BIOMECHANICS RESEARCH IN GYMNASTICS: PAST, PRESENT AND FUTURE

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It is difficult to organize such a paper into past, present and future parts, for it is impossible to tell where the past stops and the present begins, or where the present is now and where it will be. Therefore, I have taken the liberty to place a subjective classification system over the top of already published work without adhering strictly to chronology. Although the bibliography of biomechanics related gymanstics literature is not the longest, the list of references is quite lengthy due to the number of events involved. There are several sources of literature review that helped me immensely with the task. Frederick in an article entitled, "The Analysis of Gymnastics, A Survey of the Literature," in Modern Gymnast Magazine, (1969) nicely reviewed the earliest years of biomechanics in gymnastics, and from which I wrote the INITIATORS section of this paper. Christenson, in an article entitled "The Gymnast's Body," in International Gymnast, (1979) did a nice job of reviewing the research related to the anthropometric aspects of gymnasts and helped to organize my remarks on the anthropometrists. In addition, Atwater, 1973, reviewed the research that employed cinematographic analysis of arm supported skills in Exercise and Sport Science Reviews, vol. 1, and without the use of Hay's Bibliography of Biomechanics Literature, I would still be sitting in the library!

Of all of the sport activities in which the human engages, track and field, swimming, and gymnastics provide the most pure movements to analyze biomechanically. Running, jumping, throwing, swimming, and manipulating one's body within the constraints of the sport environment produce natural human movements. Gymnastics and track and field in particular evolved from early displays of bravery, daring, and simulations of the necessary survival activities such as running, throwing, and jumping for fight or flight. In addition, few sport activities are so purely mechanical. Certainly there are strategies involved in gymnastics but most are from the psychological perspective rather than the mechanical perspective. The biomechanical analysis of gymnastics activities must incorporate the human body, with its structure and structural limitations; its torque producing mechanism; the muscles; and the apparatus around, over, on, and about which the human body moves in a prescribed manner.

THE INITIATORS

Early gymnastic writing began in Germany in journals devoted to "Turnen." Frederick (1969) states "The Deutsche Volks-Turnbucher published in Leipzig, Germany and proudly displaying Turnvater Jahn's picture on the cover, is one example."

During the 1800's and early 1900's, questions about gymnastic-related analysis were focused predominantly on the gymnast from a physiological and anthropometric perspective. Although interest in the mechanical aspects of human movement was there, it was not until the beginning of very early cinematographic techniques, in the 1920's and 30's, that serious research in analysis of sport movements began. Most of the early works were initiated in the United States by Cureton, but most were related to track and field and swimming. In addition during the 30's the work of McCloy reflected an enthusiasm for mechanical analysis of sport skills as did many of Cureton's and McCloy's graduate students. Wettstone, in 1938, and some of his graduate students two decades later picked up on the anthropometric side of biomechanical analysis by pursuing the general question, "what type of person has good gymnastic potential?" It was not until the 60's however that biomechanical analysis was established as a sub-discipline and found the field of gymnastics ripe for study.

Since the revitalization of the mechanical analysis of gymnastics, the biomechanists in Germany, Japan, the Soviet Union and the United States have all contributed to the popularity of this area of study.

Two early investigations of interest are Spencer's "Ballistics in the Mat Kip" and Schvartz's "Effect of Impulse on Momentum in Performing on the Trampoline." Spencer (1963) employed cinematography and a researcher-devised giant protractor in front of which 28 subjects performed a mat kip. Results reported were the angle of leg thrust for successful and non-successful performers as well as the degree of "bend" at the hips and knees for the two groups. The data refuted a common belief at the time that "success in performance resulted from thrusting the legs in a low horizontal plane of 30 degrees."

Schvartz (1967) also employed cinematography to study the effect of impulse on momentum in performing on the trampoline. The study was one of the first to test whether a person, while free of support and during the voluntary performance of a stunt, conforms to Newton's laws. It also is one of the first studies to investigate the effect of a piece of apparatus, in this case the trampoline bed, on a human body.

Studies of the direct effects of apparatus on the human body do not appear in the literature for some time later. Herrmann (1967) reported the methods of analysis for using a high speed camera to record motion of gymnastics exercises at the 1st International Biomechanics Seminar. In this particular case, Herrmann analyzed the giant swing on the high bar.

Included in this section are those researchers that have included gymnasts as a category of subjects for anthropometric investigation. One of the earliest studies was reported by DiGiovanna in an article titled, "The Relation of Structural and Functional Measures to Success in College Athletics." The most successful male gymnasts were shorter in height, had shorter legs, and a narrower hip width. Cureton (1951) reported that the gymnasts he measured were shorter than the average college age student and were the strongest group of athletes as well as very flexible in the upper body. Read (1967) and Schmidt and Kohlrausch (1969) who measured German male athletes, also substantiated the findings of DiGiovanna. Bird (1961) and Bosco (1962) found however that champion male gymnasts had longer trunks and legs than normal college men although they were shorter in height. Medved (1966) also reported a shorter height for male gymnasts compared to the average. Bird (1961) and Bosco (1962) found male gymnasts to be in the ecto-mesomorphic somatotype classification and had significantly less body fat. Using the Heath criteria, Carter (1970) reported a mesomorphic somatotype for gymnasts.

Results on stature and somatotyping for female gymnasts appear to be similar to that of the males. Hirata (1966) and Plowman (1974) found that female gymnasts were basically small and ecto-mesomorphs. Carter (1970) found the USSR gymnasts to be the most mesomorphic. Weight, height and percent body fat all appear to be smaller in the female gymnast (Parizkova and Poupa (1963), Pool, Brinkhorst, and Vos (1969), Plowman (1974), Sinning and Lindberg (1972), Carter (1970), Medved (1966), and Sprynarova and Parizkova (1969).

Actual body segment parameters are vital to accurate results in biomechanics research. In spite of the fact that several researchers, Hebbelinck and Ross (1974), Carter (1970), and Kjeldsen (1969) to name a few, have reported mean segmental lengths for male and female gymnasts, direct measurement by the individual researchers on the segmental length, body height and body weight parameters would be far more accurate and simple enough. Other parameters such as segmental centers of gravity, radii of gyration, and segmental masses must be calculated from percentages available in the literature. Unfortunately, far too little research has been done in this area on females in general, and male and female gymnasts in particular. Most of the research studies reviewed had to rely on the work of Dempster (1955), Clauser (1969), and Santschi (1963) for these values.

Although mechanical properties of muscular contractions, neuromuscular mechanisms and electromyography do not fall directly under anthropometrics of the gymnast, they do represent physiological properties that are necessary for the biomechanist's research and will be presented in this section. Sale (1976) in Salmela's text, The Advanced Study of Gymnastics, wrote a concise and salient paper on peak force, rate of force development, impulse, work, and power relating to muscular and neuromuscular mechanisms, and made application of those properties to gymnastics moves. For example, in explaining the work of Stothart (1973) and Willems (1973) in regard to peak isometric force and rate of force development, Sale tells the reader that although one may attempt to increase the peak muscular force of gymnasts through training, peak force may never be attained in the actual gymnastics moves because of the time limitation in many of the events. Sale goes on to say that the gymnast should be attempting to increase the speed with which muscular force is to be attained and work on generating force at high velocities of contractions in order to manipulate the force-velocity relationship, rather than attempting to maximize the peak isometric force.

A gymnast support and swing movement on the pommel horse was used by Kamon (1966) in order to study the electromyograms of 14 shoulder girdle, shoulder joint and trunk muscles. The "rhythmical interplay of the right and left group muscles and the marked sudden bursts of activity of specific duration and sequence indicated the coordination and skill required to accomplish the movements." In addition, "The change in intensity of electrical activity enabled comparison of muscle action to maintain static positions, to activate movements, and to control accelerated swings." Although the focus of attention for this researcher was muscle function during movement, the use of the gymnastic exercise would allow the findings to be the basis of further investigation from the biomechanics of gymnastics perspective.

THE MECHANISTS

Beginning in the early 60's and during the last two decades, the development of instrumentation to help the researcher "see" during a gymnastic performance that which was unable to be seen before, stimulated an overwhelming amount of research which can best be described as a verbal presentation of pictures. These pictures came in the form of electrogoniograms, electromyograms and 16mm film. Although this surge in analysis was prevalent in all sports, it too caught on for numerous masters and doctoral theses in the area of gymnastics. For some reason, possibly the awkwardness of the connections to the performer, electrogoniometry and electromyography did not attain the popularity in the gymnastics research community. Most of these studies were of one selected stunt on one piece of apparatus. Dmitriev and Boyko (1973) took on a formidible task by employing electromyography, electrogoniometry, cinematography and tensiometry to study the action of a sportsman on the horizontal bar. The results showed a coincidence of basic "waves" of muscular activity with the biodynamic curves displayed from the goniograms and the tensiometer outputs on the oscillograph. Identifying efficiency of effort in performing a dismount from the horizontal bar appears to be the purpose of these researchers. Hebbelinck and Borms (1968) recorded the handspring movement cinematographically and the general pattern of muscle activity of the upper extremity electromyographically. Five upper extremity muscles were recorded. Two excellent and two poor performers were selected by a panel of experts. The authors concluded that the greatest muscle activity was during the hand-floor contact phase and that the maximum height of the pelvis during the flight was a major criterion for a well-performed handspring. Landa (1974) recorded shoulder muscle activity during selected skills on the uneven parallel bars. The electrical muscle activity during the performance was calculated as a percentage of maximal isometric contraction for each muscle. She concluded that muscle activity seems to increase with an increase in swing amplitude. The latissimus dorsi appears to contribute the greatest percentage of its maximal strength in all skills performed. The mean percentage of maximal contraction for that muscle was greater than 100%. Yamashita, et. al. (1979) recorded electromyograms for eleven muscles while six gymnasts performed forward and backward giant swings on the horizontal bar. One of the subjects, a gold medalist performer at three Olympic Games, was the only subject to demonstrate the lengthening and shortening of the radius of the long axis of the body relative to the bar by relaxing and contracting the depressors of the shoulder girdle. Apparently, this subject used this method to increase the angular velocity so as to reassume the handstand position. The other 5 subjects did not demonstrate the same EMG patterns in that the shoulder girdle depressors were partially active all the way through the swings. In addition, the other five subjects had a distinct beat just after the bottom of the swing which the gold medalist did not have.

Bajin (1979) recorded goniometric data along with cinematographical data to analyze the men's one and one half front somersault vault. The subjects were world class gymnasts. He concluded that the duration of contact with the horse, the extension of all of the joints, and the joints used for push off differed depending on which end of the horse the gymnast contacted.

Kinematic Descriptions

Kinematic descriptions of various activities in gymnastics gleaned from the analysis of film data were the bases for the next category of biomechanics of gymnastics research. From these studies we gain a wealth of information about velocities of approaches, angles of joints during different phases of the activity, angles and durations of contact with apparatus, angles of take-off from the floor or the apparatus, and the velocities of segmental movements. The most popular event to be analyzed was vaulting; activities on the horizontal bar a close second. Events noticed for their lack of attention in biomechanical analysis are the pommel horse, the balance beam, and the uneven parallel bars. Bajin (1974, 1976, 1978, 1979, and 1980) leads the way in disseminating kinematic information about world class vaulters. Bajin (1976) coaches his readers that it is the amplitude of hip joint flexion that is the critical aspect of a good score in performing a Yamashita vault over the side horse. In analyzing the handspring with 1/1 turn round the longitudinal axis, Bajin (1976) states that all other factors being satisfactory, flight duration is a positive factor for scoring. Lengths of the pre-and post-flights, durations of the vault, and horizontal speed during the pre-and post-flights were measured for three world class vaulters. In comparing three world class vaulters performing the Tsukahara vault, Bajin (1978) concludes that if contact is made with the horse lower than 35^o-45^o, the end of the vault will demonstrate serious mechanical difficulties. Secondly, the time between hand placement must be as short as possible and the gymnast must make at least a 90^o turn during the pre-flight. Bajin (1980) analyzed the men's two and one half salto vault and concluded that a speed of 75 m/sec. during the hurdle, a duration of at least 1.15 sec. during the post-flight and an angular velocity of at least $1{,}000^o$/sec. during the turn were needed.

In a less technical study, Nakajima (1974) studied 48 Japanese vaulters performing the hecht vault and Fukushima (1975) investigated the take-off, pre-flight and rebounding method for two vaulters using two methods of repulsion from the horse. The two most complete studies of vaulting in this category of research were done by Dainis (1979) and Brüggemann (1979). Dainis studied the kinematic variables and energy changes for female vaulters performing a handspring vault and correlated these to judges' scores. Results indicated that a good handspring vault is performed with good upward velocity off of the board, a body angle of 45^{o} at initial horse contact, and a strong repulsion from the horse at approximately the vertical position. Brüggemann (1979) studied the handspring and the Tsukahara vaults of male and female vaulters. A 16mm camera, a force platform under the board, and an accelerometer on the horse, provided the researcher with the kinematic variables. In addition, a rating team judged the performances. A well-performed handspring can be characterized by a relatively high running velocity which is transferred to rotatory energy during support on the board. For the Tsukahara vault, in which attention is directed to a long second flight and a large rotatory impulse around the transverse axis, Brüggemann concludes that "it seems to be disadvantageous to lift the center of gravity too much by the first hand, the best performers have a ratio of 1." In addition, a greater amount of horizontal velocity is lost during the board contact than horse contact. Most of the rotatory impulse is gained during the board phase and is changed only slightly during the support phase on the horse. Similar investigations relating basic kinematic variables through the use of cinematography have been done on various moves on the high bar, parallel bars, balance beam, uneven parallel bars, rings and floor. Knight, et. al. (1978) studied the kinematic variables that significantly contributed to a quality performance of a Russian-style front somersault. Although the results were not startling, the authors gave a thoughtful discussion of the mechanics related to this stunt.

Kinetic Descriptions

Several studies in the basic descriptive category reflect a more in-depth inquiry into the pattern of activity occurring during gymnastics moves. Dainis (1975) in an investigation entitled, "Dynamical Analysis of Ordinary Grip Giant Swings," utilized a computer program to analyze the movements of a poorly performed giant swing and a model performance obtained from the literature. Each performance was set into a three link model (arms, trunk including the head, and the legs), and then were compared. In addition to the application of the model system, the investigator calculated the torques generated at the hip and shoulder joints for the ideal and for the poor execution. The use of the computer program to calculate the torques from the kinematic data provides a method for optimizing performance techniques, something that in the previously reported studies were speculations at best. Two weaknesses in this study were that the investigator did not take the spring system of the bar into consideration and that there was some doubt as to whether the ideal performance was actually ideal.

Bergemann and Sorenson (1979) calculated shoulder, hip, and bar reaction forces from cinematographic data of five subjects performing a kip on the high bar. Data were reported on the paths of the centers of gravity, and the x and y shoulder, hip and bar reaction forces during the execution. Kinolik, et. al. (1980) studied the kinetic and kinematic factors involved in the execution of front aerial somersaults by synchronizing high speed film with a force platform to record the performance. The authors calculated horizontal and vertical ground reaction forces and angular impulses for the front and rear foot. Two subjects of similar weight but of different abilities were chosen to compare. The authors could not determine the kinematic or kinetic factors that contributed to the superior performance. The subject of inferior execution displayed greater ground reaction forces for the front and rear feet; had the same net impulse as the superior performer, had a greater angular velocity for the swinging leg, had a greater maximum elevation of the center of mass during flight, greater time in the air and greater angular impulse. The authors were unable to state any conclusions from the findings.

Comparative Studies of Two or More Techniques

Within the realm of basic descriptive studies falls a special category of describing and comparing two or more techniques or methods of performing a single gymnastics move. Osborne (1979) compared two styles of straddle staldershoots on the horizontal bar using two subjects. Cinematographic analysis revealed that one performer displayed a wide straddling technique and a pumping action through the bottom and late straddle-out phases. The author speculated that this method was more suited to long legged gymnasts with a great deal of hip flexibility. The second performer had what was described by the author as a "long" staldershoot meaning that the performer was stretched farther away from the bar during the downswing phase. This technique resulted in a greater angular momentum, and allowed easy extension to the handstand. Payne and Barker (1976) compared the take-off forces generated during the handspring and the back somersault in order to determine if the correct teaching cues were being presented to the performers by the coaches. The methods employed were cinematography and force platform data. The researchers found that the somersault action produced a doubling of flight time, one half the horizontal displacement of the body, and a more vertical take-off position. The somersault body position was a medium tuck and therefore did not require the angular momentum that the back handspring did since the handspring was performed in a layout position. These data substantiated the appropriateness of the coaches' instructions of "falling backwards and reach for the floor" and for the somersault "strive for height, jumping upwards before tucking." One of the prevalent research questions in the area of tumbling and to some extent vaulting is the ideal arm action to be used in the take-off for a front somersault or a take-off for a vault from the Reuther Board. Brown (1974) compared cinematographically, the regular front somersault take-off with the arms flexed over the head and the Russian front somersault in which the performer swings the arms down to the side and forcefully hyperextends the arms prior to take-off. Although the research techniques were simple, the findings were important. In the Russian technique, the body has greater forward lean at take-off, has greater forward momentum and travels horizontally farther. The arms display a greater angular velocity during take-off. The author concluded that these findings make the Russian technique advantageous. Young (1977) studied the differences in arm action in vertical jumping and in taking off from the Reuther Board in vaulting, and concluded that although the arm action did alter the reaction force for ground interaction, the arm action did not appreciably affect the reaction force of the vaulter coming off the Reuther Board. This finding was attributed to the fact that the performer's time on the board was substantially smaller than the time spent on the floor. Ellerd and Kerr (1979) compared three different arm actions in performing front somersaults. The overhead thrust, the underarm swing, and the Russian methods. The Russian technique showed a greater vertical displacement of the center of gravity but a smaller rotational velocity of the body than the other two styles. The author attributed this to the fact that the rotational inertia is greater in the Russian front somersaulting position.

A second area of concern to researchers is the method of initiating twisting. Van Gheluwe and Duquet (1977) employed two cameras to gather data to study which of two twisting theories was used by gymnasts performing a backward somersault - the two-axes theory (sometimes called the "cat" rotation) and the "hula" theory (a continuous bending of the body at the hips without torsion). They concluded that both theories apply. The two-axes technique seemed to be useful in starting the twist action, while the "hula" movement provided the continuation of the twist rotation. In looking at the diagrams of the performers, however, it appears as though they are using what is currently called a "twist from a somersault," that is, making the body asymmetrical about the somersaulting axis, and this method is supplemented by the other two methods. Borms, et. al. (1973) reviewed for the reader, four commonly accepted methods of initiating a twist. Two cameras were employed to analyze the full twist back somersault. The authors concluded that no twist was initiated from the ground, the arms started the twist by using a "gyroscopical effect," the right arm provided an action-reaction effect, and the hip movement showed the importance of the "gyroscopical" effect. From the diagrams provided, I concluded that the "gyroscopic" effect must have been what Van Gheluwe calls the "hula" theory. This study did not provide us with much information on the initiation of twisting.

THE THEORISTS

The following section of the review concerns those people who, based on their knowledge of physics and gymnastics, have attempted to develop a conceptual framework for analysis. Although the papers would not be considered research, they do, I believe, reflect an appreciable level of scholarly thinking on the subject. The first of these is Biesterfeldt (1974, 1975) who wrote a series of articles on salto and twisting mechanics for Gymnast Magazine. Among other things, he provided information on the conservation of angular momentum with regard to increasing rotational speed and applied that to eight body positions found in gymnastics somersaulting maneuvers. Biesterfeldt also wrote two articles applying twisting concepts to gymnastics. George (1980) also explained the twisting theories from a gymnastics perspective. This article was an excerpt from his text Biomechanics of Gymnastics Skills. Wiemann (1979) and Goehler (1977) have each applied the mechanical effects of a forward leg snap to a variety of gymnastics moves and have attempted to show the positive effects of this move to successful gymnastics performance. A similar analysis of the beat swing action was done by Calkin (1975). The final and most comprehensive article in this category was initially done with divers, however applications can be made to gymnastics as well. Frohlich (1979) very succinctly describes the ways in which airbourne bodies can initiate turning and twisting in the air. It should now be easy for the researchers to apply this information to specific gymnastics moves.

THE FUTURE

There are several studies that have obviously already been written, and chronologically belong in the "present" category in the gymnastics research but have been set apart and included in the discussion of the "future" because for one reason or another, I believe they contain something for us to look at as a guide. The areas they cover are equipment specifications and responses; modeling; and optimization.

Equipment

Some researchers have attempted to take into account forces on the gymnast as a result of the apparatus interaction. One of the first reviewed here was Dmitriev and Boyko (1973) who used tensiometers to determine deformation in the horizontal bar during the performance of a back layout somersault dismount. Kreighbaum (1974) collected data with the use of a strain gauge bridge on the bottom of a Reuther Board while 10 female vaulters performed a handspring vault. Results of the force data combined with cinematographic kinematics and calculated segmental torques, gave the researcher an indication of the time-force parameters of the vaulter board interaction during take-off and the mechanical responses of the board during impact. Chapman and Borchardt (1977) studied the biomechanical factors underlying the dislocate on the still rings. Direct recordings of force were obtained by means of a strain gauge bridge located at the ceiling fixture in series with each cable. Kinematic and kinetic factors of performance were measured against the subjective ratings of judges on the performances. Significant factors to success were peak forces in the kipping phase and swing phase of the dislocate and relative emphasis of vertical movement of the hips over that of the ankles. The authors state "Little attention has been directed in this study to a description of body postures of each subject at various stages of their performance although such information is available...for it was felt that it was likely to add little to the identification of factors pertinent to a dynamic activity." It is this point that biomechanists have been missing in the previous studies that were merely verbal descriptions of films. Sale and Judd (1979) analyzed the shoot-to-handstand on the rings with the purpose of combining cinematographical analysis with direct measurement of the tension developed in the ring cables during performance. The peak tension in the rings was five times the body weight and occurred just past the bottom of the downward swing and just after hip flexion and shoulder extension has been initiated.

Hay, Putnam and Wilson (1979) studied the forces exerted during exercises of the uneven bars using strain gauges attached to the high and low bars, a UV recorder, and motion picture cameras. The maximum forces recorded 3500 Newtons on the low bar and 2140 Newtons on the high bar. The authors concluded that bars should not be designed to withstand less than 4205 Newtons, although the authors admit that over-estimation of maximum forces could be up to 23% or an under-estimation of up to 13%. Wilkerson and Cooper (1979) developed instrumentation for analyzing force applications of the balance beam. Two mini-platforms were held between each end of the beam and its support. A light weight flexible steel bridge connected the two platforms.

Nichol (1976) devised a technique for measuring the pressure distribution over the feet which was applied to several gymnastics related activities - double take-off from the floor, from a Reuther Board, and from the take-off in performing a somersault on the trampoline. Tracings showed a considerable decrease in the total force 30 ms after the first contact with the floor and with the Reuther Board. No conclusions were drawn from the study.

Most gymnastics equipment are spring-like mechanisms to some degree. The gymnast must use those pieces of apparatus to best advantage. Some of the equipment is adjustable in size or shape, the uneven bars, for example. Some have differing material properties such as the coverings on the balance beams, the types of rails used on the uneven bars, and the various spring mechanisms for Reuther Boards. The most recent innovation is the power tumbling mat. Will we soon see spring mechanisms being placed under the cover of the balance beam? What will all of these apparatus changes do to all of these wonderful analyses we have previously discussed here today?

Modeling

Researchers at the brink of the future are attempting to model performances. Smith (1981) has attempted to determine what the centripetal force is on a gymnast performing a giant swing and how those forces change with a different body length of gymnasts and a subsequent widening or narrowing the uneven parallel bars. This mathematical model may help performers of various sizes to individualize training techniques to accommodate differences. Boykin and Breskman (1980) developed a simple model for giant swings on the high bar. That study has already been discussed. Hay, et. al. (1977) developed a computational technique to determine the angular momentum of a human body which was used in the analysis of four activities, two of which were gymnastics related. The model affords the advantage of being able to be used with all types of human movements but is limited to the calculation of angular momentum.

If the researcher can model human gymnastics responses with precision, those responses can be massaged to produce prescribed dimensions. For example, we can plug in anthropometric data to suit each gymnast on our team. We can determine what each individual will do if we work on increasing her/his approach velocity into the stunt, or change the take-off angle and if the model is valid, it may be used for male or female performers.

One of the most optimistic attempts at modeling in gymnastics is a vaulting model developed by Dainis (1981). The model may be used for any vault, but is presently restricted to actions in the plan of the approach, and does not include take-off and landing. Results were verified by four advanced-level female gynasts performing handspring vaults. An example of the use of this model are the conclusions stated by the author. A decrease of 7% in the horizontal speed at take-off would cause a reduction of 13% in after-flight distance. A similar decrease in vertical speed would produce a 25% reduction in after-flight distance. The force exerted by the performer during the repulsion phase has only a minimal effect on the after-flight characteristics of the vault.

It is difficult to determine where we will be by the year 2000. First we need a comprehensive, valid and reliable method of determining body and segmental parameters; data that are precise enough to be used on the male and female gymnast population. As we have seen, gymnasts are significantly different from the mean individual in body mass, shape, and stature. Specifically, we need mass, location and rotational inertia parameters for female gymnasts. I would speculate that they are more different from the average female population than are their male counterparts. At present, researchers must rely on male data for certain measures that are critical to valid results.

Second, we need data on the kinematics and kinetics involved in neuromuscular mechanisms so that we may set potentials on forces, torques, impulses, velocities of contractions and accelerations.

Third, we need generalized models of performance as Dainis and Hay have initiated with which we can optimize the variables and predict the outcomes. A miniscule amount has been done with three dimensional analysis or modeling for any sport. While it is true that much of gymnastics is symmetrical, there are some moves that are not. With the increased spring of the floor exercise mats, we will see increases in multiple twisting moves.

Fourth, we need a vast amount of data on the mechanical properties of the apparatus. The apparatus we use today does not afford equal opportunity to all gymnasts. We, in a crude manner, adjust diving boards for just that purpose. There are numerous examples. The width of the parallel bars, the width of the pommels on the side horse, the deflection of the horizontal bar, the inflexibility of the rings, are all factors to consider in the future. Even without changing the apparatus, we know very little about their present mechanical properties.

How much spring does a spring mat need, if a spring mat could spring--- a 135 pound gymnast into the air displaying a quadruple, triple twist front somersault? Could we not test reaction and movement time for leg extension and adjust or select a Reuther Board to maximize that interaction?

We should be ready to take on those questions and provide answers. The coaches will be expecting it. Biomechanics is becoming a popular field - even in the gym!

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