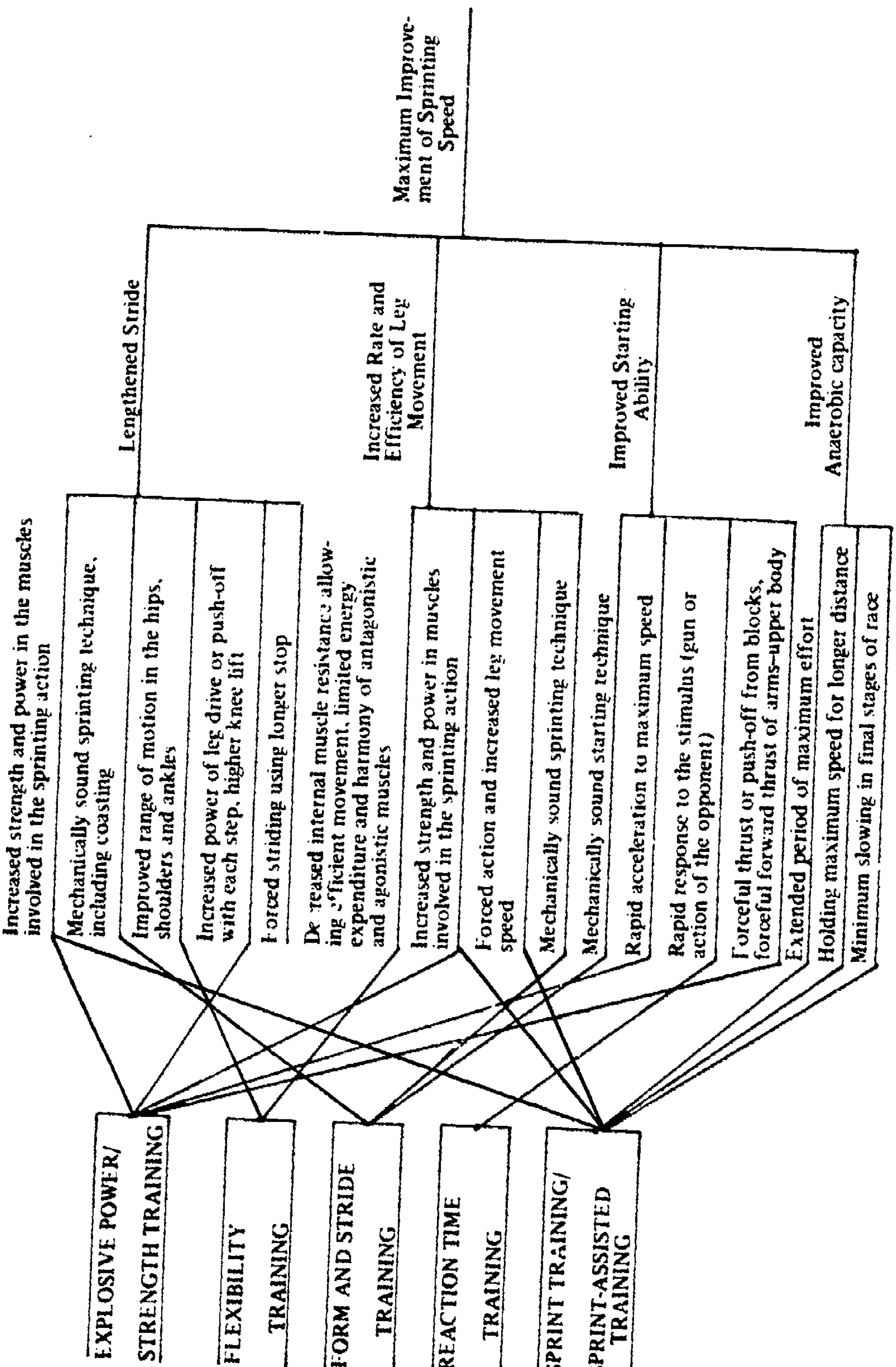

Figure 1. Maximum improvement of sprinting speed through specialized training programs.

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