A BIOMECHANICAL ANALYSIS OF ACCELERATING GIANT SWINGS ON THE HORIZONTAL BAR

by

Paul J. Thiessen

A thesis
presented to the University of Manitoba
in partial fulfillment of the
requirements for the degree of
Master of Physical Education
in
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ABSTRACT

The purpose of the study was to analyse the kinematics, kinetics and energy exchanges involved in the performance of accelerating giant swings on the horizontal bar. A secondary purpose of the study was to develop a computer program capable of modelling the gymnast/bar system. Four steps were taken to analyse the skill; strain gauges were bonded to the horizontal bar, the subjects were filmed while performing accelerating giant swings, the kinematics, kinetics, and energy parameters of the performances were analysed, and a computer program was developed to model the gymnast/bar system. Rigid body modelling was used throughout the study. A pattern of hip flexion, extension, flexion again, and finally extension was found. These actions caused an exchange of angular momentum and energy between the segments and altered the forces applied to the bar by the hands, as well as the energy stored in the bar. It was concluded that; the interaction of the gymnast and bar is a significant factor in the execution of the skill, energy exchanges are caused by the actions at the hip joint, the gymnast should try to maximize the energy stored in the bar, the frequency of the bar should be close to the frequency of the athlete for maximum responsiveness, and computer modelling can be used to investigate swings on the horizontal bar.

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INTRODUCTION

Scope of the Problem

Accurate prediction is one of the goals of any science. The predictive aspect of sport biomechanics occurs when devising the most efficient and effective technique for executing a skill. It is necessary to understand the forces and torques that cause a motion to be able to describe an efficient method of executing the motion. The internal forces in a giant swing can most easily be measured indirectly from displacement data, while the external forces acting on the horizontal bar can be either calculated indirectly from film data or measured directly using strain gauge measurement techniques. Using both methods an accurate estimate of the forces and torques involved in the execution of a giant swing is possible. This information may then be used to predict how changing some aspect of the motion under study will influence the final motion.

The movement to be studied is an accelerating giant swing. Since the interaction of the gymnast with the horizontal bar was of primary interest, accelerating giant swings were selected as the skill to be examined. This skill provides more gymnast - bar interaction than does constant velocity swings. When a gymnast performing on the horizontal bar prepares for a release from the bar he usually attempts to "wind up" or accelerate his giant swings in an attempt to generate maximum vertical velocity at the time of release. The gymnast also slightly alters the nature of the giant swing, just prior to release, to thrust on the bar and thus store energy in the apparatus which can be used at the time of release to further increase his vertical acceleration (Biesterfeldt, 1977). Since the giant swings executed just prior to release magnify the interaction of gymnast and bar, they will be used in the study and will be called "accelerating giant swings".

Statement of the Problem

The purpose of this study was to analyse the kinematics, kinetics and energy exchanges involved in the performance of accelerating giant swings on the horizontal bar. A secondary purpose of this study was to create a computer model capable of simulating the movements of a gymnast on the horizontal bar.

Delimitations

In both the analysis and subsequent modelling, the athlete-bar system was considered in a simplified manner. The bar was represented as a spring-mass system. The athlete was represented as a three-link rigid body, under the following assumptions: "1) the body segments are considered to be rigid, of uniform density and simple geometric shape; 2) the rigid links rotate about fixed axes; and 3) tissue deformation and asymmetrical location of internal organs are considered negligible," (Miller, 1979, p 118). The three links will represent the three major segments of the body used in the execution of giant swings. Both the right and left arms (hands, forearms, and upper arms) will be represented as one segment, the trunk including the head and neck will be represented as the second segment, and both legs (thighs, shanks, and feet) will make up the last segment. The trunk segment including the head and neck will be considered completely rigid, even at the neck. The head and neck will always be represented as being in line with the trunk, so that the segment is one straight unit, rotating about the shoulder joints.

The system will be constrained to only two dimensional motion within the sagittal plane (perpendicular to the bar). The axes of rotation will thus always be parallel to the bar. The axis of the arm segment will be the bar, while the axis of the trunk segment will be the shoulders, and the axis of the leg segment will be the hips. Note that the point representing the bar will not be fixed in space but will move as if it were attached to a spring.

Definition of Terms

Giant Swing or Giant

A giant swing or giant is a movement executed on a horizontal bar which consists of a complete rotation of the body through 360 degrees using the hands and bar as the pivot point around which the body rotates. Giants can be executed in two directions; a forward, or front giant swing consists of a clockwise rotation as viewed from the right side of the athlete, a backward, or back giant swing consists of a counter-clockwise rotation as viewed from the right side of the athlete.

Accelerating Giant Swings

Accelerating giant swings are giant swings whose average angular velocity is increasing over time. That is, the average velocity of an accelerating giant swing will be greater than the average velocity of the previous giant swing.

Kinematics

Kinematics deals with the displacement, velocity, acceleration, and temporal aspects of motion without reference to the causes of motion.

Kinetics

Kinetics describes the forces acting on a body, the mass and inertial properties of the body and the resulting motion.

Strain Gauge

A strain gauge is an electrical device used to directly measue the strain of a material due to forces exerted on the material.

Strain

Strain is the deformation of a material as a result of stress on the material. The relationship between stress and strain is linear within the proportional limit of the material, but is not linear past this limit. Each material has it's own proportional limit.

Stress

Stress is a measure of the amount of force exerted on a material, per unit of area, Newtons per square centimeter.

External Forces

External forces are forces exerted on a body by another body, such as the forces from the ground exerted on the feet in standing, or the forces exerted by a bar on the hands when hanging from the bar.

Internal Forces

Internal forces are forces exerted on one segment of a body by another segment of the same body, such as the forces of muscles on bones, forces caused by friction in joints, or the weight of a limb acting on another limb.

Digitizing

The process of digitizing consists of converting either an analog signal or a spatial coordinate into digital or numeric form. A more detailed description is included in the Methods and Procedures section of the paper.

REVIEW OF LITERATURE

The most common method employed in the analysis of human motion in sport has been to compare some aspect of the performance of highly skilled athletes to that of less skilled athletes. This method is an effective way of understanding the differences between a good performance and a great performance, and the resulting information can be used to help less skilled athletes improve. One significant draw-back of this method is that because the elite athlete is used as the "ideal" model, it is difficult to isolate what the elite athlete can do to improve his/her performance. For this reason sport scientists are often in the position of waiting for the elite athlete to develop a new technique and then analysing the finished product. One of the primary reasons that this occurs is because the nature of sports movement is so extremely complex that simply understanding the movement in terms of the mechanics involved is a difficult task. Any extrapolation to "possible" improvements is therefore an even more difficult task. Still, one ultimate goal of sport biomechanics is to understand a skill to such an extent that reliable prediction is possible.

The digital computer has proven to be a powerful tool in analysing human motion. Techniques have been developed to model an athlete, or some part of an athlete in motion and use the computer to calculate the relevant motion parameters. The key to this method is the fact that the number of variables, and therefore the amount of mathematical analysis necessary, can be reduced by representing the athlete as a simplified system. One way to represent the body in a simplified manner is what is called "rigid body modelling" (Miller, 1979). In this technique the body, or some part of the body, is modelled as a system of rigid, geometrically simple, uniform links of known mass and inertia. In this way the mechanics of motion can be approximated by limiting the analysis of the skill to a smaller number of significant variables. Other modelling techniques represent a part of the body as a deformable element, not a rigid link. This second technique has been used to model the trunk, vertebral column and associated structures, and has been applied to clinical studies, but has not been used to directly model sports skills (Miller, 1979).

Rigid body models have been used quite extensively in the analysis of sports skills. In some cases the entire body is modelled, however often only a segment of the body is represented in the model. Several models of the entire body have been created using the rigid body technique (Dapena, 1981; Hatze, 1971; Ramey & Tang, 1981; Aleshinsky & Zatsiorsky, 1978). These models are extremely complex but have the advantage of being applicable to almost any motion of the human body. Hatze (1971) included the muscular system in his model, representing individual muscle groups as spring elements. These types of models vary in the total number of segments used to represent the body, but usually involve from twenty-one to twenty-three segments. As was stated earlier, the entire body is not necessarily included in the modelling of a skill. By limiting the model to the relevant segment(s) involved in the motion, the analysis can be more focussed toward developing a detailed understanding of the mechanics of the skill.

Limited representation of the body has been extensively used in gait analysis (Miyazaki & Arimoto, 1980; Ober, 1973; Onyshko & Winter, 1980; Townsend & Tsai, 1977; Thornton-Trump & Daher). In most gait analysis models the trunk, head and arms are represented by one segment, while the legs and feet are represented by several segments. For this reason the analysis is limited to the motions of the two legs and how they interact with each other and the entire upper body to produce locomotion. Models representing specific segments of the body have also been used quite extensively (Alexander, 1978; Halliwel, 1977; Hatze, 1975; Hubbard, 1980; Karas & Stapleton, 1976; Mclaughlin et al, 1977; Miller, 1970; Nordeen & Cavanagh, 1975; Otahal, 1967; Putnam, 1979; Walton & Kane, 1975; Youm & Yoon). In these models a specific limb, or joint, or segment is represented, or a simplified model of the body is employed.

Models of this type have also been used to analyse the motion of implements such as golf clubs and bats and the arm motions that contribute to moving these implements (Budney & Bellow, 1982; McIntyre & Pfautsch, 1982; Milburn, 1982). These models are used in a variety of ways including kinematic analysis (Alexander, 1978; McIntyre & Pfautsch, 1982; Mclaughlin et al, 1977; Milburn, 1982; Nordeen & Cavanagh, 1975; Otohal, 1976), energy and momentum analysis (Miller, 1970; Putnam, 1979; Walton & Kane, 1975), and kinetic analysis (Budney & Bellow, 1982; Halliwell, 1977; Hatze, 1975; Hubbard, 1980; Karas & Stapelton, 1969).

The use of models to analyse forces and torques is quite common. In fact, modelling is perhaps the only way to approximate internal forces, or the forces between joints. There is no way of directly measuring these forces, so a model of the system is created and an estimation of the internal forces is made based on measureable parameters such as external forces (on the ground or an apparatus), linear velocities and accelerations, and angular velocities and accelerations. The model, as usual, is a simplified representation of the system so that the principles of mechanics can more easily be applied to find the internal forces.

Another use of models is in motion optimization. In motion optimization a computer, using a simplified model and the principles of mechanics, calculates the optimal performance of a skill based on specific predefined criteria. In most cases the approach is to use differential calculus to derive a set of differential equations to represent the system in motion. The computer is then used to solve the differential equations, given the initial conditions of the system and the movement to be modelled. To find the optimal performance the computer must recalculate the equation repeatedly using varying initial conditions and input parameters, until the best possible performance is isolated. It would be nearly impossible to make all the calculations necessary by hand, but given enough time a computer can determine the optimal performance (Hatze, 1975). Models using differential equations to represent simplified systems of motion have been used to simulate skills in a variety of sports such as football (Hatze, 1975), pole vaulting (Hubbard, 1980), skating (Halliwell, 1977), and gymnastics (Dainis, 1973; Duck, 1978).

Biomechanical Analysis of Gymnastics Skills

Gymnastics skills have been the subject of study since the beginnings of the science of sports biomechanics. Cureton (1939), in discussing the uses of cinematography in the study of sports skills, used gymnastics skills to illustrate his article. Since then, gymnastics skills have been quite extensively analysed using cinematography. Studies have been done on a variety of gymnastics apparatus including: the floor (Borms, Duquet & Hebbelinck, 1971), the still rings (Borchardt, 1976; Sale & Judd, 1974), vaulting (Cargill, 1975), the parallel bars (Grossfeldt, 1962), the uneven bars (Hay, Putnam & Wilson, 1979; Smith, 1981), and the horizontal bar (Borms, Moers & Hebbelink, 1975; Kopp & Reid, 1980). Cinematography is particularily well suited for analysing movements on the horizontal bar since most skills on the bar are planar in nature, that is, they only occur in one plane. For this reason there is less likelihood of neglecting to describe motions which occur out of the primary plane of motion.

Another technique that has been used in the analysis of gymnastics skills is the use of strain gauge or force platform devices to directly measure the external forces involved in the execution of a skill. A strain gauge is an electrical transducer in which the resistance changes when it is stretched. By bonding a strain gauge onto a material such as a steel bar, the strain of the material can be measured by measuring the change in the electrical resistance of the gauge (Beer & Johnson, 1981). The strain of a material is directly proportional to the amount of stress applied to the material, within its specific proportional limit (Hurlock, 1966). By measuring the strain on the material the amount of force that an athlete is exerting on the apparatus can be calculated. This constitutes a direct measurement of external forces, and can help in understanding the kinetics of the skill.

Force platforms are devices that employ numerous strain gauges wired to a platform, and are used to measure ground reaction forces. Payne & Barker (1975) used a force platform to measure the ground reaction forces in back handsprings (flic-flacs) and back somersaults in tumbling. Strain gauges have been used on several types of gymnastics apparatus to measure the forces applied to the apparatus during the execution of various skills.

Sale and Judd (1974) developed a load cell using strain gauges to measure the forces generated on the still rings. The system was applied to the analysis of a shoot-to-handstand on the rings. The load cell was connected in series with the cable of one of the rings. It consisted of a three sixteenth inch thick aluminum diaphragm welded to an external ring. Eight strain gauges were bonded to the diaphragm, four per side at ninety degree intervals. A Budd Model P350 strain indicator amplified and modified the signal and displayed it on an oscilloscope. A Hycam 16mm movie camera was used to simultaneously film the gymnast and the oscilloscope at a rate of 100 frames per second. The load cell was calibrated by statically loading the cell using precision weights. It was calibrated for a linear scale of 0 to 500 pounds. The film, after processing, was projected onto scaled paper to interpret the force records. The width of the oscilloscope lines were equivalent to 20 pounds on the scale so that the center of the line was used to make the measurements. The estimated accuracy of this method was approximately plus or minus ten pounds. The impulses generated during performances were also calculated. Sale and Judd found that forces of up to five times body weight were generated in the execution of the shoot-to-handstand. They also found that the better performers generated larger impulses during two phases of the swing, the bottom of the downward swing and the hip extension phase of the upward swing.

Hay, Putnam and Wilson (1979) used strain gauges to estimate the maximum forces exerted on the uneven bars. They combined the use of cinematography and the application of strain gauges to the bars to measure the vertical and horizontal forces on the bars. Two gauges were placed on one end of each of the bars along the horizontal and vertical axes of the bars. By measuring the horizontal and vertical components, the resultant force could easily be calculated using vector addition. Filming was necessary to determine the point where the bar and athlete made contact because the strain gauge output was dependent on the distance of the point of application of the force from the gauges. The strain gauge output was recorded on a Brush UV recorder and then digitized using a Hewlett-Packard 9107A digitizer. The resulting data was then analysed to find the maximum application of force on the bars. An estimate was made of the maximum forces that the bars should be made to withstand to ensure safety. The bars reacted linearly to the stress within the limits of the forces being measured. Several sources of error within the measurement system were determined including signal amplification due to the dynamic response of the bars (less than 10%), sensitivity of the gauges to perpendicular strain (less than 7%), errors associated with estimating the point of application of the force (less than 2.5%) and errors associated with digitizing and curve fitting the data (less than 3.5%). The maximum forces exerted on the bars were 3500 Newtons (low bar) and 2140 Newtons (high bar). Suggestions for the improvement of the measurement technique included the use of strain gauges on both ends of the bars to eliminate the need for estimating the point of application of the forces, and the use of an analog to digital converter to convert the strain gauge output into digital form and enter it directly into a computer.

Kopp and Reid (1980) used a strain gauge system to analyse the forces and torques exerted on the horizontal bar during the execution of giant swings. They filmed six national caliber gymnasts performing on the bar while taking strain gauge measurements of the forces on the bar. Their strain gauge system consisted of four gauges, two on either end of the bar, that measured the resultant strain on the bar independent of the point of application of the force. They also used four torque gauges to measure the torque being applied to the bar. The output was recorded on a Grass

Polygraph and an FM recorder. The FM recordings were later digitized using an analog to digital converter. The system was calibrated by loading the bars in the horizontal and vertical directions with known forces and applying known torques. The system was found to react linearily to the applied loads. The maximum forces recorded were 2208 Newtons (back giant swings) and 2166 Newtons (front giant swings) or 3.57 and 3.50 times body weight respectively. The maximum torques recorded were 23.3 Newton meters for the back giant swings and 41.3 Newton meters for the front giant swings. The maximum force in the backward giant swings occurred when the gymnast's center of gravity was at an inclination of 210 degrees (standard deviation of 11.6 degrees) and occurred when the gymnast's center of gravity was at an angle of 166 degrees (standard deviation of 35.0 degrees) in the forward giant swings.

Modelling of Gymnastics Skills

Modelling has also been used to study gymnastics skills. Several models have been used to analyse gymnastics movements on the horizontal bar. The simplest model of a gymnast on the horizontal bar was presented by Boykin and Breskman (1980). The gymnast was represented as a concentrated mass capable of sliding on a light pendulus rod. The mass represented the center of mass of the gymnast. Just as the gymnast is capable of altering the distance of his center of mass relative to the bar by altering the positions of his body segments, the mass of the model was able to move up and down the pendulum, closer or further from the axis point. The model was used to develop a simple strategy for creating swing prior to a kip, by manipulating the time history of the center of mass of the model. Once a strategy was developed using the model, a gymnast was filmed performing a beat swing and a kip and the time histories of the model and the gymnast were compared. It was found that the time histories of the model and the gymnast agreed quite well and it was concluded that the model could be used to describe the mechanics of the beat swing prior to a kip.

More complex, three-link models of a gymnast on the hortizontal bar have been presented by Dainis (1973) and Duck (1978). In these models differential calculus was used to develop continuous models of the gymnast-bar system. Differential equations were used to mathematically model the system, and then computer algorithms were used to solve the equations. The term continuous, applied here, denotes the fact that the torques and forces involved in the skill under investigation could be calculated over a continuous time range given the initial conditions of the system and certain input data. Dainis' model consisted of a rigid body representation of the gymnast, rotating about a fixed axis. The model was developed in such a way that any number of links could be used to represent the athlete, however a three-link version of the model was the one chosen to simulate giant swings on the bar. The model was designed to accept either joint torques or angular accelerations of the segments as input, from which the resultant motion was calculated. Dainis found it extremely difficult to duplicate the motion of a giant swing using joint torques as input due to the complex interaction of the torques on the resulting motion. Using angular accelerations as input proved to be an easier method of producing the desired motion. Dainis found that the model generated joint torques that were close to torques calculated from actual performances. In comparing what were considered ideally executed giant swings and poorly executed giants he found several fundamental differences. A poor performance consisted of a relaxed body during the descent phase of the swing, a late flexion at the hip joint, and a lack of coordinated effort between the hip and shoulder joints. In contrast, a well executed swing consisted of a rigid body during the descent phase to prevent hyperextension at the hip and shoulder joints, a relatively early flexion of the hip joint just prior to reaching the bottom of the swing, and a coordinated flexion of both the hip and shoulder joints.

As was mentioned previously, Dainis' model simulated the bar as a fixed, immovable axis. Biesterfeldt (1975), commenting on Dainis' paper, pointed out that a horizontal bar is actually very resilient. He further noted that the gymnast in performing on the horizontal bar takes advantage of the spring characteristics of the bar. By storing energy in the bar and using this energy at opportune moments the gymnast can reduce the amount of total energy needed to execute the giant swing. Dainis recognized the mechanical difference between a rigid bar and a flexible bar; "Lack of flexibility makes the performance of giant swings a little more difficult, but does not significantly alter the nature of the movement." (Dainis, 1975, p 38). He proposed that further research would be done to incorporate a representation of the bar as a spring element and possibly include a release from the bar.

A similar study by Duck (1978), also used a three segment representation of the gymnast on the bar. Duck also represented the bar as an immovable hinge. Newtonian mechanics were used to calculate the displacements of the centers of gravity of the segments. The three segments were separated into three free body diagrams to derive the differential equations necessary to simulate the system. Duck attempted to validate the model by comparing the angle of the arm segment and the position of the center of gravity of the system derived from the model with data collected from actual performances. He found a mean difference of 7.09 degrees (standard deviation of 5.84) in the angle of the arm segment between the model and the actual performances. The mean difference in the distances of the center of gravity from the bar was 3.05 inches (standard deviation of 2.08). He concluded that his mathematical model of the gymnast was accurate enough to be a valuable tool in studying motions on the horizontal bar. He was also aware of the problems associated with representing the bar as a fixed axis and suggested that future models should incorporate a mass-spring representation of the bar.

Summary

The goal of sport biomechanics is to acquire an understanding of the mechanics of sports motion. Ultimately this knowledge could be applied to develop new or better methods of executing sports skills. In studying the human body in motion it is necessary to model the body as a system of simple links, in an attempt to reduce the complexity of the mechanics involved in the calculation of relevant motion parameters. The body is most commonly modelled as a system of rigid links of known inertia and simple geometry. Models incorporate numerous segments to represent the entire body or a few segments to represent a part of the body.

In the study of gymnastics skills cinematography has been used as early as 1939 (Cureton, 1939). It has been applied to most of the apparatus used in gymnastics, but is particularily well suited for studying horizontal bar skills. Another method employed in the study of gymnastics is the use of strain gauge technology to measure the external forces generated during gymnastics movements. Strain gauge technology has been used to study forces on the still rings, uneven bars and the horizontal bar. Modelling of a gymnast on the horizontal bar has also been attempted. The simplest model used a concentrated mass sliding on a light pendulum to represent the center of mass of the gymnast. Two other models consisted of three-link rigid body representations of the gymnast and bar. Both models represented the bar as a fixed axis, but suggested that further models use a spring-mass representation of the bar.

METHODS AND PROCEDURES

In an attempt to develop an understanding of the kinetics of accelerating giant swings, and the interaction of the bar and gymnast, four steps were taken. First, strain gauges were used on the horizontal bar to directly measure the forces exerted on the bar. Secondly, cinematography was used to collect data on the displacements of the segments of subjects performing accelerating giant swings. The displacement data was then used to calculate the kinematics of the motion, and these in turn were used to calculate the forces, torques, and energy exchanges at the three major joints under study. The final step was the development of a simple computer program capable of modelling the gymnast-bar system.

Strain Gauge Measurement

Strain gauges were used to directly measure the forces exerted on the bar by measuring the strain of the bar. Strain is the deformation of a material under stress (Beer & Johnson, 1981). Within the proportional limit of any material the relationship between stress and strain is linear (see figure 1). Provided strain gauge measurement is undertaken within this range the force being applied to a material is directly proportional to the measured strain. Previous studies have determined that the range of forces exerted on gymnastics apparatus is within the proportional limit (Hay, Putnam & Wilson, 1979; Kopp & Reid, 1980). An initial study was undertaken to estimate the range of forces exerted during accelerating giant swings. One strain gauge was bonded to the horizontal bar at a distance of 27 centimeters from one support, along the top surface of the bar to measure the vertical forces generated. This simplified system was calibrated statically using a range of weights from 0 to 365 pounds (1624 Newtons). Giant swings were then executed on the bar and the maximum forces estimated to be approximately 470 pounds (2091 Newtons), or three times body weight.

The final strain gauge measurement system consisted of eight 120 ohm gauges (Micro-Measurements type EA-06-250BG-120). The eight gauges were placed along the two major axes of the bar to detect strain in both the horizontal and vertical directions. They were wired into two Wheatstone bridges, one for vertical force, and one for horizontal force (see figure 2). The gauges were placed in such a way as to measure the strain on the bar independent of the point of application of the force. They were also positioned so that measurement of strain on the principle axes would be independent of each other (see figure 3). The two bridges were then amplified using two channels of a

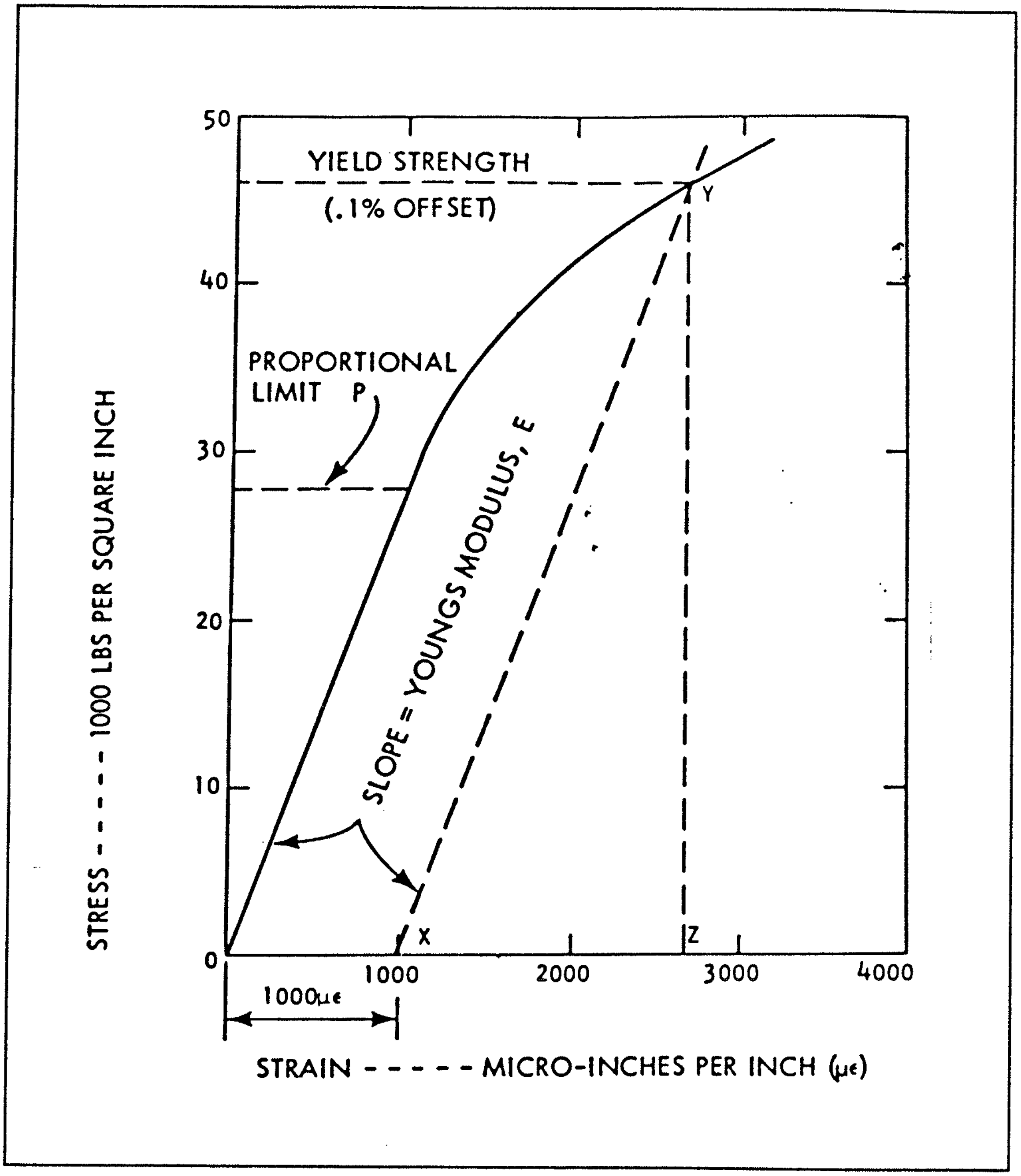


Figure 1: Stress vs. strain curve for stainless steel. From Hurlock (1966), pg 2-4

strain bridge amplifier. The output from the amplifier was fed directly into an analog to digital converter (Hewlett-Packard 47310A) which was interfaced to a micro-computer (Hewlett-Packard 9835A). An assembly language program was written to allow the micro-computer to read data from the analog to digital converter at the A/D converter's maximum speed. The maximum speed of the A/D converter used was 200 samples per second. This sample rate, used with two channels, allowed a time of 0.01 seconds between samples.

The measurement system was calibrated by loading the bar with known weights in both the horizontal and vertical directions. An apparatus for loading the bar in the horizontal direction was built so that a cable strung through a pulley allowed weights to be hung from the apparatus while transferring the force of the weights horizontally to the bar (see figure 4). The apparatus was built out of wood using a metal badminton stand for a base and therefore was not strong enough to handle large forces. For this reason only forces up to just over the body weights of the subjects were used (up to 215 pounds or 957 Newtons). The measurement system reacted linearily using this range of weights, with linear correlation coefficients in all calibration attempts being well over point nine (0.9). A linear regression and correlation computer program was used to calculate the conversion formula and correlation coefficients necessary to convert the digitized data to actual forces. While the bar

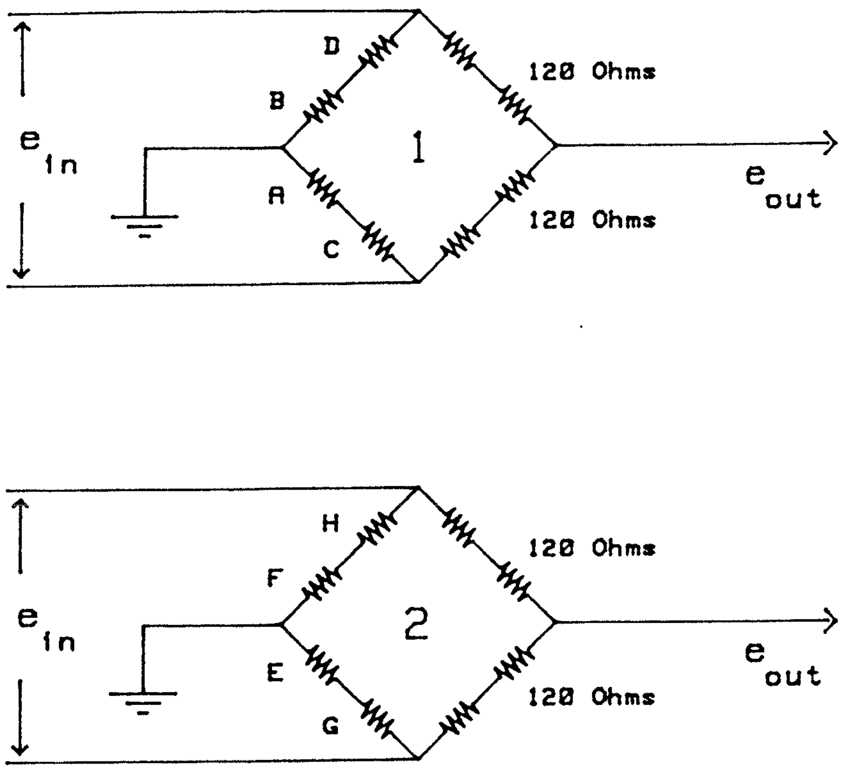


Figure 2: Strain gauge bridge configurations. 1) Vertical bridge 2) Horizontal bridge (Note: Letters on the arm of a bridge signify strain gauges. Resistors were used on the other arms of the bridges.)

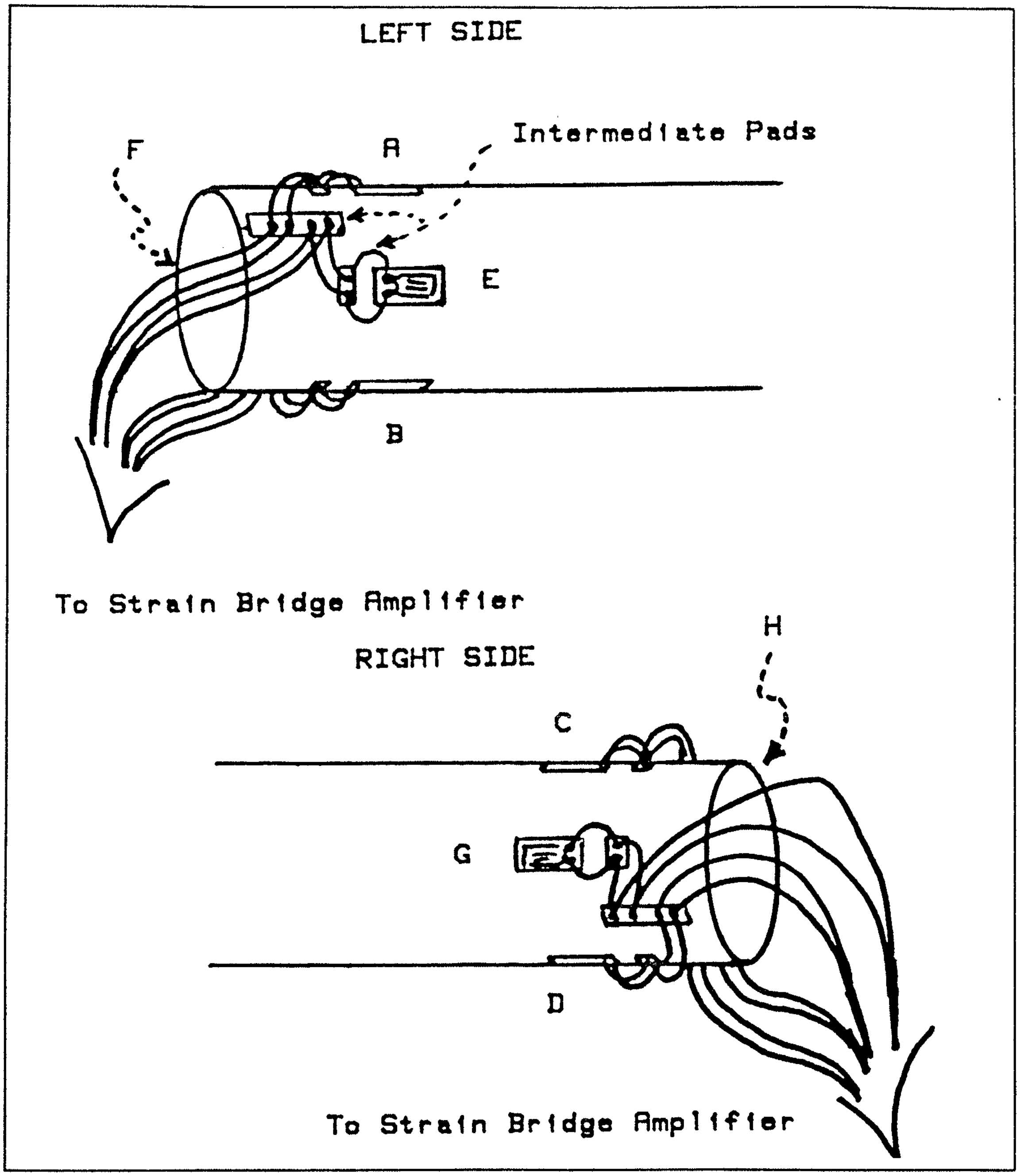


Figure 3: Placement of the strain gauges on the horizontal bar

was being loaded with these weights a measure of the deflection of the bar was also being done so that the spring constant of the bar could be calculated. As was proposed, the bar was modelled as a spring-mass system, with the mass in the case of calibration being the mass of the weight used to load the bar. Using the formula; force equals the spring constant of the bar times the deflection of the bar;

$$F = k\ d,$$

the value of k (the spring constant) could be estimated by dividing the force being applied to the bar (F) by the deflection of the bar (d). The mean value of k was 28238 (standard deviation of 157.1).

Several problems associated with using the strain gauge system arose which prevented use of the horizontal bridge. The first problem was associated with the design of the support apparatus for the horizontal bar. The bar is a solid metal (tempered steel) bar with sleeves attached at either end that slot into two brackets on the two support posts (see figure 5). These sleeves have pins through them which slide into slots on the brackets on the support posts. The pins are not secured to the sleeve, but can slide within their holes. This allows the bar to slide forward and backward in the slot as the gymnast swings around the bar unless the sleeve and its corresponding slot in the bracket are completely snug. This shifting of the position of the bar

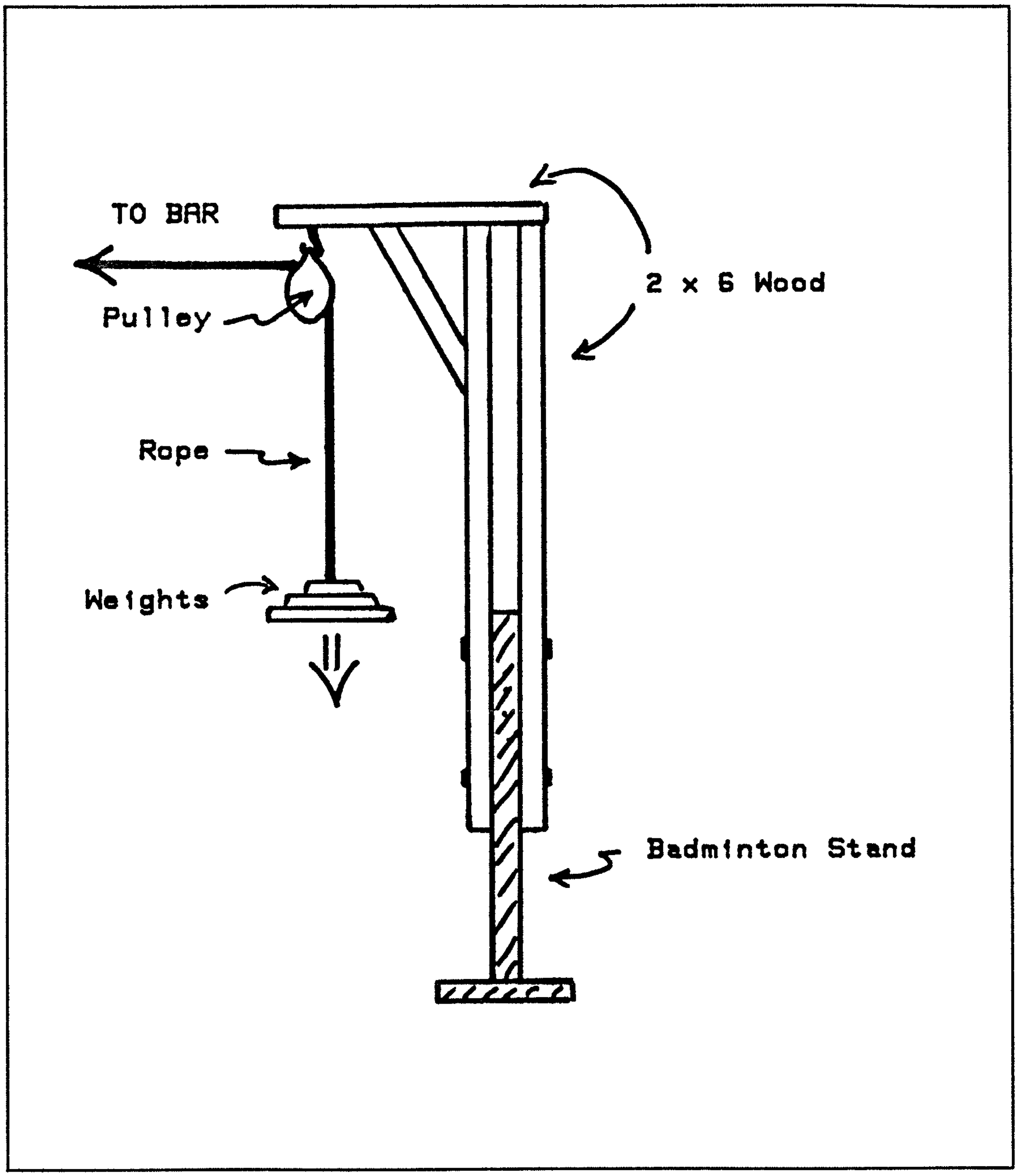


Figure 4: Apparatus for calibrating in the horizontal direction

in the slot apparently altered the horizontal tension on the bar, which caused the horizontal strain on the bar to change. This meant that any calibration done was invalidated because the strain gauge output would change with the changes in strain on the bar. In fact, even the settings of the strain gauge amplifier fell out of range of the strain gauge output if the bar shifted. This problem was not evident when a subject simply took light swings on the bar, but was greatly magnified during giant swings, making measurement in the horizontal direction virtually impossible under the given conditions. Attempts to wedge pieces of wood or metal between the sleeve and the slot proved unsuccessful in solving the problem. For this reason the output from the horizontal bridge could not be used.

Another problem that plagued this aspect of the investigation was the constant breaking of the strain gauges. This, it is suspected, was not due to the large strain on the bar, but rather the normal use of the bar in university physical education classes, gymnastics team practices and gymnastics classes. The gauges were simply ripped out by persons inadvertently pulling on the wires while using the bar. In an attempt to prevent damage to the actual gauges themselves each gauge was wired to several intermediate pads so that pulling on the end wire would simply rip the protective pads, rather than destroy the gauge, but even this did not prevent the gauges from being damaged on several occasions (see figure 3).

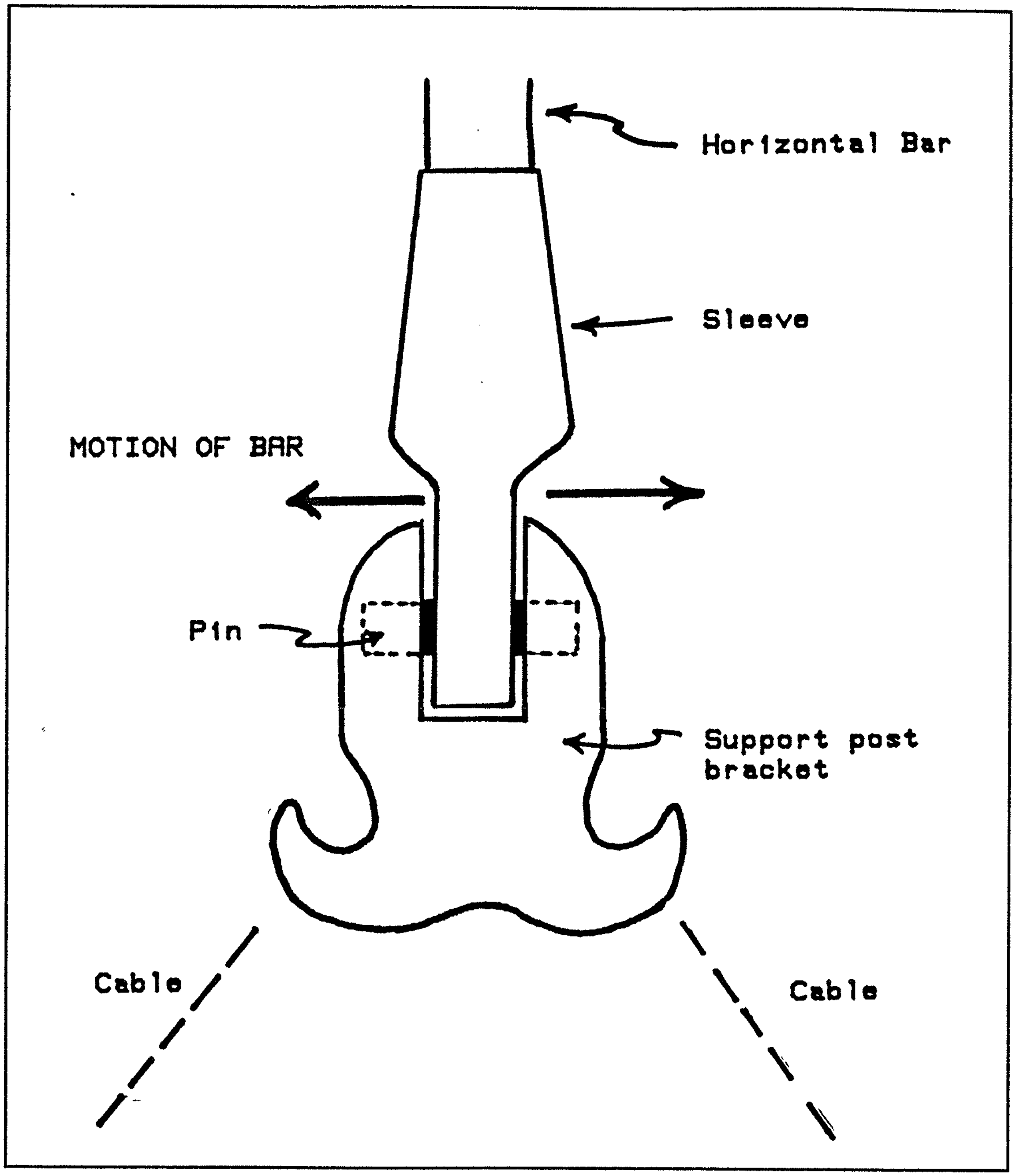


Figure 5: The horizontal bar and the support bracket it rests in

Cinematography

At the same time that the strain gauge data was being collected the subject was being filmed. Two 16mm cameras were used to film the gymnast swinging on the bar. One camera was positioned beside the bar to get a clear view of the sagittal plane of the subject (perpendicular to the bar). The second camera faced the gymnast to get a front view of the bar. The side camera was set to 100 frames per second, while the front camera was set at 50 frames per second. The subjects were asked to perform wearing only white shorts and socks.

Each subject was asked to perform a flyaway dismount from the bar after executing at least one wind up giant swing. The reason that the subjects were asked to perform this dismount was so that they would be attempting to accelerate their giant swings as much as possible. Also, in performing a flyaway dismount, the gymnast tries to flex the bar as much as possible to use the spring of the bar to help propel him into the air upon release. For these reasons the ideal giant for investigating the interaction of gymnast and bar was the giant just prior to release from the bar. Only two gymnasts were able to perform the flyaway with sufficient proficiency to be used in the study. The first subject was a former member of the university men's gymnastics team, while the second subject was a third year member of the team.

Six joints on the subject's body were marked with black electrical tape to make them easier to see in the films. The joints marked were; the wrists, elbows, shoulders, hips, knees and ankles. Both the near side and the front of the joints were marked so that they would be more visible in both cameras. The horizontal (X) and vertical (Y) coordinates of ten points on the subject's body were then derived from the films. These points were either joints or ends of body segments and included the following: the bar, the wrists, the elbows, the shoulders, the top of the head, the hips, the knees, the ankles, the heels and the toes. Note that because the far side of the athlete in the side view film was not visible, all coordinates were taken from the near side of the subjects.

The coordinates were derived by digitizing them using a Hewlett-Packard 9874A digitizer. The films were projected through the digitizer so that by placing the digitizer cursor over a point on the film and pressing the digitizer key the vertical and horizontal coordinate of the point could be entered into the Hewlett-Packard 9835A micro-computer. Because the films were projected through the digitizer, a mirror image of the coordinates was returned. To transform the coordinates back to their original form the X-coordinates had to be flipped. This was done by subtracting the X-coordinate of the point from 17400, which is the maximum X-axis digitizer value.

Once the coordinates had been entered into the computer in digitizer units they had to be converted to actual, real distance units (meters). This was done by calculating a conversion factor by which the digitizer units could be multiplied to give the actual coordinates of a point. To calculate this conversion factor two points in the field of view of the camera were digitized. The real distance between these two points was known so that by using the digitized distance between the points a conversion factor equal to the real distance divided by the digitized value could be calculated. The conversion factor was then stored with each data file of coordinates so that they could be converted to real distances for analysis. Another step necessary in the filming process was the accurate calibration of the film speeds. This was done by placing a clock in the field of view of both cameras. The clock rotated at one half revolution per second and was marked at equal intervals so that it was possible to count the number of frames of film per revolution. From this information the speed of the film could easily be calculated.

Initially the coordinates were stored with no reference to their positions in space relative to a set point in space, however this method of storing the coordinates proved troublesome. Because the points were not given in relation to a stationary point in space but only the origin of the digitizer, and the point of the center of the bar was not included in the data files, it was impossible to determine the distance of the points relative to the center of the bar (that is, the center of the bar before it had been flexed by the forces applied to it). To solve this problem the subjects were re-digitized using the relative positions of the points to the center of the bar. This was done by digitizing the top of the near post at a point corresponding to the center of the bar, and then subtracting the XY-coordinates of this point from each of the coordinates of the points on the subject. In this way the position of each point would be given relative to the bar.

This method also prevented digitizing errors caused by the projector not centering each frame of film in exactly the same spot on the digitizer. When stepping from one frame to the next, the projector would position the frame of film slightly higher or lower than the previous frame (approx. + or - 2 centimeters). This would result in having the coordinates digitized from the frame of film being slightly higher or lower than the previous set of coordinates. By using the bar as the origin however, this problem could be avoided. This was because as a frame of film shifted up or down, the origin (the bar point) also shifted, and since each coordinate was relative to the origin the effect of the movement of the film was cancelled out.

Kinematic Analysis

Once the coordinates of the points for each frame of film were digitized and stored in data files they could be read back into the computer and analysed. A computer program was written to read in the coordinates and then calculate the linear and angular kinematics of the performance and use this data to calculate the segment kinetics and energy exchanges involved in producing the motion. The coordinates were stored in their original digitizer units (integer form) so the first step was to convert them to real units (meters) and flip the X-coordinates to their original form (to reverse the mirroring effect of projecting through the digitizer). Because only three segments were to be used in the analysis, not all the points were read in. Only the positions of the hands, shoulders, hips and ankles were used.

From these points the inclinations of the three segments were calculated. To correct any discrepancies in the lengths of the segments due to digitizing error, the points were then recalculated using the hand point as the starting point and the inclinations and lengths of each segment to calculate the corrected positions of the endpoints of the segments. Using these new coordinates the center of gravity of each segment was then calculated. The segmental center of gravity positions and weightings were derived from Diffrient et al (1974).

Once the endpoint and segmental center of gravity position, and inclination of each segment was calculated each of these sets of data was smoothed and then differentiated to return the kinematics of the motion. Two smoothing algorithms were available to smooth the data points, a fast fourier analysis subprogram , and a cubic spline subprogram. The cubic spline subprogram, after several test runs, was found to be the most practical algorithm for smoothing the data points. This was because the algorithm demanded less memory, was slightly faster, and seemed to smooth the data points as effectively as the fourier technique.

The fact that the subprogram demanded less memory was the primary consideration. The Hewlett-Packard 9835A micro-computer used for the analysis had 128K of RAM (random access memory). With this amount of memory it was only possible (with the use of the spline subprogram) to analyse 90 frames of film at a time. It was decided that every frame of film would be analysed, as opposed to every second or third, so that the greatest possible resolution could be maintained. This meant that the maximum time frame that could be analysed at one time was 0.9 seconds (90 frames at approximately 0.01 seconds per frame). This was an adequate time range since the most significant part of the accelerating giant swing occurred from a position just past vertical to just prior to the athlete's release from the bar. In all the performances this part of the skill was within the 0.9 second limit, and could be analysed with one pass through the program. Once the segment points and inclinations had been smoothed they were differentiated using a first finite differences technique. The resulting data included the linear kinematics of each segment endpoint, segmental center of gravity, and total body center of gravity, and the angular kinematics of each segment for every frame.

Kinetic Analysis

Using the kinematic data it was then possible to estimate the forces and torques at each of the segment axes using vector mechanics. Using the assumptions necessary for a rigid body model of the body a set of kinetic equations were derived. Figure 6 depicts the forces acting on the three segments. The forces and torques acting on each segment are as follows:

Segment 1:

Tb = torque produced by the friction of the bar acting on the hands

F1 = the force exerted on the hands by the bar

W1 = the weight of segment one

Mf1 = sum of muscle forces acting across the shoulder joint

F2 = the reaction force at the shoulder joint

Segment 2: $-F2$ = the reaction force at the shoulder joint

$-Mf1$ = sum of muscle forces acting across the shoulder joint

$W2$ = the weight of segment two

$Mf2$ = sum of muscle forces acting across the hip joint

$F3$ = the reaction force at the hips

Segment 3: $-F3$ = reaction force at the hips

$-Mf2$ = sum of muscle forces acting across the hip joint

$W3$ = the weight of segment three

Newtonian mechanics was used to solve for the unknown forces using the following three equations:

1) $Fx = m\,ax$ The sum of forces in the horizontal (X) direction equals mass times acceleration in the horizontal direction.

2) $Fy = m\,ay$ The sum of forces in the vertical (Y) direction equals mass times acceleration in the vertical direction.

3) $T = Ig\ aa$ The sum of torques equals moment of inertia times angular acceleration

Applying these three equations to the free body diagrams in figure 6 results in the equations of motion for each segment. The resulting equations have too many unknowns however, and therefore cannot be solved. The unknown quantities that prevent solution of the equations are the magnitudes and points of application of the muscle forces acting across the joints. The technique necessary to eliminate one of the unknowns, the point of application of the forces, is called a resolution of a force into an equivalent force and torque (Beer & Johnson, 1977). This technique is illustrated in figure 7 and results in the free body diagrams shown in figure 8. There are now enough equations to solve for the unknowns and vector mechanics can be used to find the forces and torques acting on the segments. The resulting equations of motion are listed in Appendix A. These equations were incorporated into the same computer program that calculated the kinematics and so the linear and angular accelerations necessary to solve the equations could be used to find the forces and torques.

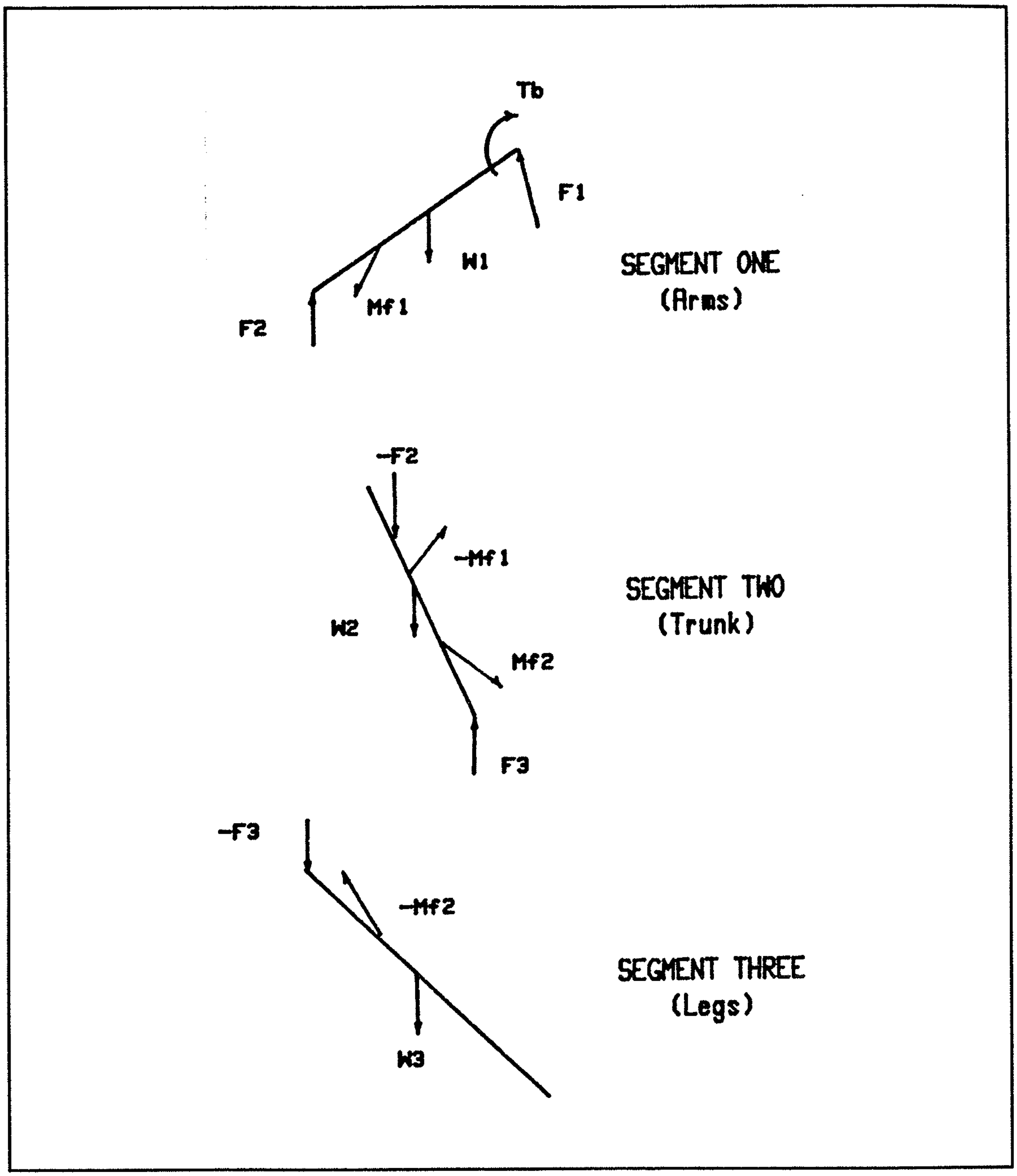
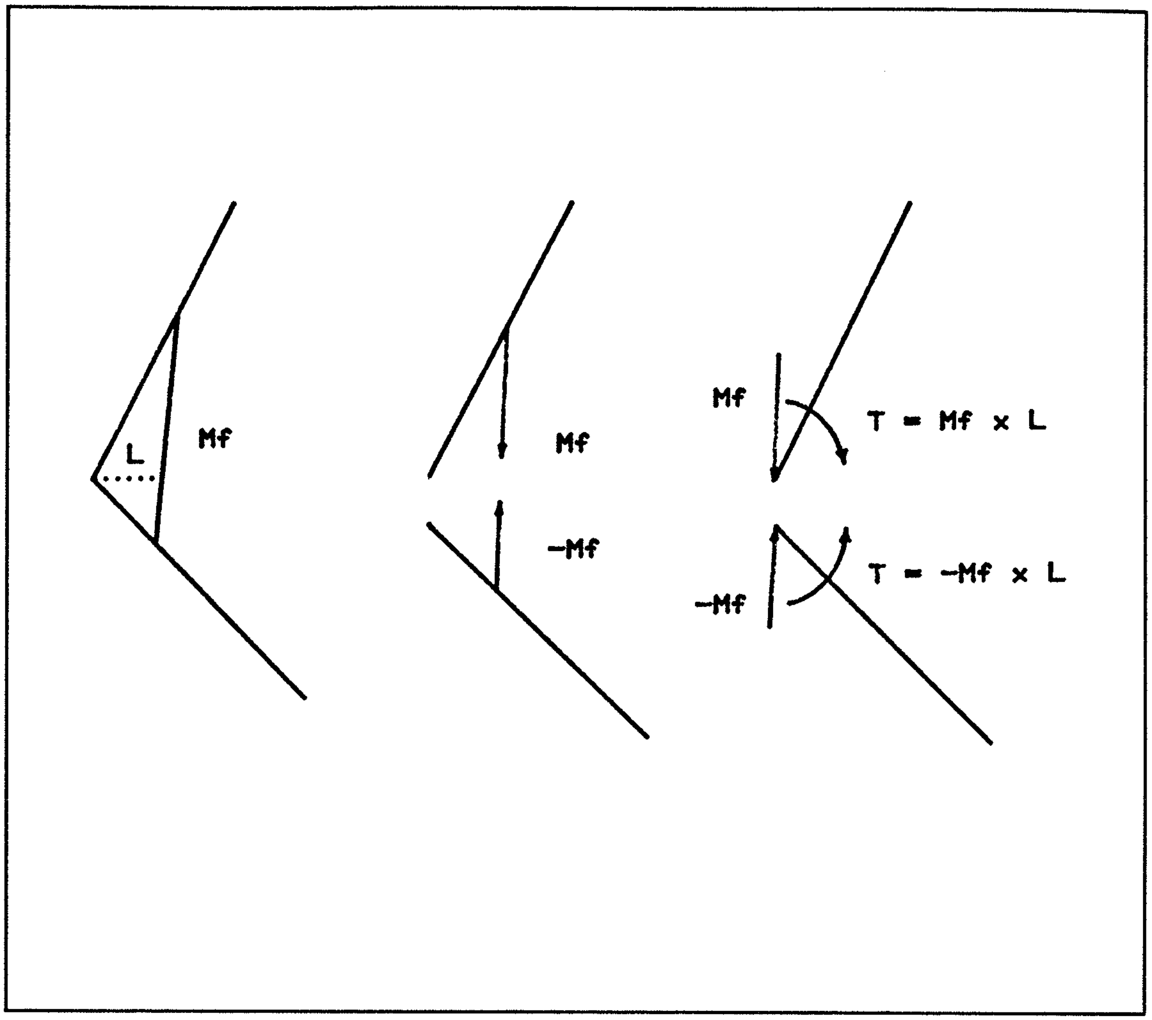


Figure 6: Forces acting on the three body segments



(a) Two segments are shown with a muscle force MF acting on both segments (L = perpendicular distance of MF about point J).

(b) The segments are separated and the forces on both shown (Note: forces are equal and opposite)

(c) Each force is resolved into an equivalent force and torque (Note: torque T is calculated as being MF times L)

Figure 7: Resolution of a force into a force and torque.

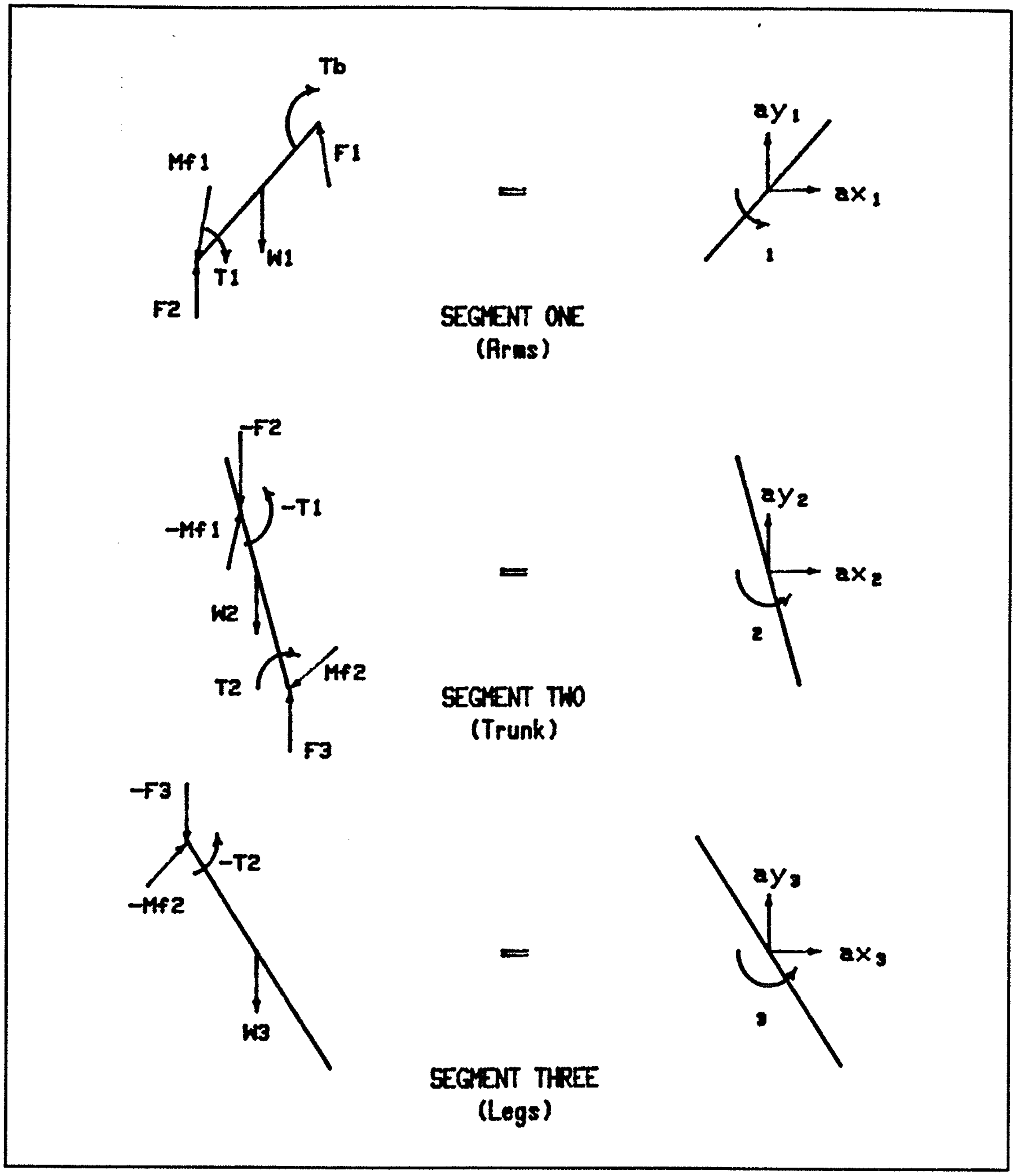


Figure 8: Final reduced form of forces acting on the segments

Energy Analysis

The final step in the analysis of the actual performances was to calculate the energy in each of the body segments as well as the total body energy and the energy stored in the bar. The energy of each body segment came in three forms, potential energy which is dependent on the height of the segment, translational energy which is dependent on the linear velocity of the segment, and rotational energy which is dependent on the angular velocity of the segment. The potential energy of a segment is given by multiplying the height of the center of gravity of the segment by the mass of the segment and the acceleration of gravity (9.81 meters per second per second):

$$P.E. = m\ g\ h$$

Where: P.E. = the potential energy in a segment
m = the mass of the segment
g = acceleration of gravity (9.81 m/s/s)
h = height of the segment C. of G.

The translational energy of a segment is given by multiplying one half the mass of the segment times the linear velocity of the segment squared:

$$K.E.t = 1/2\ m\ v^2$$

Where: K.E.t = translational kinetic energy
1/2 = one divided by two (one half)
m = mass of the segment

v = linear velocity of the segment

Note that the linear velocity is the resultant velocity. This is the vector sum of the horizontal component and the vertical component of the velocity of the segment center of gravity and is given by:

$$v = \sqrt{Vx^2 + Vy^2}$$

Where: v = the resultant velocity

Vx = horizontal velocity

Vy = vertical velocity

In a similar manner, the rotational energy is given by multiplying one half the moment of inertia of the segment times the angular velocity of the segment squared:

$$K.E.r = 1/2\ I\ w^2$$

Where: K.E.r = rotational kinetic energy

1/2 = one divided by two (one half)

I = moment of inertia

w = angular velocity of the segment

Therefore the energy of a segment is the sum of each of the components of energy, the potential plus the rotational, plus the translational energy:

$$E = P.E. + K.E.t + K.E.r$$

Where: E = energy of the segment

P.E. = potential energy of the segment

K.E.t = translational energy

K.E.r = rotational energy

The total energy of the body is simply the sum of the energy of each segment, so once the energy of each segment has been calculated it is a simple matter to sum the values to get the total body energy.

The spring energy stored in the bar is dependent on the displacement of the bar from its equilibrium position and its spring constant, and is given by the formula:

$$S.E. = 1/2\ k\ d^2$$

Where: S.E. = spring energy

1/2 = one divided by two (one half)

k = spring constant of the bar

d = displacement of the bar

Note that the displacement of the bar is the resultant displacement which is a vector sum of the horizontal and vertical displacements and is given by the formula:

$$d = \sqrt{x^2 + y^2}$$

Where: d = resultant displacement

x = horizontal displacement

y = vertical displacement

Once the kinematics, kinetics and energy data of a performance had been calculated a subroutine to graph the data and plot the positions of the subject was supplied in the program so that the data could be graphically presented. All the data generated was also printed out onto hardcopy for future reference.

Computer Modelling

The final step, after analysing the actual performances, was the development of a computer program that could model the gymnast performing on the horizontal bar. The program would have to create a set of coordinate points that could be analysed in the same way that the original segment point coordinates were analysed. To do this some aspect of an actual performance would have to be used as a reference for creating the modelled coordinate points. Dainis (1973) in a similar study found that using the angular accelerations of the body segments was the most practical method of creating a set of coordinate points. Following Dainis' example the joint coordinates were produced by digitizing the angular acceleration curves of actual performances, and then integrating the data once to get the angular velocities of the segments, and a second time to get the inclinations of the segments. The position of the hands would also be digitized so that by using the hand as the starting point it would be possible to calculate the coordinates of each of the segment endpoints using the inclinations of the segments and the lengths of the segments. The X-coordinate of a point was therefore given by the X-coordinate of the previous point plus the cosine of the inclination of the segment times the segment length. For example, the X-position of the shoulder could be found by adding the cosine of the inclination of the arm segment times the length of the arm segment to the X-position of the hand:

$$Xs = COS(Ia)\ La + Xh$$

Where: Xs = X-coord. of the shoulder
Ia = Inclination of arms
La = Length of the arms
Xh = X-coord. of the hand

The process of entering the angular accelerations of the segments consisted of placing the graph of the angular accelerations of a performance onto the Hewlett-Packard 9874A digitizer. The digitizer output was then scaled to match the scale of the graph by digitizing the lower left, upper left and lower right points of the axes on the graph, and using these points to derive equations to convert digitizer units to graph units. Once the digitizer was scaled significant points on the curve were digitized. These points were sent to a cubic spline interpolating subprogram. The interpolating subprogram, using the initial angular acceleration value, the time between values, and the digitized set of points was able to generate a data set that was similar to the original angular acceleration data set. The accuracy of this method of reproducing the acceleration curves was very much dependent on the points sent to the interpolating sub-program. Each peak and trough could be digitized to produce a very accurate copy of the original data set, or minor peaks and troughs could be left out to just reproduce the general shape of the original data set. The advantages of using this method were that it was not necessary to enter the entire set of angular acceleration data points individually, and also, that it was very easy to slightly modify the output. It was a simple matter to digitize a point a little higher than a particular peak to see what effect a little more acceleration would cause, or even to skip a peak or create a new one. This way it would be possible to test the effects of changing a performance very slightly. A similar process was used to digitize the positions of the hands throughout the skill.

Once the angular acceleration data had been entered the data was integrated once to find the angular velocities of the segments and once more to derive the inclinations of the segments. To calculate the velocity of a segment at a given time the angular acceleration of the segment times the elapsed time was added to the previous angular velocity:

$$v(2) = v(1) + a(1)t$$

Where: $v(2)$ = velocity at time 2
$v(1)$ = velocity at time 1 (previous)
$a(1)$ = acceleration at time 1
t = elapsed time since time 1

Similarily, the inclination of a segment was calculated by adding the angular velocity times the elapsed time plus half the angular acceleration times the elapsed time squared to the previous inclination:

$$p(2) = p(1) + v(1)t + 1/2\ a(1)t^2$$

Where: $p(2)$ = position at time 2
$p(1)$ = position at time 1 (previous)
$v(1)$ = velocity at time 1
$a(1)$ = acceleration at time 1
t = elapsed time since time 1

The initial angular velocities and inclinations of the segments in the first frame were entered individually, and then each successive frame was calculated by using the data from the previous frame. In this way the inclinations of each of the segments was calculated for each frame of the modelled performance. Given the hand point and the inclination of each segment it was possible to calculate the positions of the segment endpoints using the formula given previously. These points were then processed by several subroutines that calculated the segmental centers of gravity, the total body center of gravity, and the kinematics and kinetics of the modelled performance, in a manner similar to the kinematic and kinetic analysis of the original performance. A facility for plotting the body positions and graphing the data was again provided in the program so that the kinematic and kinetic data curves could be further studied.

To validate the accuracy of the model an actual performance was modelled. The input data was not altered in any way so that the kinetic data generated by the model would be identical to the kinetic data returned by the initial analysis program, provided the model was 100% accurate. As a statistical measure of the differences between the modelled kinetic data and the actual kinetic data a dependent (paired) t-test was used on the horizontal and vertical force data as well as the torque data.

RESULTS AND DISCUSSION

A detailed analysis of the results was undertaken from several viewpoints. First the film records of each performance were studied to derive the timing of any noticeable movements. Then an analysis of the kinematics was performed. Next the kinetics of the performances were compared to try to determine the causes of the differences in the performances. Then an energy analysis was undertaken to try to determine how energy was being exchanged between the body segments and between the gymnast and bar. The final step was to attempt to reproduce an actual performance using the computer model.

Positional and Temporal Analysis

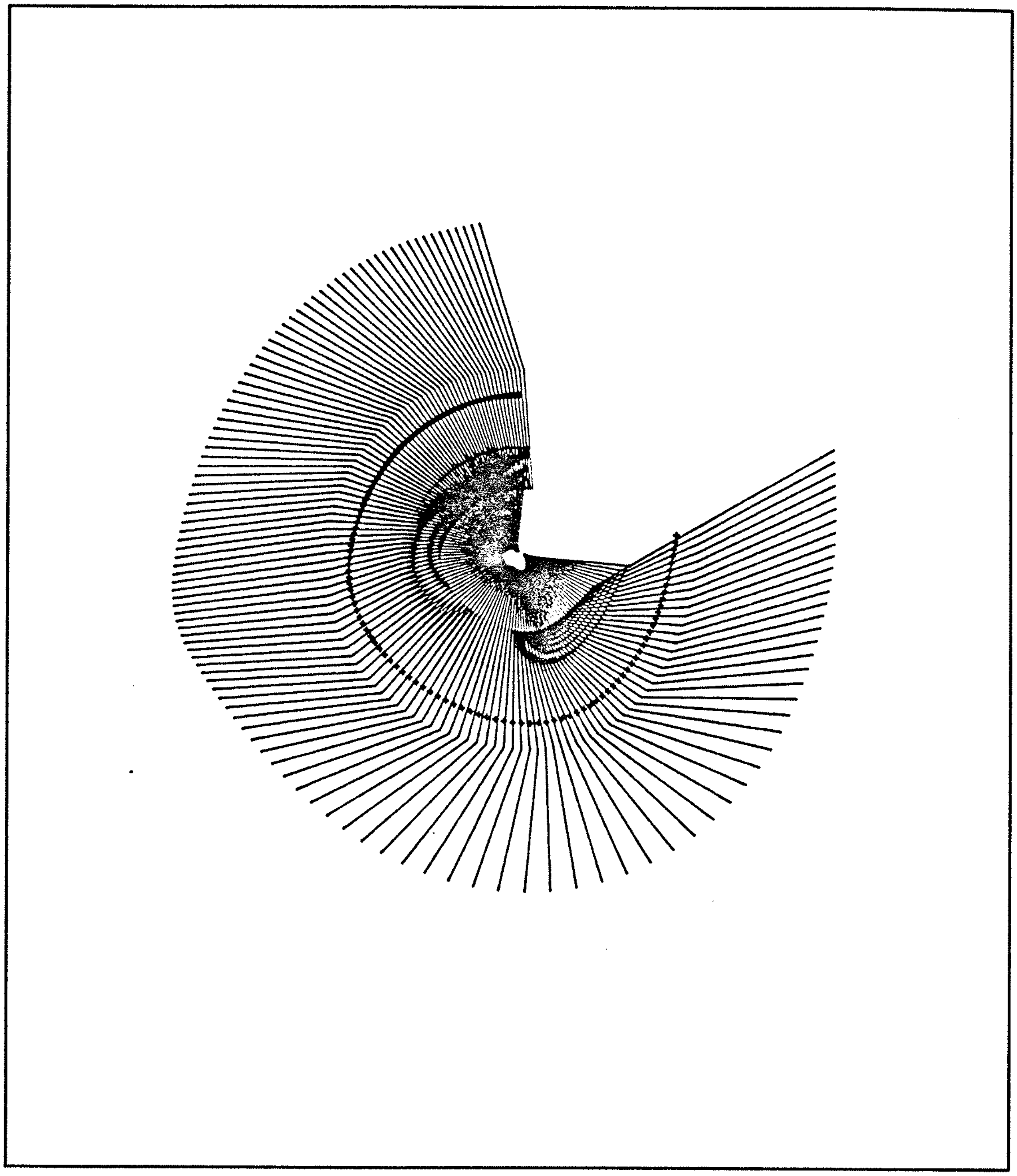
As was stated earlier, the last giant swing prior to a flyaway was to be the giant under investigation. The two subjects executed this giant quite differently. The first subject was considered to be the more skilled performer. This was because in executing the flyaway dismount, the first subject acquired greater vertical displacement than the second subject. Also, visual inspection of the film indicated that subject one caused the horizontal bar to flex significantly more than did subject 2, despite there being only a small difference in the weights of the two subjects (see Appendix B). A more detailed analysis of body positions revealed other differences. To describe the differences between the two subjects the best performance of each subject will be used, however any differences in one subject's pattern of motion between trials will also be mentioned when noteworthy. Subject one's best performance was trial five, subject two's best performance was trial two.

The starting point of the analysis was determined to be the point were the subjects' hips passed directly over the horizontal bar. Even at this point in the skill, subject one and subject two differed in their body positions. Subject one was flexed at the hips as he passed over the bar, while subject two was relatively straight. In the execution of the previous giant swing both subjects had flexed at the hips to draw their centers of gravity closer to the bar to allow them to maintain enough velocity to pass over the bar. The difference between subject one and subject two was that subject one maintained that flexion of the hips even as he passed over the bar, while subject two extended his hip joints to return to a straight position.

George (1980), in discussing the important aspects of swing in gymnastics pointed out that "There are two important mechanical factors which serve to regulate (and ultimately maximize) descent swing amplitude. The first, and perhaps most obvious, variable deals with the starting height of the swing." (George, 1980, p 25). Since the positioning of body segments alters the position of the center of gravity, and a flexed position of the hips would effectively lower the center of gravity of the body, subject two has positioned his center of gravity higher above the horizontal bar than subject one. This would seem to be a more effective starting position for beginning the final giant swing into a flyaway dismount.

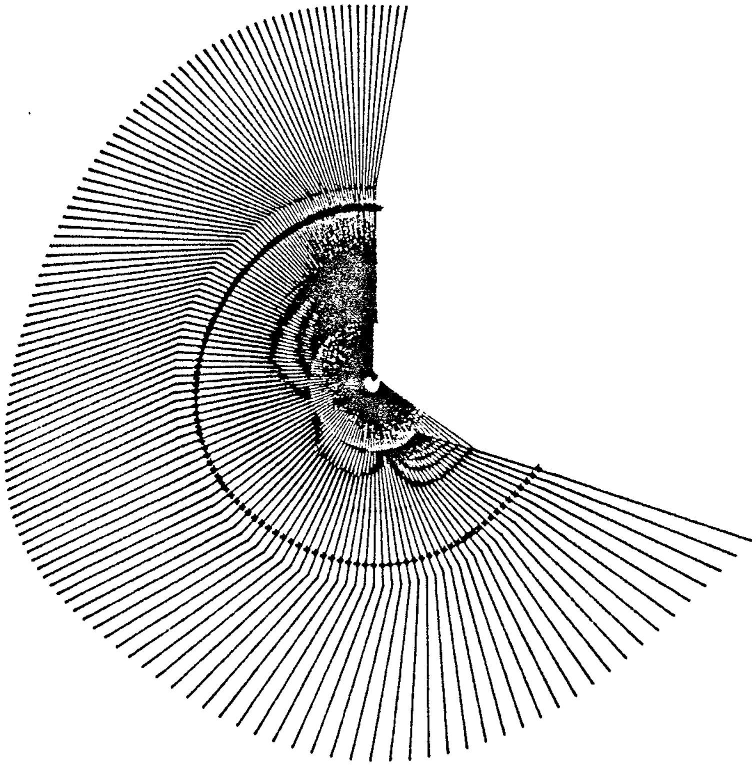
As the subjects began their descent down to the bottom of the swing their body positions changed. Both subjects began to flex at the hips to decrease the angle between the leg segment and the trunk segment. Subject two flexed more than subject one, achieving a minimum angle between his legs and trunk of 135.2 degrees (best performance). Subject one achieved a minimum angle of 152.0 degrees (best performance). For subject two, this position of maximum flexion of the hips occurred 0.508 seconds into the giant while for subject one it occurred 0.388 seconds into the giant. This flexed position will move the center of gravity of the subject in closer to the bar. Rather than allowing the center of gravity to fall in a circular path away from the bar, both subjects flex and alter the path of the center of gravity to make it fall more vertically.

Once the position of maximum flexion had been achieved both subjects began to increase the angle between the trunk and legs by extending at the hips. This extension phase



Note: Center of gravity of body represented by "+"

Figure 9: Tracings of body positions for subject one (good performance)



Note: Center of gravity of body represented by "+"

Figure 10: Tracings of body positions for subject two (poor performance)

continued past the 180 degree mark (straight position) to 203 degrees for subject two and 226 degrees for subject one. Subject two acheived this position of maximum hyperextension 0.898 seconds after passing over the top of the bar while subject two achieved maximum hyperextension at 0.796 seconds after vertical. At this point in the swing (for both subjects) the effect of this action is to draw the center of gravity away from the bar and again cause it to fall more vertically, rather than have it move in a circular path towards the bottom of the swing.

As with the flexion phase, after completing this extension phase both subjects reversed the action at the hips to begin flexing once again. There was a significant difference in this part of the giant swing however. Subject one actively flexed at the hips until his trunk and legs had reached an angle of 145 degrees. Subject two on the other hand only flexed slightly so that his body remained slightly hyperextended at the hips. Subject one began to slightly open up the leg/trunk angle, extending at the hips just before release. In all but the best trial this final extension phase was very minimal and he released from the bar with his hips still flexed. In the best performance however this final extension phase was quite pronounced so that the hips were completely extended (180 degrees) at release. This occured at a time when in all previous trials subject one had released from the bar. In his best trial he held on longer as he extended at the hips. Subject two did not have either the flexion phase or the final extension phase in this last part of the swing. Once he had slightly flexed at the hips and achieved a relatively straight body position he held this position until release. He also released considerably earlier than subject one while his body was well below the height of the bar.

The flexion and extension actions at the end of the swing, performed by subject one, have a similar effect on the path of the subject's center of gravity as the first flexion and extension phase. In this case however the path of the center of gravity is made to move straight up. Towards the end of the swing the tendency is for the center of gravity to move in a circular path over top of the bar, as in a normal giant swing without the release. The goal for a flyaway however is to gain as much height as possible without moving too close to the horizontal bar. The longer the gymnast holds on the greater the tendency of the center of gravity to move towards the bar at release. Since the path of the center of gravity of the body will be a tangent to its path at release, if the subject releases right at horizontal the center of gravity will move straight up. If he releases before horizontal the path of the center of gravity will be at an angle away from the bar. Theoretically, if the athlete were to release past the horizontal position his center of gravity would travel at an angle slightly towards the bar. Subject one in his best performance however does release when his center of gravity is above the bar very slightly, yet the path of his center of gravity on release was slightly away from the bar. The final extension phase, because it moves the center of gravity away from the bar, prevents subject one from moving towards the bar on release, yet allows him to hold on to the bar longer. By extending at the hips he is moving his leg segment farther from the bar. This results in his total body center of gravity moving away from the bar as well, since the legs make up a large portion of his total body center of gravity.

Besides the changes in the angle between the trunk and hips there was also some change in the angle between the arms and trunk. For both subjects the changes in shoulder angle were not as marked as those of the hip angle. At the point of maximum hip flexion both subjects were slightly flexed at the shoulders. As subject two moved into the extension phase, he began extending at the shoulder, so that by the time maximum hip hyperextension had been achieved his shoulder joint was also slightly hyperextended. Subject one did not follow this pattern. As he moved into the hyperextension phase he continued to remain flexed at the shoulders, however just before the point of maximum hip hyperextension, he too began to extend at the shoulders. By the time maximum hip hyperextension had been achieved subject one's arms were in line with his trunk. As both subjects began flexing at the hips (subject two very slightly, as mentioned) they both began flexing at the shoulders. Subject two did not flex at the shoulders to the same extent as subject one. The flexion was slower and did not reach as small an angle as subject one. Subject one on the other hand flexed significantly more than subject two and did so in every trial. In subject one's best performance he flexed the most, releasing from the bar with a shoulder angle of 145 degrees. In subject two's best performance his shoulder angle was 161 degrees.

Another significant difference between subject one and subject two was the time of release from the bar. Subject one released from the bar considerably later than subject two. Although this aspect of the giant was not of particular interest within the delimitations of the study, it was of particular note that subject one did not release from the bar until his hips (and center of gravity) were above the bar in his best performance. In the poorer performances, by both subjects, release from the bar came considerably earlier, when the hips were still below bar height.

Analysis of the center of gravity positions of the total body throughout the skill was also done to see whether there were any significant differences between subjects one and two, and the better performances and poorer ones. There were some significant differences in the shape that the center of gravity traced in space between the different performances. Generally, in poorer performances the center of gravity traced a path that was more circular, while in better performances the C of G traced a rectangular path. Subject two's center of gravity traced a more circular path. Subject one's center of gravity in all performances was more rectangular than subject two's, and was most rectangular in the best performance.

The rectangular shape of the better performances was characterised by two "corners" or transition points. The first transition point came just past horizontal, as the subject went through complete extension, moving into hyperextension. At this point the center of gravity is furthest away from the bar, at least in the downward phase of the swing. Just past this point the center of gravity begins to move forward and slightly closer to the bar. The second "corner" occurs just past the point where the subject has reached bottom. At this point the center of gravity has reached it's lowest position and is again quite far from the bar. Just after this "corner" the center of gravity begins it's upward climb. During the upward phase of the swing in the better performances the center of gravity rose almost vertically, or at an angle away from the bar. In the best performances the center of gravity rose more vertically. In the best performance subject one's center of gravity rose at an extremely steep angle of 82.0 degrees just prior to release. This meant that at release his body would be travelling almost completely vertical with very little forward motion. Since the goal of a flyaway dismount is to achieve maximum height with only enough horizontal displacement to avoid hitting the bar, a steeper angle of release results in a better performance.

Figures 9 and 10 show the positions of subjects one and two in their best performances. Note the path of the center of gravity. The pattern of flexion, extension and then flexion again has been called "beating" in gymnastics (Calkin, 1975). The primary effect of this action according to Calkin is "translating rotational 'swing' motion .... to linear 'lift' motion." (Calkin, 1975, p 51). This effect appears to show up quite clearly in the better performances in this study, by the rectangular path of the center of gravity, and the almost vertical path of the center of gravity at release.

Another aspect of this motion which may contribute to the effectiveness of the giant swing has been suggested by Biesterfeldt, ".... if for some reason the hollow (flexed) downswing allows the performer to more naturally sink and thrust on the bars, then there will be a great increase in the energy stored in the apparatus, and returned to the performer in rise on the upswing." (Calkin, 1975, p 50).

The pattern of motion of the bar, as seen in figure 11, shows that there is significant deflection of the bar. The bar was deflected furthest from the horizontal just after the subjects reached the bottom of the swing. The maximum flexion of the bar seemed to occur at approximately the same time for all the performances. The magnitude of the deflection was always greater for subject one.

The shape of the path of the bar was quite different between the two subjects. For subject one the bar traced a more pointed path going into the phase of maximum deflection downward, while the path of the bar for subject two was more rounded. Clearly, if the bar is to be modelled as a spring/mass system there must be a great deal of energy being stored in the bar as it bends away from it's equilibrium position. What effect this energy may have on the performance would greatly depend on how it was returned to the gymnast on the upward phase of the swing. By flexing the bar more dramatically, just past the bottom, subject one appears to be storing energy in the bar which he may be retrieving during the last part of the upward swing. This is also done by subject two, but not to as great an extent. Note also that in the last phase of the swing the path of the bar for subject one rises at a steep angle upward, while the path of the bar for subject two is more rounded. This indicates that at the end of the swing subject one is rapidly transferring any energy stored in the bar back into his body, while subject two does not appear to do this as efficiently. and energy exchanges of the performances. A positional analysis of the skill brought out the following patterns of motion:

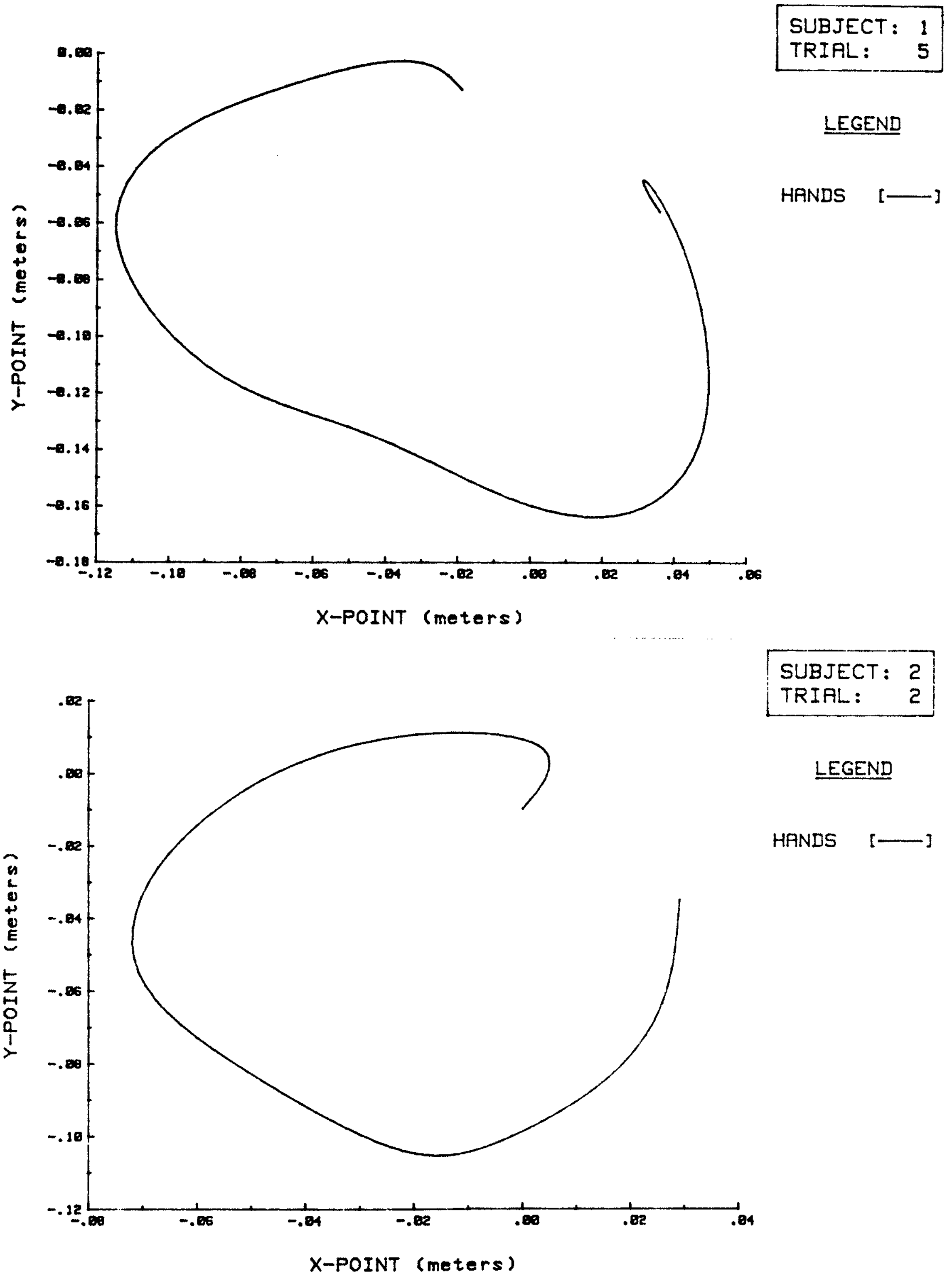


Figure 11: Horizontal bar deflection curves for two best performances

1) The gymnast passes over the bar with the arm/ trunk angle close to 180 degrees and the hips flexed.

2) During the downswing the gymnast extends at the hips and keeps flexed at the shoulders.

3) Just before reaching the bottom of the swing the hips pass through a fully extended position into a hyperextended position.

4) Shortly afterwards, still before reaching the bottom of the swing, the gymnast begins to flex at the hips.

5) Passing through the bottom of the swing the gymnast is in a fully extended position once again. In the poorer performances the gymnast was sometimes slightly hyperextended at the hips.

6) In the poorer performances the gymnast remained in a relatively extended position until release.

7) In the better performances the gymnast flexed at the hips in the early part of the upswing and then extended at the hips just before release.

8) In the better performances the center of gravity was close to the height of the bar and the body angle of the gymnast was nearly horizontal.

Kinematic Analysis

Having studied the positional and temporal aspects of the giant swings, a kinematic analysis was undertaken. The kinematic analysis consisted of graphing the linear and angular velocities and accelerations of the various segment points, segmental center of gravity points, segment inclinations, and the total body center of gravity. Studying these graphs revealed some significant differences between the better and poorer performances, and shed more light on the effects of the various changes in body positions.

Linear Kinematics

In the kinematic and kinetic analysis of the performances the segmental centers of gravity had to be determined. Since the segmental centers of gravity are, in effect, a summation of the individual particles of a segment, an investigation of the linear kinematics of the segmental C of G's would tell much about the motions of the segments. There were some interesting differences in the linear velocities and accelerations of the three body segments in different performances. Generally, as the body falls on the downward side of the giant swing, the vertical (Y) velocities of the segmental C of G's are becoming more negative. As the body begins to swing forward however, the vertical velocity rapidly increases until it is positive (just after passing under the bar). This general pattern is similar in all performances but is not identical.

There are noticeable differences between the better performances and the poorer ones. In the better performances the vertical velocities of the segments do not drop evenly. The vertical velocity of the legs is almost flat, and the vertical velocities of the trunk and arms are delayed slightly. This is due to the extension of the hip joint as the subject falls. This extension slows the fall of the legs and seems to delay the peak negative velocity in the upper two segments. In the poorer performances this effect is much less noticeable. Once the subject has passed through the bottom of the swing it is inevitable that the vertical velocities of the segments will become positive and increase. This seems to occur in a similar fashion for both the good and poor performances.

There is a striking difference in the change in the horizontal (X) velocities as the subject passes the bottom however. In the better performances the segmental X-velocity of the legs decreases dramatically throughout the whole upward phase of the giant swing. The trunk and arm segments also decrease in horizontal velocity as well, though not as dramatically. In the poorer performances this drop in horizontal velocity is not as dramatic and is not maintained throughout the entire upswing of the giant. Just before release from the bar the subjects horizontal velocities level off. These velocities do not reach as low a level, as well. In the better performances the horizontal velocities steadily decrease and reach relatively low levels at release, whereas in the poorer performances the horizontal velocities are not as low. The result is that the ratio of vertical velocities over horizontal velocities is much greater in the better performances. This has a direct effect on the direction that the segmental velocity vectors take since the angle of the vectors is given by the arctangent of the vertical (Y) velocity divided by the horizontal (X) velocity. A simple calculation of the trunk velocities in the best and worst performances dramatically illustrated the differences.

In the best performance the resultant linear velocity (combining the vertical and horizontal velocities) was 4.82 meters per second at an angle of 75.15 degrees. In the poorest performance the linear velocity was only 3.95 meters per second at an angle of 50.11 degrees. Since the trunk segment carries the majority of the weight of a person it is clear that the effect of this difference in linear velocity would result in the better performer travelling more vertically than the poorer (see figures 11 and 12).

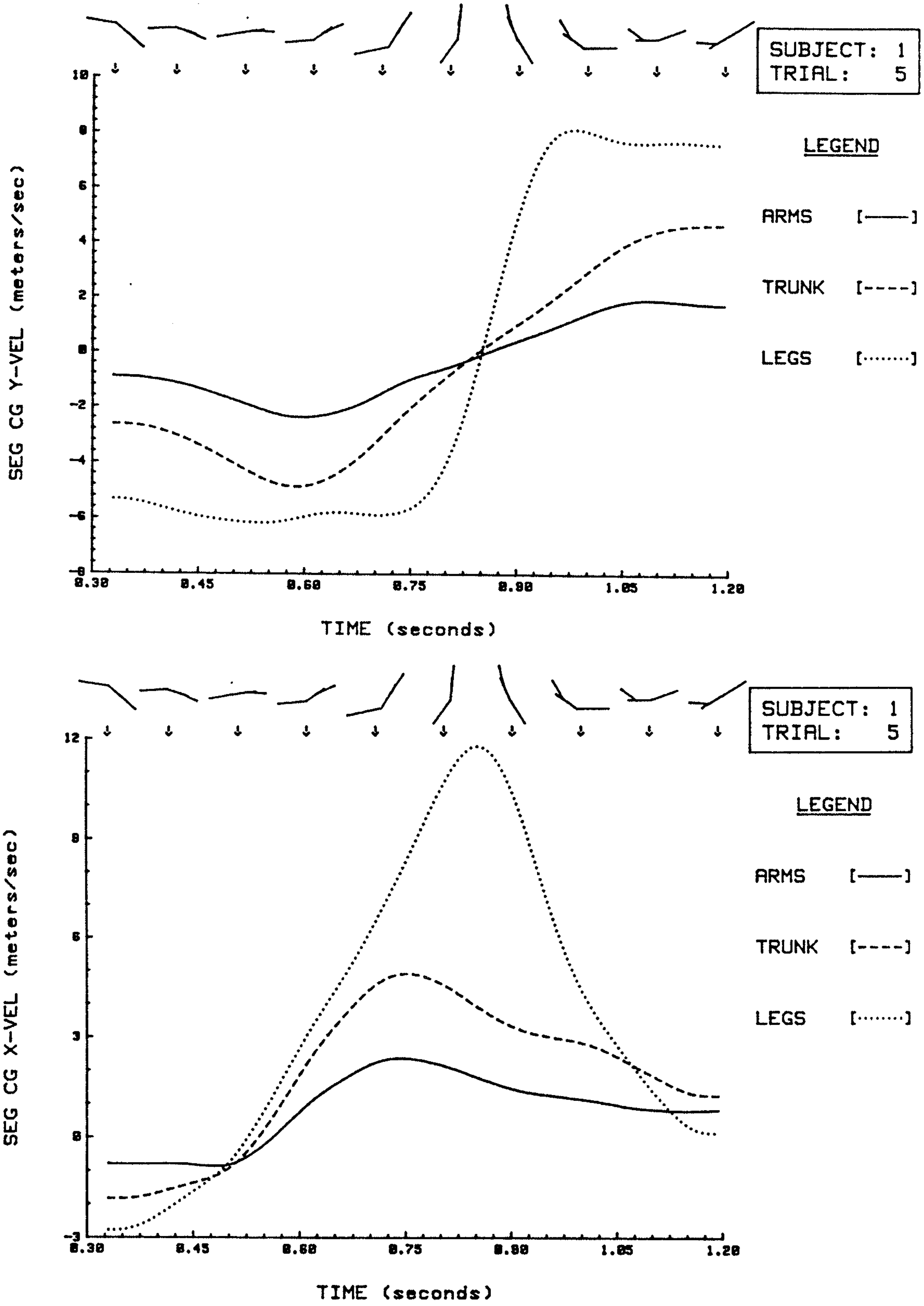


Figure 12: Segmental C of G velocity curves for best performance

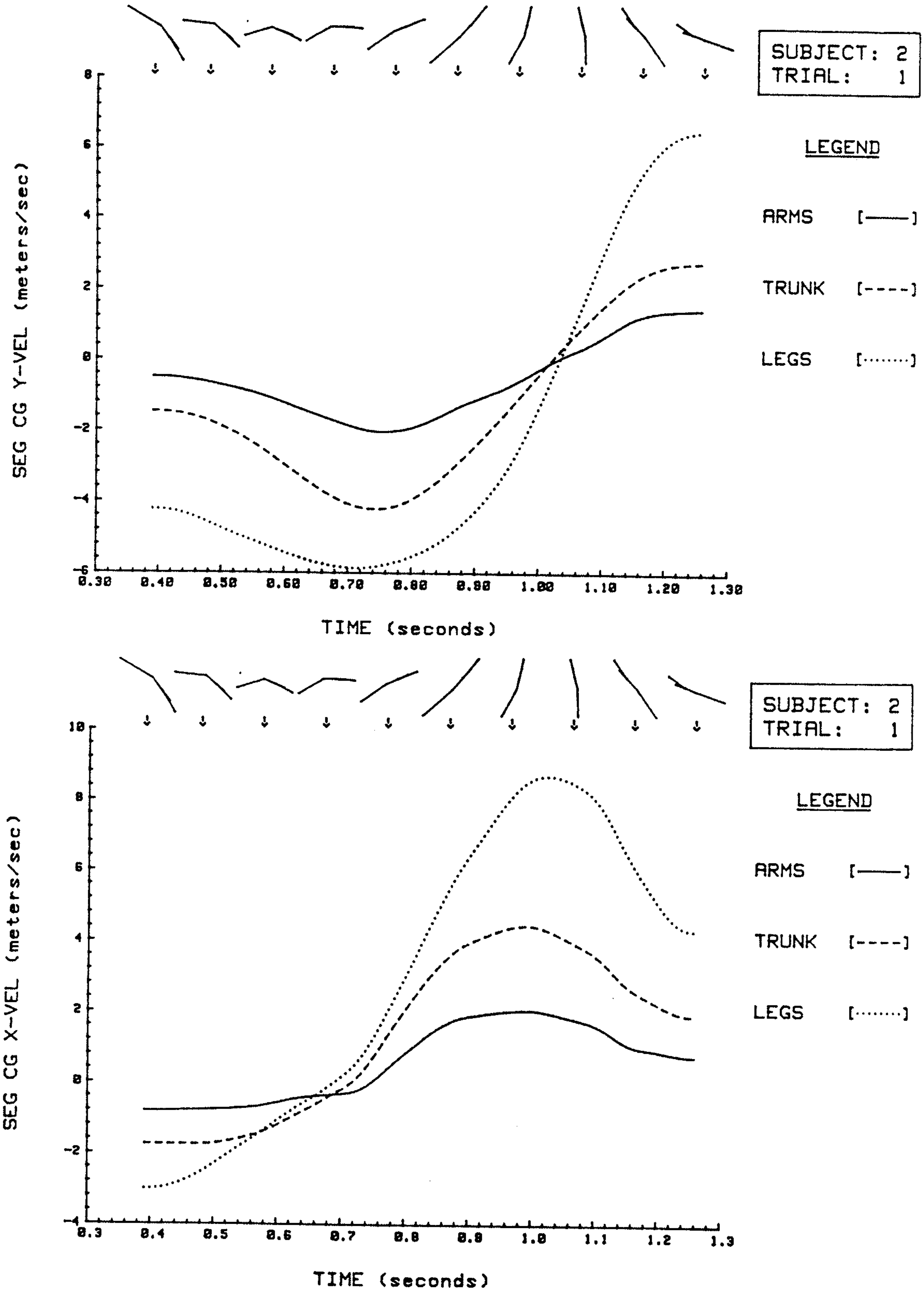


Figure 13: Segmental C of G velocity curves for poor performance

The vertical acceleration curves of the best and worst performances show some differences as well. In the middle section of the curve of the acceleration of the trunk segment the vertical acceleration rises above 10 meters per second per second. In the better performance, this section of high acceleration lasts longer (0.45 seconds), is generally higher, and is more steady. The poorer performance has a more variable acceleration during this section which does not last as long (0.38 seconds). The effect of an acceleration acting over a longer period of time is, of course, a greater final velocity. Therefore since the trunk is accelerating vertically at a high level, for longer, the result is a greater final velocity.

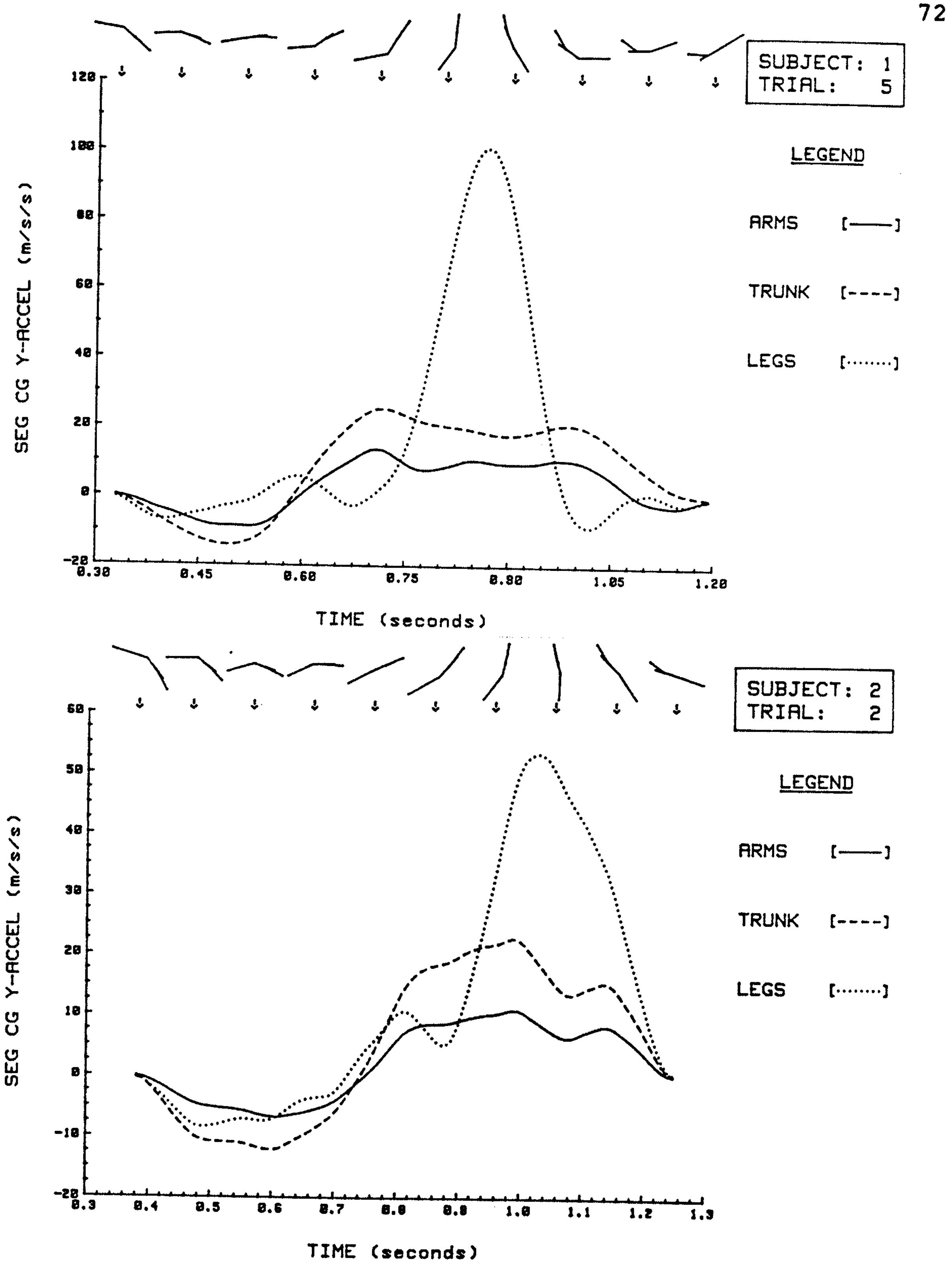


Figure 14: Segmental C of G acceleration curves

Angular Kinematics

The angular kinematics of the segments offer further insight into the interactions of the three body segments. Segmental center of gravity positions are determined in part by the inclinations of the segments. In a similar way, the linear velocities of the segmental centers of gravity are determined by the angular velocities of the segments. The most striking features of the angular velocity curves generated by each performance was the shape of the angular velocity curve of the leg segment. There were some significant differences found in the shape of this curve, between the better and poorer performances. In both examples of angular velocity curves (see figure 15), it seems evident that the subjects are using their legs quite a lot. Initially each subjects' leg segment has a small amount of angular velocity (approx. 3-4 rad/sec.). The angular velocity of the segment decreases to just under zero for both subjects. This occurs at a time when both subjects are extending at the hips and slowing down the fall of the leg segment. The difference in leg angular velocity occurs after the subjects have passed through the bottom of the swing. At this point the better performer (subject one) accelerates his legs to a very high angular velocity (maximum 13.63 rad/sec.). Subject two is also accelerating his legs, but does not reach as high an angular velocity (maximum of 7.41 rad/sec.). Subject one's peak angular velocity appears to occur consistently later in the giant as well. Just before release from the bar both subjects decrease the angular velocity of their legs, however subject one's angular velocity returns to a value close to it's initial velocity while subject two's does not decrease as much.

The angular acceleration curves of the two subjects begin to demonstrate the difference more dramatically (see figure 16). The angular acceleration of subject one's leg segment is sinusoidal in shape. That is, there is a phase of high positive acceleration, followed by a rapid drop to a phase of high negative acceleration. Subject two's angular acceleration curve shows the high initial positive peak but does not have the corresponding low phase. Clearly subject one is first increasing the angular velocity of his legs, and then rapidly slowing down the angular velocity of his legs. Subject two effectively accelerates his leg segment, but does not slow down the angular velocity of the legs as well. As the subjects decelerate their leg segments the trunk segment is accelerating. The phase of rapid deceleration of the leg segment is found in all the better performances.

This phenomenon of accelerating one segment and then decelerating it and transferring it's angular momentum to an adjoining segment is well documented in biomechanics research (Alexander, 1978; Budney & Bellow, 1982; Koniar, 1973; Milburn, 1982). In most cases, such as in a baseball throw or golf swing, the angular velocities of the more

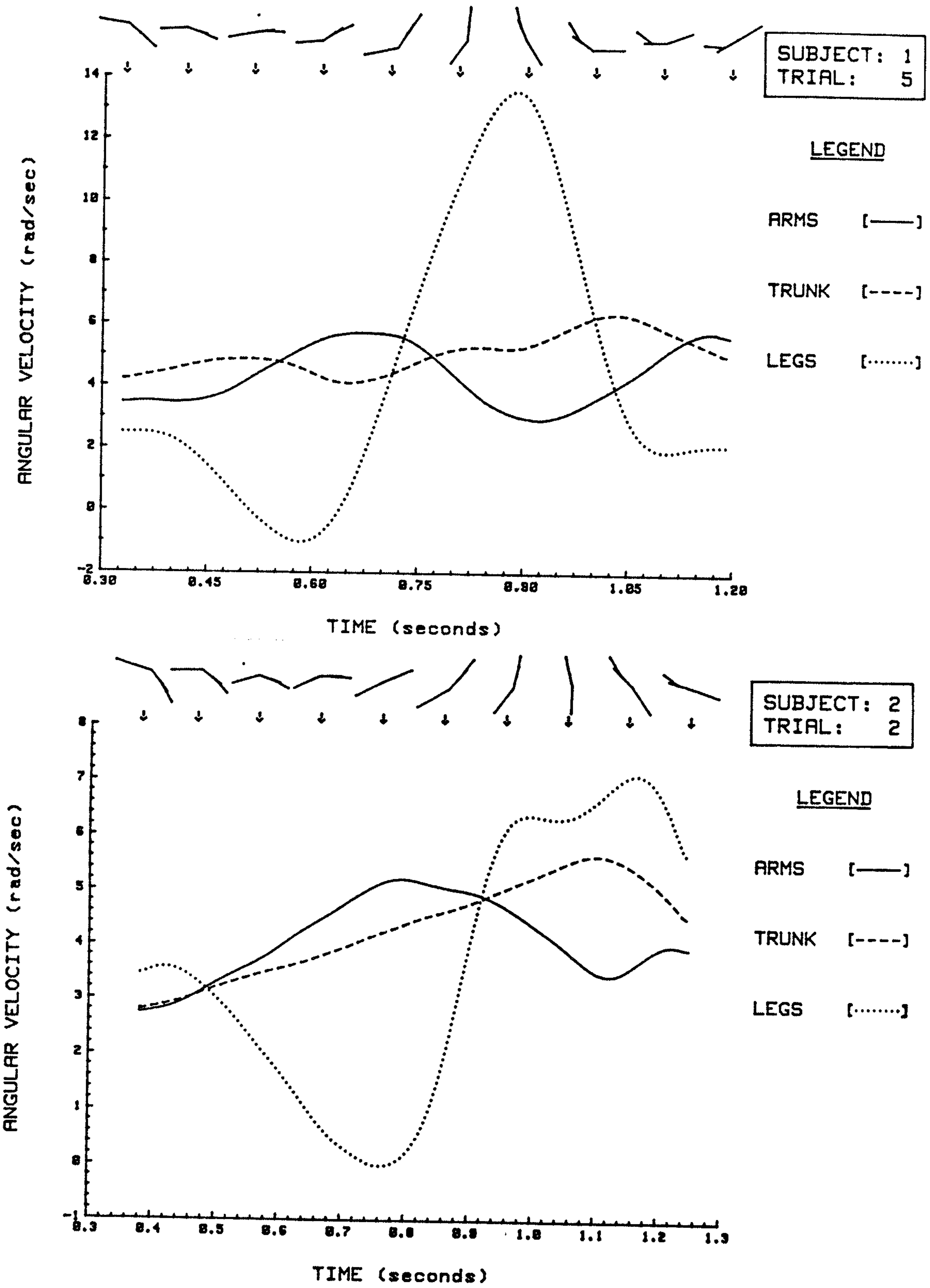


Figure 15: Angular velocity curves of a good and a poor performance

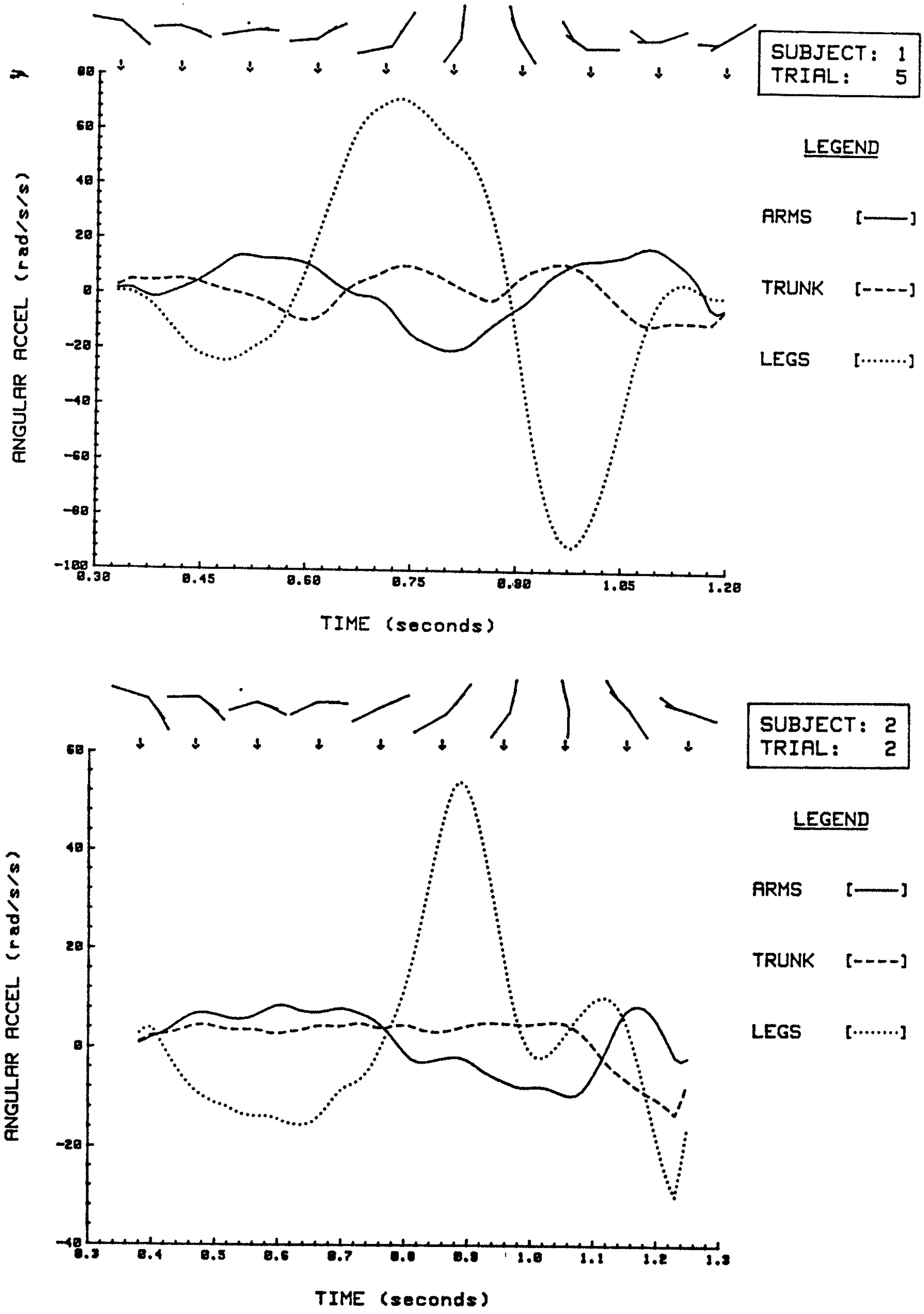


Figure 16: Angular accel. curves of a good and a poor performance

proximal segments are progressively passed on to the more distal segments, one after the other, until the last segment has reached a maximum velocity. Although it would seem this pattern is not used by the subjects here to maximize the angular velocity of the feet, a slightly different form of the same phenomena is occurring. Initially the process is the same, as the subject swings under the bar. From the position of maximum hyperextension of the hips the subjects transfer the velocity of the trunk segment to the legs. The difference occurs when the gymnast begins to swing back up. In the better performances the subject passes this angular momentum back to the trunk segment just before release, so that the most significant segment, the trunk (because it is heavier), can have the greatest momentum during the upward swing. The summation of angular velocities travels down the body to the legs, and then back up to the trunk during the upward phase of the giant.

Kinetic Analysis

The interaction of the body segment motions further requires an explanation of the forces and torques causing these actions. It was also important that the interaction of gymnast and bar be investigated. This could not be done with the kinematic data alone. The kinetic data for each of the performances was therefore output in graphical form for closer study.

Torque Analysis

Since it was evident that the angular kinematics showed some of the differences between the good and poor performances, and these differences would be caused by the torques occuring at the joints, an investigation of the torque patterns was undertaken. Note that a positive (counter-clockwise) torque at the hip joint will cause the legs to flex and the hip/leg angle to decrease. Likewise, a positive torque at the shoulders will cause the trunk/arm angle to decrease by extending the shoulders.

In the initial downswing phase of the giant both subjects are extending at the hips. The torque curves in all the trials show this initial extension phase as negative torque at the hips, shoulders and hands. The shoulder/trunk angle in most cases remained relatively still throughout the downswing so that likely the initial shoulder torques are acting to keep the angle open (that is, close to 180 degrees). The hip torque however, clearly is causing the hip/leg angle to increase by extending at the hips. As the gymnasts progress through the downswing these negative torques gradually decrease in magnitude to zero and then continue as positive torques. This is occurring as the hip angle has reached its point of maximum extension (hyperextension). The positive torques are causing the extension of the hips to decrease until at maximum hyperextension the hips begin to flex. The torques peak for the first

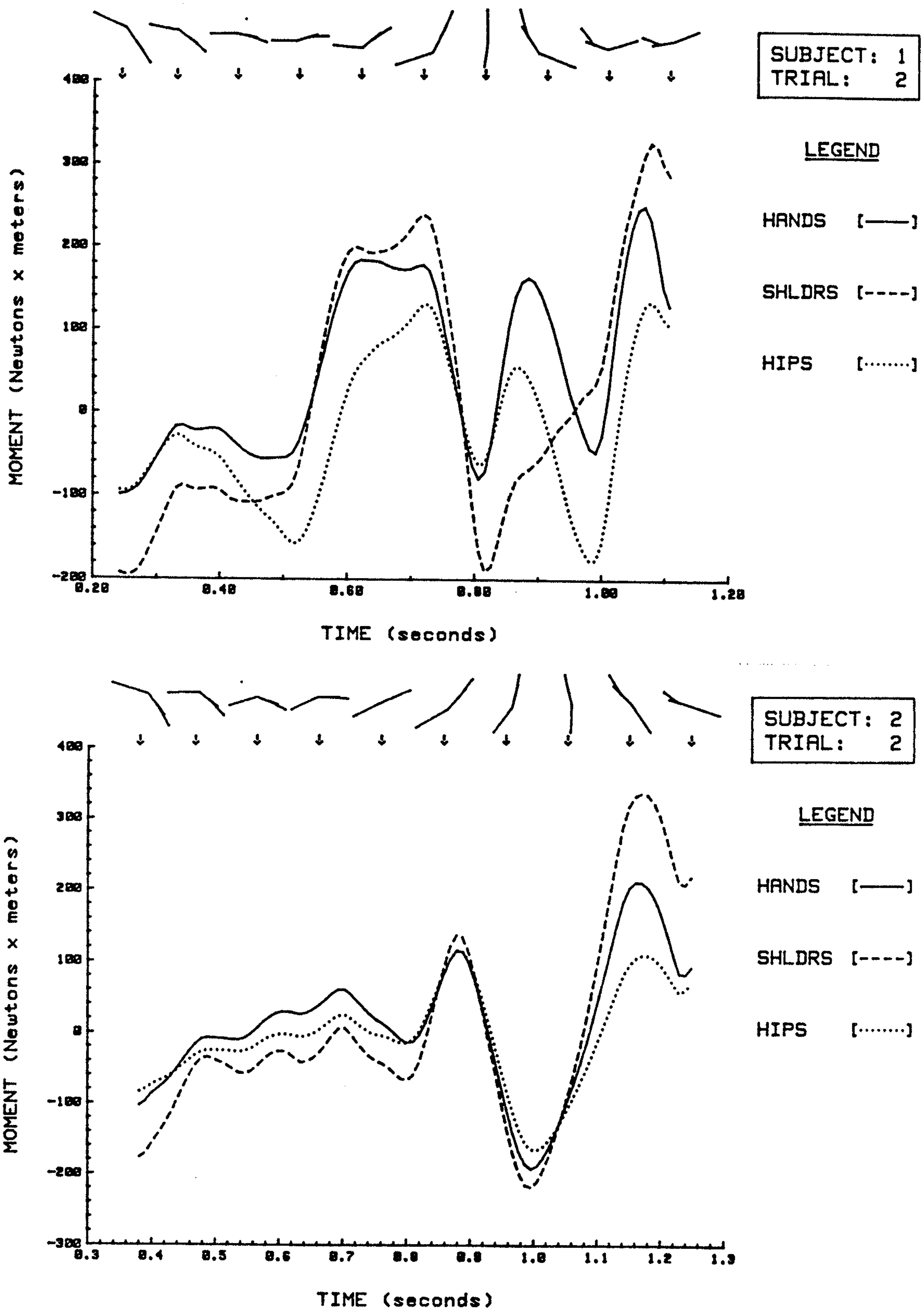


Figure 17: Torque curves for a good and poor performance

time at this point, having reversed the motion of the legs, and begin to decrease. They are still positive however and the hips as a result are flexing. Up to this point in the skill each subject has used the same action in all the trials. The torque patterns, as with the other patterns of motion begin to vary from this point in the skill. In all cases the hip and shoulder torques are decreasing from the point of hip flexion until just before the bottom of the swing. In some cases the torques do not decrease steadily, however they do decrease past zero in most cases. In the few milliseconds at the bottom of the swing there is a great deal of variation.

For subject one in most of the trials, the shoulder torque going through the bottom of the swing decreases well below zero to a value of less than -200 Newton meters. This negative torque is causing the shoulder angle to flex. This flexion torque however, does not appear to change the shoulder/trunk angle to any significant degree. The torque is forcing the angle to remain open to 180 degrees. There is some variation in this pattern for subject one. In two of the trials (trials 1 and 5) the shoulder torque does not drop to as low a level. Nonetheless, the shoulder angles in these two trials are identical to the others. This implies that a lesser negative torque was required in these trials. For subject two there is also some variability in the shoulder torques. The same two patterns of either a large negative torque, or a smaller negative torque are shown. For subject one a large torque is used in most of the trials, but a low torque is used in the best trial (5). For subject two a low negative torque is used in the worst performance and a large negative torque is used in the best performance (trial 2). At this time in the swing when the body is moving with the greatest velocity it appears that either a large negative torque or a lesser negative torque is used to control the shoulder angle. In all the performances the shoulder angle remains open at close to 180 degrees, so that the results of the torques remains consistent.

The hip torques at this time are more consistent both within and between each subject's trials. For subject one the hip torques drop to just below zero and then begin another upward climb. This is not the case for subject two. His hip torques drop well below zero and remain negative after passing through the bottom of the swing. This negative torque has an extension effect on the hips. This shows in that the hip angle for subject two remains extended. He is actively forcing the angle open with this negative torque. For subject one the smaller negative torque climbs to a positive value from the absolute bottom of the swing to approximately 0.1 seconds later. At this time for subject one the hips are flexing. The hip torque is therefore swinging the legs forward. This flexion torque only lasts for a short time however. The torque again drops rapidly to a value well below zero. The flexion torque therefore acts like an impulse in that it acts on the hips for only a short time, letting the hips "coast" through the next few milliseconds as it drops. Why the torque drops to a very low negative value is not clear. This negative torque will cause the legs to slow down their flexion, which would seem to negate the initial flexion torque, however the legs continue to flex even at this point. To further complicate the understanding of this drop in torque there follows another rapid increase in torque to another positive impulse. Perhaps the short drop in torque acts in some way to control the flexion phase. As this complex pattern of positive and negative torques is occurring for subject one, the torques for subject two are consistently negative.

Only at the last few moments before release do the torque patterns of the two subjects again become consistent. For both subjects, in all the trials the last action is a positive torque at the hips and shoulders. This last positive torque for subject one continues the flexion action of the leg segment and causes the trunk to flex as well. For subject two this positive torque causes only a very small flexing of the hips and trunk. Although subject two begins to flex slightly at the end of the giant he releases before the hip/trunk angle gets much below 180 degrees. For all but subject two's worst trial, the last few milliseconds are characterized by a short drop in the hip and shoulder torques as the subjects prepare to release from the bar.

Force Analysis

The next step in the kinetic analysis was to study the forces that occurred at the hands in an attempt to see how forces were being transferred to and from the bar. The pattern of horizontal (X) forces at the hands was relatively simple for all the performances. As the subject swings down in the first half of the giant swing the horizontal force increases from zero. This positive force is what keeps the subject falling in a relatively circular path. The more even this increase in horizontal force the more circular the path of the subjects swing. As can be seen in figure 18 the horizontal force at the hands and shoulders for subject two increases steadily up until a point where subject two's body is in a completely extended position and then tapers off to zero just after he passes below the bar. As he begins the upward phase of the swing the horizontal force on the hands becomes negative and reaches a negative peak just before release. Subject two's swing is correspondingly circular in nature.

Subject one's pattern of X-forces is similar in general shape but is not as smooth. The horizontal force does not increase steadily, but is somewhat delayed at the beginning of the downward swing of the giant. This lack of horizontal force shows up in the more linear drop of subject one's downward swing (figure 9). The maximum positive horizontal force at subject one's hands occurs earlier than for subject two. It occurs as subject one's hip angle is in transition from a position of slight flexion to slight hyperextension. This is the same position that subject two is in at the time of his maximum X-force, except that this occurs later in the giant for subject two. As subject one passes under the bar his X-force drops to zero and then drops further to reach a peak just after passing under the bar. This negative peak occurs at the same time for both subjects. Since subject one holds onto the bar longer than subject two the horizontal force at his hands lasts longer as well. By the time both subjects release from the bar however, they have both managed to reduce the horizontal force on their hands to zero. This means that at the time of release the bar is not contributing any horizontal force to the gymnast and so cannot be accelerating him in the horizontal direction.

The vertical force curves for all the performances were also quite simple in shape. The initial vertical force for both subjects is very close to their body weights. Since they are not accelerating downward initially it is clear that the vertical force at the hands must equal the subjects body weight to allow a net force of zero. This initial force begins to drop off almost immediately for all the performances. The weight of the gymnast is now greater than the vertical force at the hands, so the system is no longer at equilibrium and the gymnast begins to rotate downward.

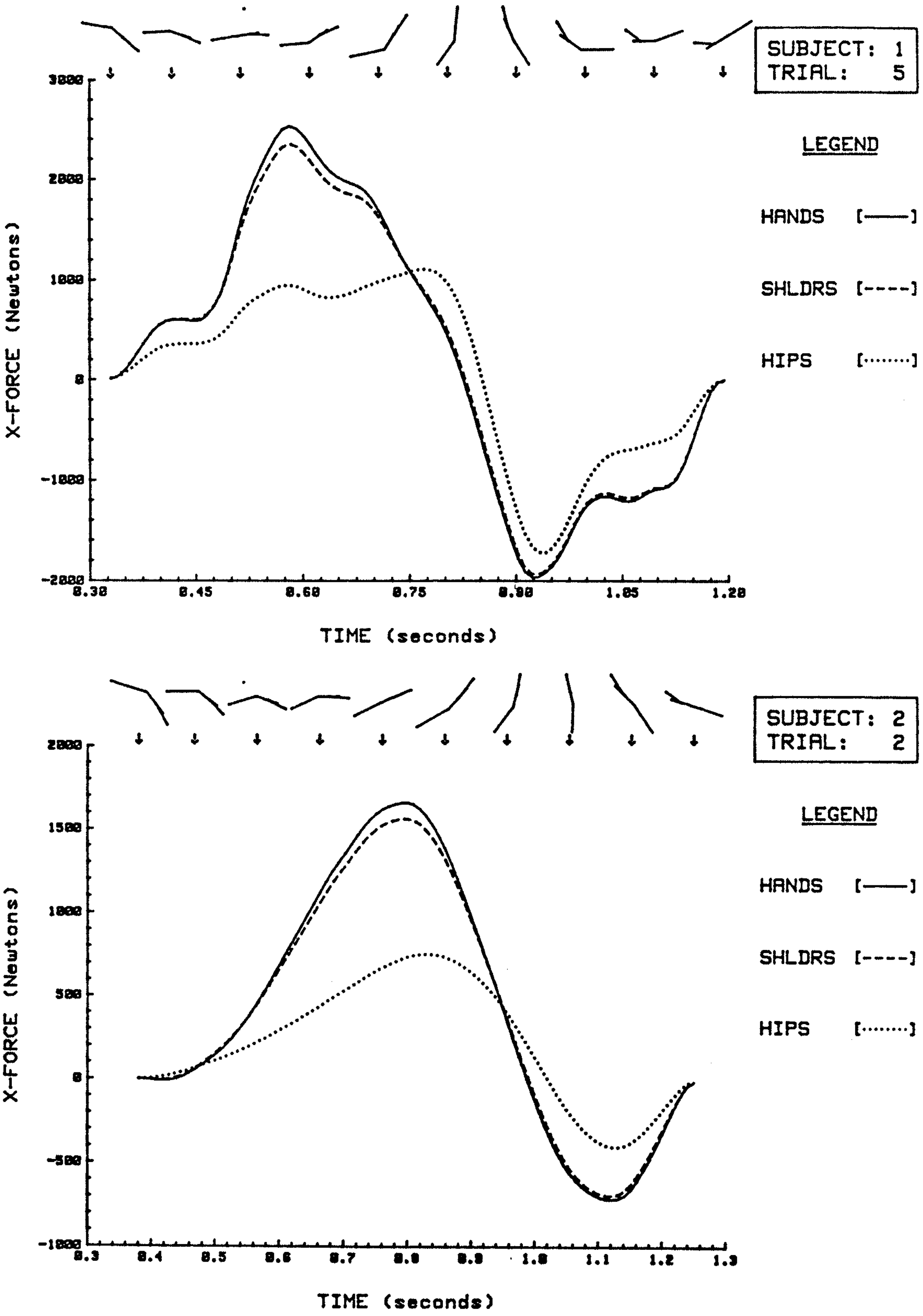


Figure 18: Horizontal forces in a good and a poor performance
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For both subjects there is a time when the vertical force on the hands is close to zero (for approx. 0.2 seconds). After this initial time of zero vertical force the force begins to rise. It continues to rise until it reaches a peak as the gymnast passes under the bar. This is true for both subjects. The shape of this increase is slightly different between the two subjects. For subject one this increase in vertical force is relatively constant, while for subject two there is a brief pause in the increase just at the point where he is beginning to hyperextend at the hips. For both subjects the rise in vertical force increases just before they pass under the bar and peaks as they swing through to the upward phase of the giant.

Initially, in the upward phase, the vertical force for both subjects drops off rapidly, however the force on subject two's hands again plateaus before taking a final drop. It is essential at this stage of the giant that the force on the hands decrease as rapidly as possible. A decrease at this point means that the bar, after being flexed downward, will now begin to rise very rapidly, pulling the gymnast up with it. Biesterfeldt (1975) referred to this motion as having the energy stored in the bar returned to the athlete. Subject one seems to allow this to happen more effectively than subject two.

Note also the differences in magnitude of the maximum vertical force of the two subjects. Subject one has generated close to 4000 Newtons of force at the bottom of his swing, while subject two generated just under 2800 Newtons. This is the best performance for each subject. Clearly, subject one has more energy to regain from the bar during the ascent phase of his swing than does subject two. Subject one held onto the bar for longer and therefore has the vertical force of the bar applied to his hands for longer. This also must contribute to the vertical acceleration of subject one's body. This pattern of greater vertical force generation and rapid reduction of the vertical force just prior to release was typical of the better performances.

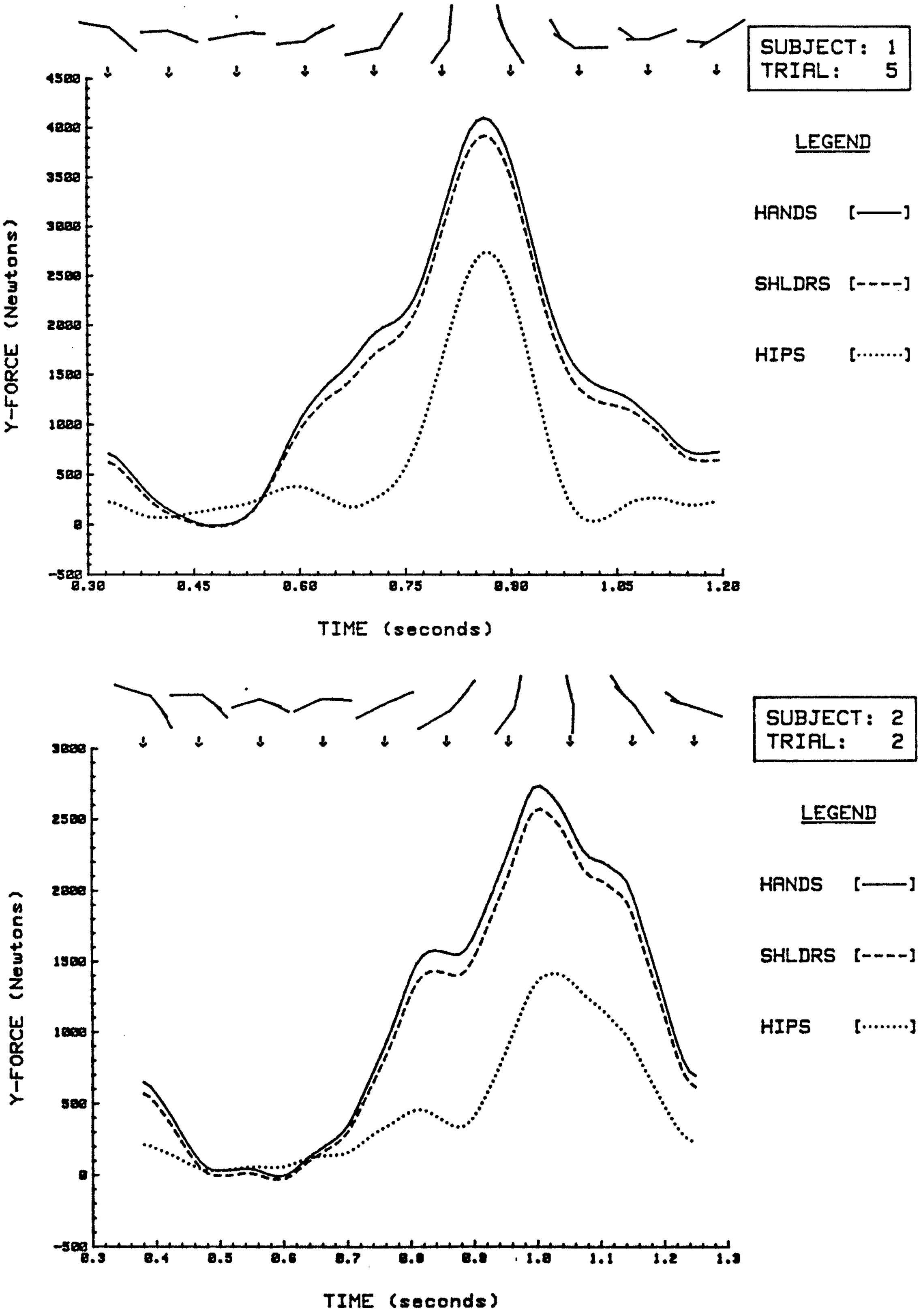

Figure 19: Vertical forces in a good and a poor performance

Energy Analysis

The next step in the analysis was to study the energy exchanges, to see whether this aspect of the performances could offer insight into how the skill was being executed. First the energy exchanges between the subjects' body segments were studied, then the total energy in the body as compared to the energy stored in the bar was studied.

Segmental Energy Exchanges

The segmental energy curves generated by the analysis program (figure 20) showed a great deal of energy exchange between the trunk and leg segments, however there seemed to be very little variation in the energy curve of the arms implying that most of the work in the performance of the skill is done by the trunk and leg segments. This would seem reasonable since the arms are extended throughout the performance of the giant swing and could not contribute much to the performance while in this mechanically disadvantaged position. The arm segment also does not carry much of the mass of the body and so could not be used very effectively to pass angular momentum to the trunk which is much greater in mass. The trunk and leg segments on the other hand, appear to vary a great deal in energy throughout the skill with changes of up to 1300 Joules in some cases.

In the downswing stage of the skill the energy curves for both subjects appear to be quite similar. The leg segment

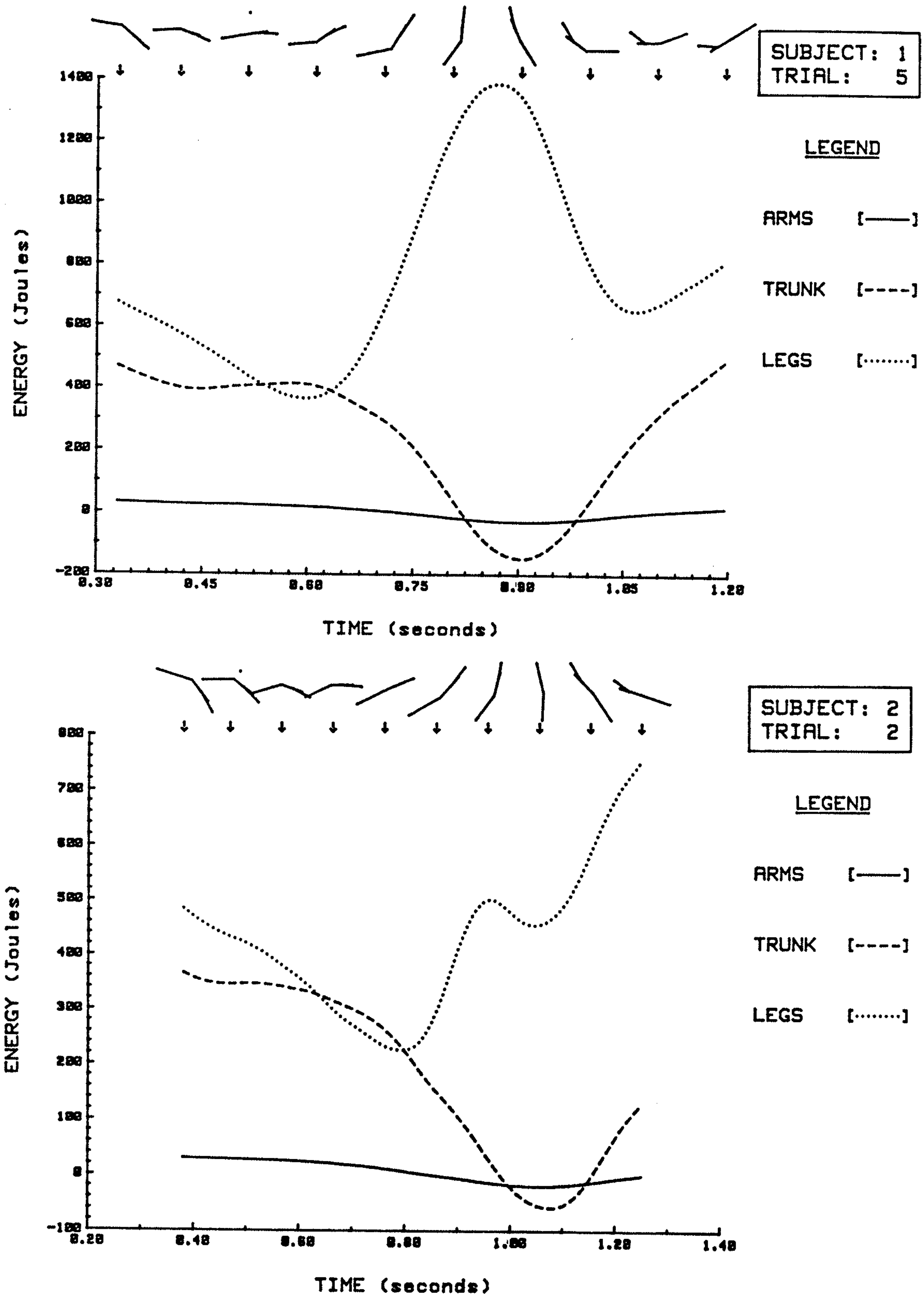

Figure 20: Segmental energy curves for two typical performances

is losing energy as it falls due to the extending action at the hips which is slowing the fall of the legs. At the same time the trunk segment's energy appears to remain relatively level for all of subject one's trials. For subject two the energy level of the trunk also remains quite level but does drop slightly. As the subjects are falling they are extending at the hips. This action appears to cause the leg segment to lose energy but keeps the energy level of the trunk segment relatively level. Both subjects appear to execute this energy exchange equally effectively.

Through the bottom of the swing there is a significant difference in the segmental energy curves between the better and poorer performances. In the better performances the leg segment reverses it's trend of energy loss and rapidly begins gaining energy. This is occurring at the same time that the phase of hip extension is also reversing and the hips are beginning to flex. As the leg segment very quickly gains energy the trunk segment is losing energy. The flexion action at the hips is decreasing the angular velocity of the trunk segment while increasing the angular velocity of the leg segment. Energy is being passed from the trunk segment to the leg segment. In the better performances the legs gain between 1000 and 1300 Joules of energy as the trunk is losing from 500 to 600 Joules. The point of maximum leg energy and minimum trunk energy occur when the subject is just past the bottom of the swing. The hips at this time are completely extended, having been flexed from their hyperextended position prior to this time.

As was mentioned, the pattern of energy exchange between the trunk and leg segments is not the same between the two subjects. For subject two the pattern of rapid energy loss by the trunk and the corresponding energy gain by the legs does not occur to the same extent. At a time when subject one's leg segment is gaining up to 1300 Joules of energy subject two's leg segment is gaining only 250 Joules. Subject one's trunk segment is losing even more energy than the legs are gaining with an energy loss of approximately 350 Joules even in the best performance. Subject two's flexion phase at this time is not as powerful as the flexion phase demonstrated by subject one. This prevents him from effectively transferring energy to the leg segment. At a time when subject one appears to be generating large quantities of energy subject two appears to be only minimally generating energy.

In the second half of the swing, just after the subjects have passed under the bar there are again some significant differences. As subject one begins to rise in the forward part of the swing his legs very rapidly begin to lose energy again. His trunk segment begins to gain energy. The leg segment is passing energy back to the trunk, as hip flexion begins to slow down. In the very last few moments just prior to release in most of subject one's trials there is a final phase when both the legs and trunk are gaining energy. This occurs as the final hips flexion stage is ending and the hip and shoulder angles open slightly (hips extending, shoulders flexing). In subject one's best performance this final stage is quite pronounced. Both segments gain energy for approximately 0.15 seconds just prior to release. This may be due to both a greater extension phase at the hips and also the fact that in this trial subject one holds on to the bar longer.

For subject two this phase of energy loss by the legs and energy gain by the trunk does not occur in the same way. It appears as if the legs do have a slight loss in energy temporarily but again increase in energy in the last tenth of a second just before release. There is no really effective transferring of energy to the trunk segment. As a result the energy values are quite low in magnitude (legs have 600-800 Joules, trunk has 50-100 Joules) compared to subject one (legs have 600-800 Joules, trunk has 400-500 Joules).

Clearly subject one appears to be more effectively transferring energy between his legs and trunk than subject two. He appears to be using torque at the hips to generate energy in the legs and then transfers this energy to the trunk segment just before release. In the best performance by subject one there is also a final stage where both the legs and trunk gain energy just before release.

Total Body Energy

Once the various patterns of energy exchange between the segments had been determined the energy patterns of the whole body were studied in relation to the segmental energy curves, and the spring energy curves. There are rapid changes in the total body energy curves corresponding to the peaks and troughs of the segmental energy curves (figure 21).

During the downswing phase of the swing the total energy of the body is dropping rapidly. This is because the leg segment energy is dropping while the trunk segment remains level (or drops slightly). Since the total body energy value is a sum of the segment energies it must drop. All the trials for both subjects followed this same pattern of dropping total body energy. This continued for all trials until the hip extension action was completed and the hip joint was at maximum hyperextension. As the subjects began to flex again at the hips the pattern of decreasing total body energy reversed and body energy began to rise. For subject one the body energy rose dramatically as he actively flexed at the hips, peaking just before the hip angle reached 180 degrees, and just before the body passed under the bar. This pattern was very consistent for subject one. His total body energy reached very high levels, close to 1600 Joules in some cases. For subject two the total body energy rose only slightly as he flexed at the hips. His hip flexion stage,

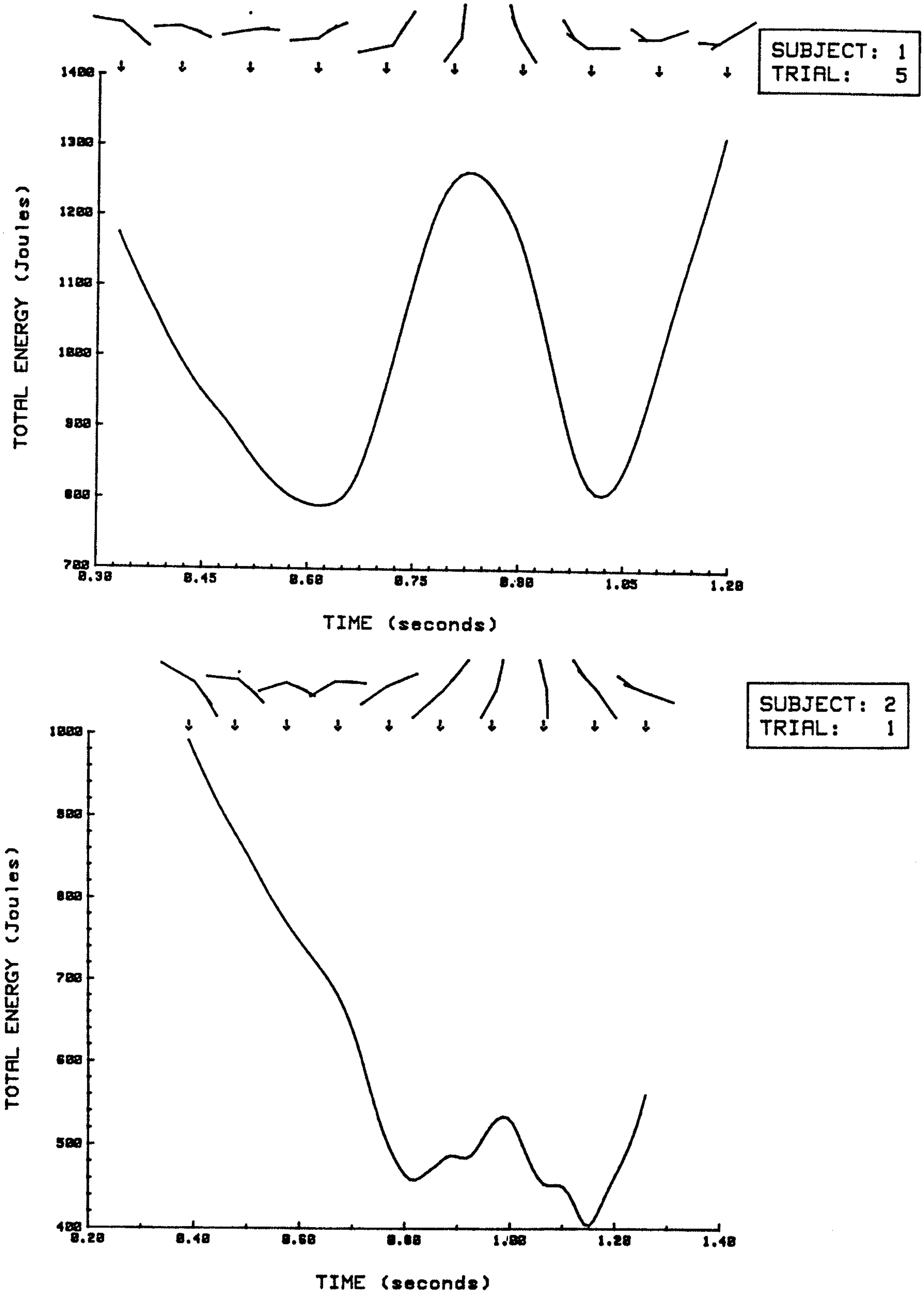

Figure 21: Total body energy curves for two typical performances

as mentioned previously, was very minimal, and the corresponding energy peak was small in comparison to subject one (peaking at approx. 500 Joules). This peak in total body energy corresponded to the peak in leg segment energy, although it occurred a few milliseconds earlier. This is also just before the trunk energy has reached its lowest point, meaning that most of the total body energy was being generated by the leg segment at this time.

Once the total body energies of the subjects had peaked they again dropped very rapidly, corresponding to the simultaneous drop in leg segment energy and rise in trunk segment energy. For both subjects this occurred just after passing through the bottom of the swing. Subject one was still actively flexing the hips at this time. Subject two was also flexing, but only slightly. For subject two, since the peak was less dramatic, the drop in total body energy was also less dramatic. Subject one's total body energy changed from approximately 800 Joules just prior to the bottom of the swing, to a peak of over 1600 Joules (in some cases), to a drop again back to approximately 800 Joules. In all of his trials this meant an energy variation of up to 800 Joules in the span of only 0.4 seconds. For subject two the minimum values were approximately 400 to 450 Joules and the maximum values of the peak were approximately 500 Joules meaning a variation of only 100 Joules during the same time interval. Clearly subject two is not altering his total body energy to the same extent as subject one during this phase of the swing.

In the last phase of the swing the total body energy levels for the two subjects again rose. For both subjects there were some variations in the final level that the body energy reached before release. For subject one the energy levels were usually quite high, close to the starting energy levels. In the best performance his energy level at release actually was higher than his initial energy level, signifying that he had actually gained energy (over 1000 Joules) while swinging through the bottom. For subject one the differences in final total body energy were quite marked. In his worst trial his total body energy was very low, rising only slightly from the last trough. He released with a net loss of over 600 Joules. This may be due to his very early release from the bar. It did appear that the energy level was rising, however he released from the bar before it had risen very far. In his best performance his total body energy level rose to close to its original value of 900 Joules. Subject one's energy levels at release ranged from 900 to over 1300 Joules, while subject two's energy levels at release were 550 and 900 Joules. Even relative to body mass, subject one consistently generated much higher total body energy levels at release than subject two.

In summary, the total body energy curves for the two subjects generally followed the shape of the letter "W". The energy level began at a high level and fell in the downswing till it reached an initial trough just as the subjects completed their maximum hyperextension phase. It then rose (dramatically, in the better trials) to a mid-swing peak just before the subjects passed under the bar, and dropped again just after passing under the bar. This was followed by a second rise in body energy as the subjects began to swing upward. In the better performances this last increase in body energy was dramatic.

Once the pattern of total body energy had been established it was compared to the spring energy curves of the horizontal bar to try to see what energy exchange there might be taking place between the gymnast and bar. This analysis revealed a dramatic pattern of energy exchange. The spring energy in the bar is related to the square of the linear displacement of the bar, as previously discussed in the Methods and Procedures chapter. This pattern of energy variation in the bar was very similar for all the trials, for both subjects. The spring energy level was quite low initially but began to rise as the subjects fell in the downswing of the giant. As the subjects were falling they were pulling on the bar to keep their paths circular. This began to displace the bar from its origin and thus store energy in the bar. This initial rise in bar energy is occurring as the total body energy of the subjects is dropping, implying that energy is being transferred from the athlete

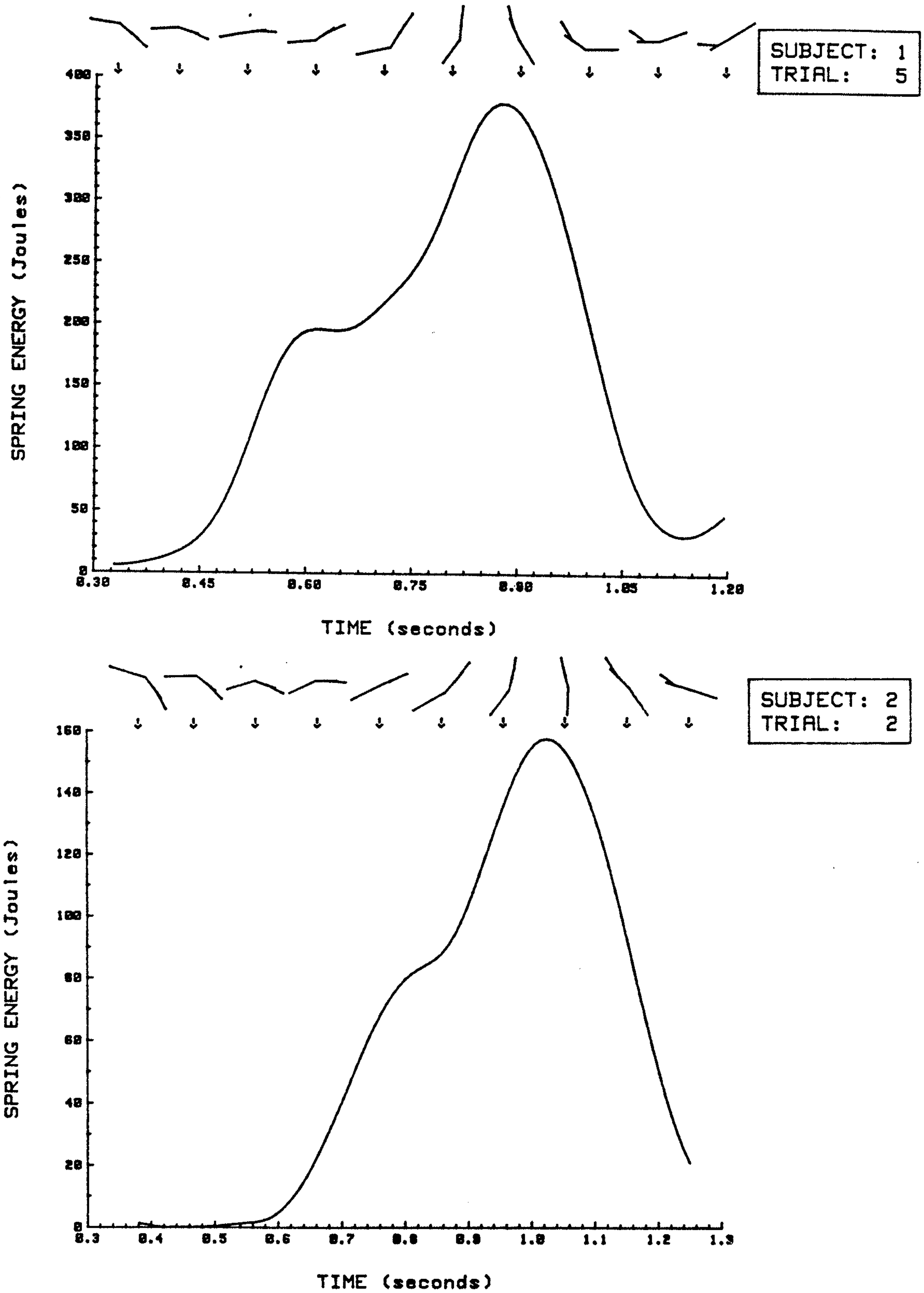

Figure 22: Spring energy curves for two typical performances

to the bar. The spring energy in the bar continued to rise until it reached a pause, or plateau as the hips began to reach maximum hyperextension. In some cases, as the subjects stopped extending and began to flex at the hips the energy level of the bar even dropped slightly, as energy was passed back into the body. As the subjects flexed at the hips and continued to fall the spring energy in the bar again continued to increase. It peaked for all the trials at a point just after the subjects had passed under the bar. Note that this is approximately 0.1 seconds after the total body energy in the subjects had reached its peak. The spring energy of the bar was therefore peaking as the total body energy of the subjects was dropping dramatically. This would seem to indicate that at this point in the swing, as the subjects energy level is beginning to drop, energy is being transferred to the bar.

Very soon, however, the spring energy in the bar also began to drop dramatically. It continued to drop throughout the last phase of the swing. Towards the end of the swing, when the total body energy of the subjects (particularily in the better performances) increased before release, the energy in the bar was still dropping. This indicates that energy is very rapidly being transferred back into the body of the gymnast in the last few milliseconds of the swing, just prior to release. The gymnasts are therefore getting back the energy lost to the bar just before releasing from the bar. In subject one's best trial there is one final, slight increase in bar energy, just before release. This is caused by the subject's final extension phase. He is giving a final push off the bar just before releasing. This final push deflects the bar somewhat, storing a small amount of energy in the bar.

The peaks in spring energy stored in the bar ranged from just under 160 Joules (subject two, worst trial) to close to 450 Joules (subject one, second best trial). This is approximately half of the range in variation of the total body energy (450 Joules as compared to 800 Joules). This indicates that of the 800 Joules being lost and gained from the body, half is being stored in the bar and then retrieved just before release. Clearly the elastic nature of the bar contributes a substantial amount to the performance of the skill. This aspect of the swing cannot be ignored without losing a great deal of information on how the skill is being executed.

Strain Gauge Comparison

An attempt was also made to relate the strain gauge measurements to the force data. As was mentioned, only the vertical strain gauge bridges were operational, so that only comparisons with the calculated vertical forces could be made. As part of the kinetic analysis of the skill the vertical force applied to the hands was calculated. The strain gauge output was a representation of the forces being applied to the bar. Since the force applied to the bar is actually equal, but opposite to the force applied to the hands, the strain gauge data, when graphed was multiplied by negative one. By multiplying the data by minus one the strain gauge graphs now represent the measured force applied to the hands rather than the force applied to the bar (see figures 23 and 24).

There are significant differences between the measured vertical force curves and the calculated force curves. In the initial downswing phase of the giant both sets of data are similar. For both the measured curves and the calculated curves the vertical force is dropping as the gymnast falls. The force on the hands drops well below subject body weight and the system is not in equilibrium so the gymnast falls. There is some difference in the vertical force curves for the subject one's performance however. Notice that the initial vertical force as measured from the strain gauges is approximately 200 Newtons which is well below body weight. The corresponding calculated vertical force curve shows an initial force of approximately 700 Newtons. This latter value is much closer to the actual weight of the subject. Note also that the measured force curve drops to a value well below zero (approx. -400 Newtons) during the initial downswing. This same drop occurs in the calculated force curve data, but doesn't pass below zero. It is likely

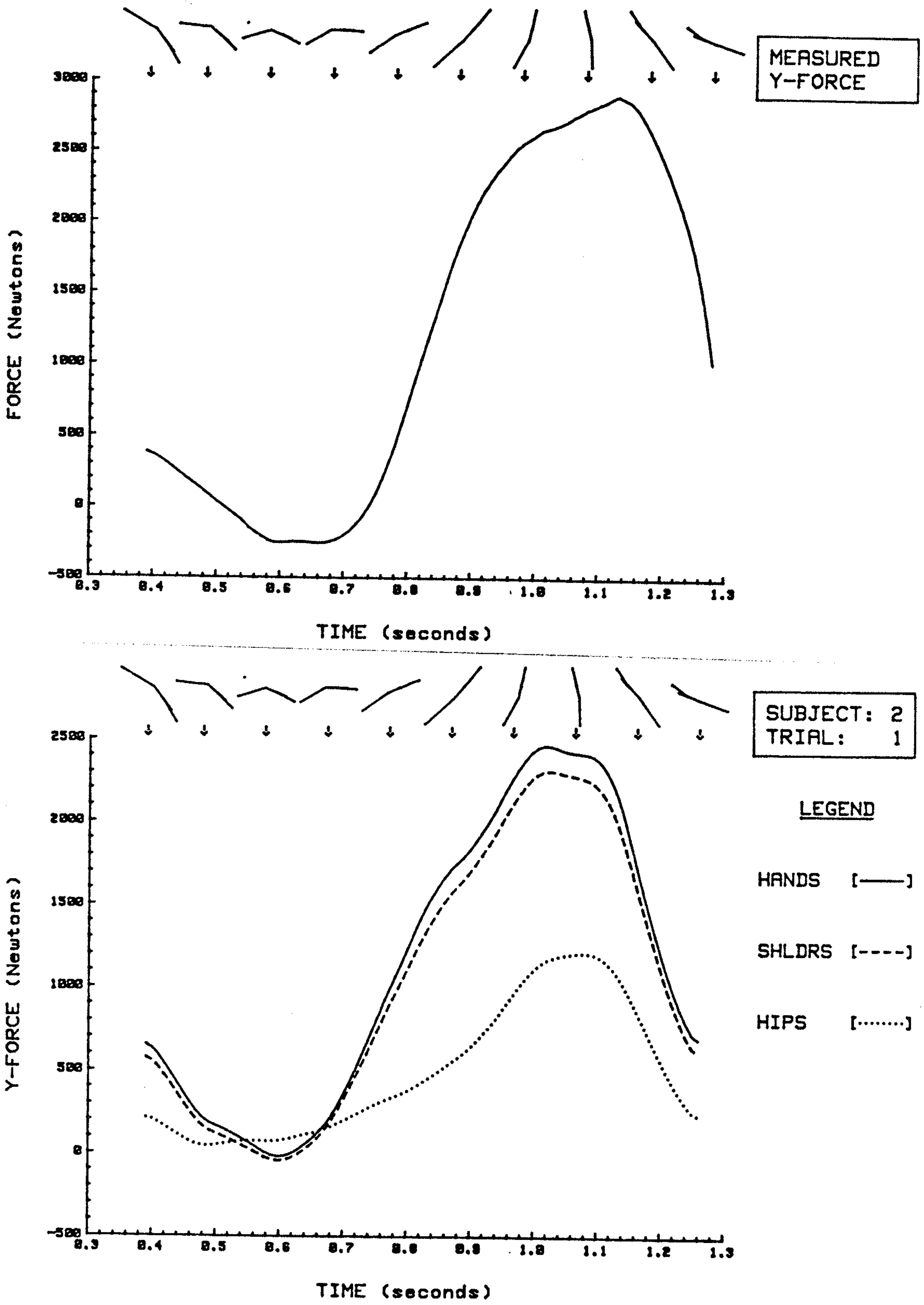

Figure 23: Measured versus calculated vertical strain in a poor performance

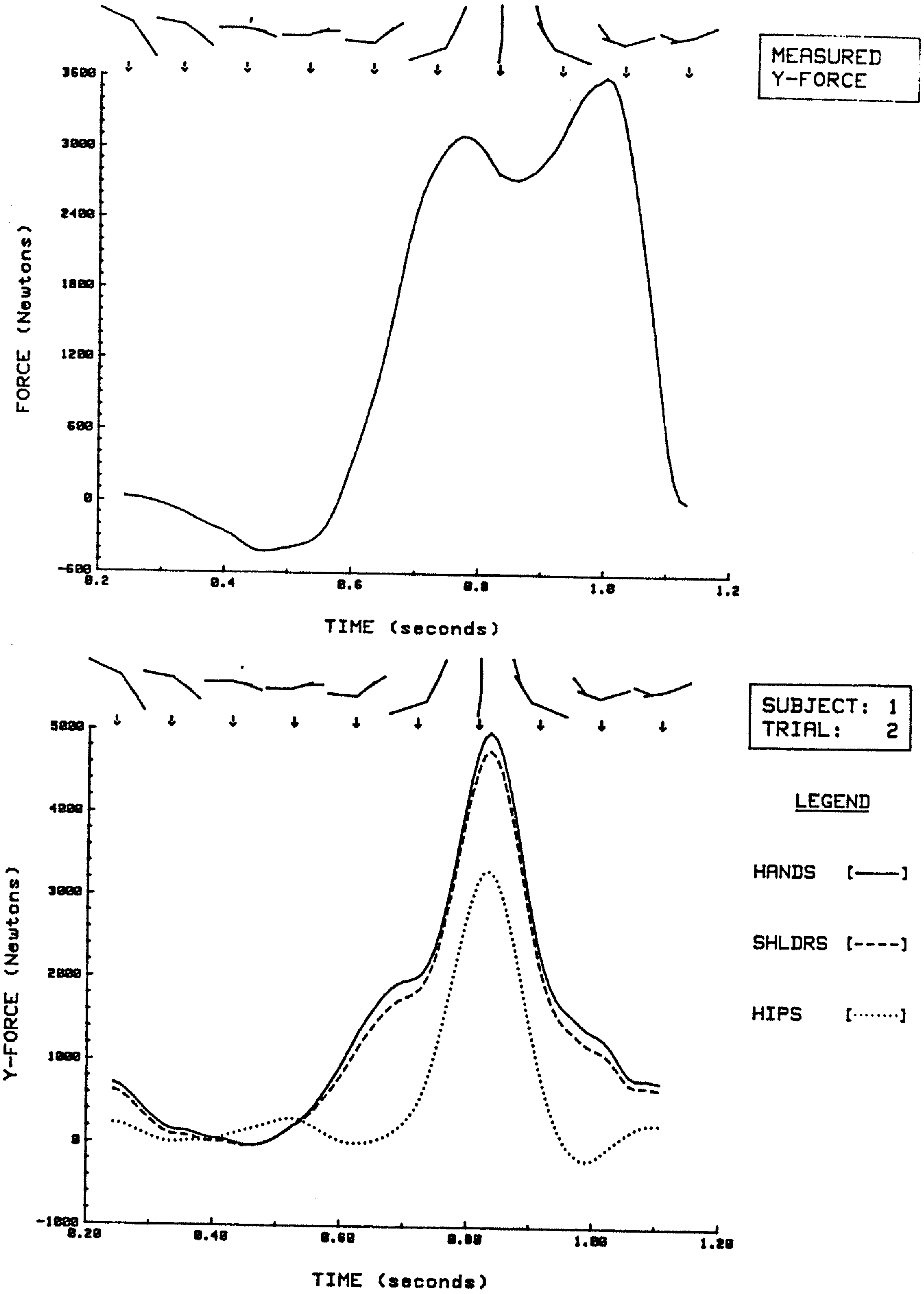

Figure 24: Measured versus calculated vertical strain in a good performance

that the vertical forces at this time are in fact above zero. It is unlikely that they would be negative because that would mean that the hands are being pulled down, which doesn't appear to be the case. It may be that the calibration factor used to convert the strain gauge data to actual forces was inaccurate. This would account for the negative values in this part of the performance and might also explain why the peak forces later in the giant are below the calculated values.

Past this initial phase of dropping vertical force and into the last part of the downswing the vertical forces begin to rise. In both the measured strain gauge force curves and the calculated force curves for subject two trial one, the slope of this rise is quite similar. The vertical force smoothly increases until just before the bottom of the swing. At this point it begins to level off. The measured peak value (subject two, trial one) is approximately 3000 Newtons, while the calculated peak is approximately 2500 Newtons. For this trial the measured peak occurs slightly later than the calculated peak.

For the other performances the measured and calculated force curves do not agree as well as for subject two trial one. In the measured graphs the increase in vertical force is relatively steep and begins an initial peak just before the bottom of the swing. In most cases this initial peak is followed by a slight drop in force as the subjects passed under the bar, and then another greater peak during the beginning of the upward swing. In the calculated curves this is not the pattern. The force rises only slowly at first and then, just before the gymnast swings under the bar, the force rises dramatically. There is only one peak in the force curve usually occuring just a few milliseconds after the subjects pass under the bar. After the peak the vertical force drops again, first steeply, and then more gradually at the end of the giant. The measured force from the strain gauge data drops off very rapidly, but does so much later, only a few milliseconds before release.

There are two major factors that could be contributing to the differences in the two sets of data. The first factor has to do with the process of modelling the gymnast as a simple rigid body system of links having pinned joints is inaccurate. This representation of the gymnast does not allow for the elastic properties of the actual athlete, particularily in the shoulder joint. With forces of over three times body weight being applied to the shoulders the gymnast is forced to elevate the shoulders. This action of elevating the shoulders is similar to lengthening the arm segment link, which is analogous to stretching the link. Since the model does not allow this type of movement to be taken into account some information is lost.

The second factor that may contribute to the differences has to do with the spring properties of the bar. The bar, acting as a spring mass system must follow certain patterns of motion. It will have a natural frequency related to both the spring constant (k) and the mass of the system, the gymnast's mass. Using the measured value of k and the mass of subject one the natural frequency of the bar is given by:

$$Wn = \sqrt{k / m}$$

Where: Wn = natural frequency of the bar
k = the spring constant of the bar
m = the mass of the subject

The value calculated was 19.425 which represents a cyclic frequency of 3.09 cycles per second or 0.323 seconds per cycle. This means that the if the bar was pulled to a stretched position and then released to vibrate, it would vibrate one complete cycle in 0.323 seconds. The natural frequency also has implications in terms of the capacity of the bar to respond to forces applied to it. If a force is applied to the bar very rapidly, faster than the natural frequency of the bar, the bar will be unable to flex fast enough and so will respond to the force more slowly. Likewise, if the bar, in its natural vibration, is flexing and a force is slowly applied to it (slower than its natural frequency) the bar will follow its natural path and only alter its path as the force builds. The result of this responsive nature of the bar is that the displacement of the bar has two components that must be taken into account. One component is the natural frequency of the bar. The other is the frequency of the force being applied to the bar and how close it is to this natural frequency. In the system under study the frequency of the bar appears to be slightly slower than the frequency of the force being applied to the bar, which is approximately 0.25 seconds. This forcing frequency was estimated by calculating the time from the beginning of the rise in vertical force to the end of the peak when the force had decreased back to its initial value. In most cases this time difference was approximately 0.25 seconds, as mentioned. This may account for the differences in the strain gauge measurements and the calculated values. Recall that the strain gauge data is dependent on the displacement of the bar. Since the force being applied to the bar is faster than the natural frequency of the bar the bar responds slower and somewhat later, and then drops off rapidly to catch up with the rapid drop in force being applied to the bar.

This relationship between the natural frequency of the bar and the forcing frequency has tremendous implications with regard to the design of horizontal bars. As the frequency of a forced vibration nears the natural frequency of the structure being forced, the amplitude of the vibration begins to increase. This magnification of displacement amplitude is given by the equation:

$$Mf = 1 / (1 - (w/p)^2)$$

Where: Mf = the magnification factor
w = the forcing frequency
p = natural frequency of structure

As can be seen from this equation, as the forcing frequency (w) approaches the same value as the natural frequency of the system (p) the magnification factor increases dramatically and will theoretically reach infinity when the forcing frequency and natural frequency are the same. The forcing frequency is then said to be in resonance with the given system (Beer & Johnson, 1981). As the forcing frequency approaches the natural frequency the structure will begin to vibrate more and more until it shakes itself apart. In actual fact the magnification factor will never reach infinity because of damping. Nonetheless, in most engineering design problems the goal is to develop a structure that will have a natural frequency that is not close to the anticipated forcing frequency. For some machines such as paint mixers or concrete vibrators however the goal is to vibrate the machine with as little input force as possible. In those cases the machine would be designed so that the natural frequency and forcing frequency were very close, to take advantage of the magnification factor.

The horizontal bar falls into the catagory of structures that should be designed to be responsive to forcing. The gymnast is trying to use the spring characteristics of the bar to store and retrieve energy. He must apply force to the bar to deflect it, and then absorb force from the bar to help lift him in the upward phase of a swing. He does this by flexing and extending his joints.[1] By flexing at the hips the gymnast draws his center of gravity in closer to the bar while swinging around the bar. This action of drawing the center of gravity in requires an increase in the normal component of the force applied to the bar (the component along the body length of the gymnast). The forcing frequency of the gymnast is therefore determined by the timing used to flex and extend the body. By changing the rates of flexion and extension of his body the gymnast can alter the frequency of the forces being applied to the bar. Since there is probably a very limited range of frequencies at which the gymnast can apply force to the bar it would be beneficial to design the bar to be very responsive to this limited range. It may even be possible to adjust the natural frequency of the bar to suit the body types and swing characteristics of individual gymnasts. Such possibilities should be taken into account when designing any gymnastics apparatus.

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[1] Often referred to as "beating" in gymnastics.

Computer Modelling

The final phase of this study was to validate the proposed computer model and then use it to further investigate the interaction of the gymnast and horizontal bar.

Model Validation

In an attempt to validate the model the input data from an actual performance was entered without modification and the performance was reproduced. This consisted of, as described earlier, the digitizing and interpolating of the angular acceleration curves of the three segments as well as the horizontal and vertical displacements of the bar, integration of the angular acceleration data twice to derive the inclinations of the segments, and the recalculation of the segment endpoints from the bar coordinates and the segment inclinations. Once the coordinates were calculated the linear and angular kinematics and kinetics were calculated.

Since the initial input data was not altered in any way (other than possible digitizing errors) the kinetic data calculated by the model should be exactly the same as the kinetic data calculated from the film data. To determine the differences between the modelled kinetic data and the calculated kinetic data dependent t-tests were done for each segment, on the horizontal (X) force, vertical (Y) force, and torque throughout the entire performance. The results of these tests are given in table 1.

TABLE 1

Comparison of Calculated and Modelled Kinetic Data

Dependent t-Scores

SEGMENT ONE

	Mean Diff.	S.E.M.	t-Score
X-force	-9.280	66.73	-0.139
Y-force	7.558	17.72	0.426
Torque	-23.960	10.78	-2.223 **

SEGMENT TWO

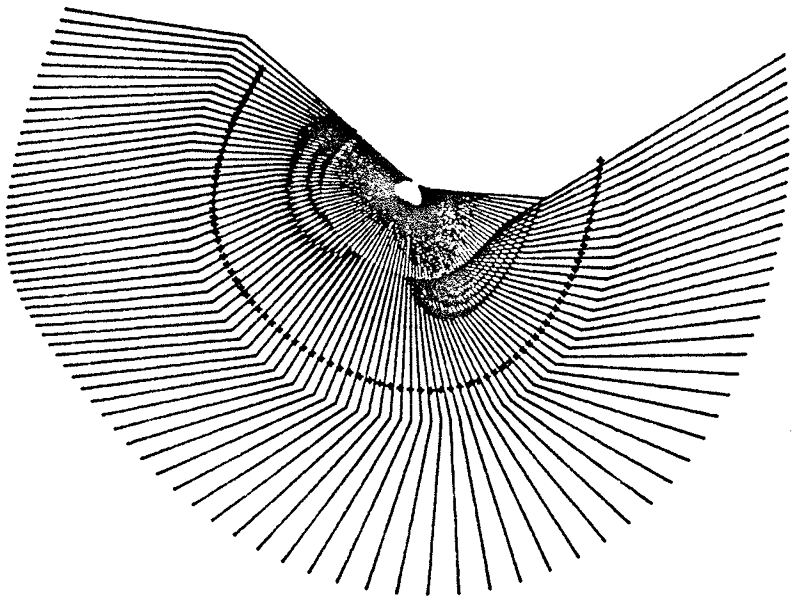
	Mean Diff.	S.E.M.	t-Score
X-force	58.207	47.18	1.234
Y-force	-32.036	43.44	-0.737
Torque	-21.742	11.68	-1.861 **

SEGMENT THREE

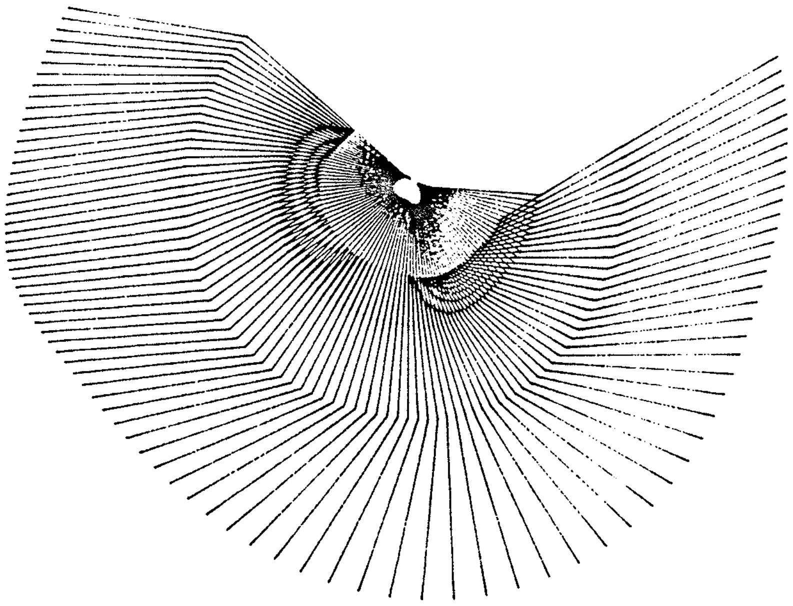
	Mean Diff.	S.E.M.	t-Score
X-force	-8.081	33.93	-0.238
Y-force	5.620	12.37	0.454
Torque	-9.603	5.91	-1.624 *

Note: One star (*) denotes significant at .05 confidence level. Two stars (**) denotes significant at .1 confidence level.

The only modelled kinetic data that resulted in significant differences from the calculated data is the torque data. The horizontal and vertical force data appear to be quite accurate. The positions of the body segments throughout the performance are presented in figure 25. Also, the kinetic data for both the modelled and actual performances are presented in figures 26 to 28. As the graphs illustrate, there are some significant differences in all the curves, particularily the torque curves.



SUBJECT 1, TRIAL 5



MODEL OF SUBJECT 1, TRIAL 5

Figure 25: Modelled versus actual body positions

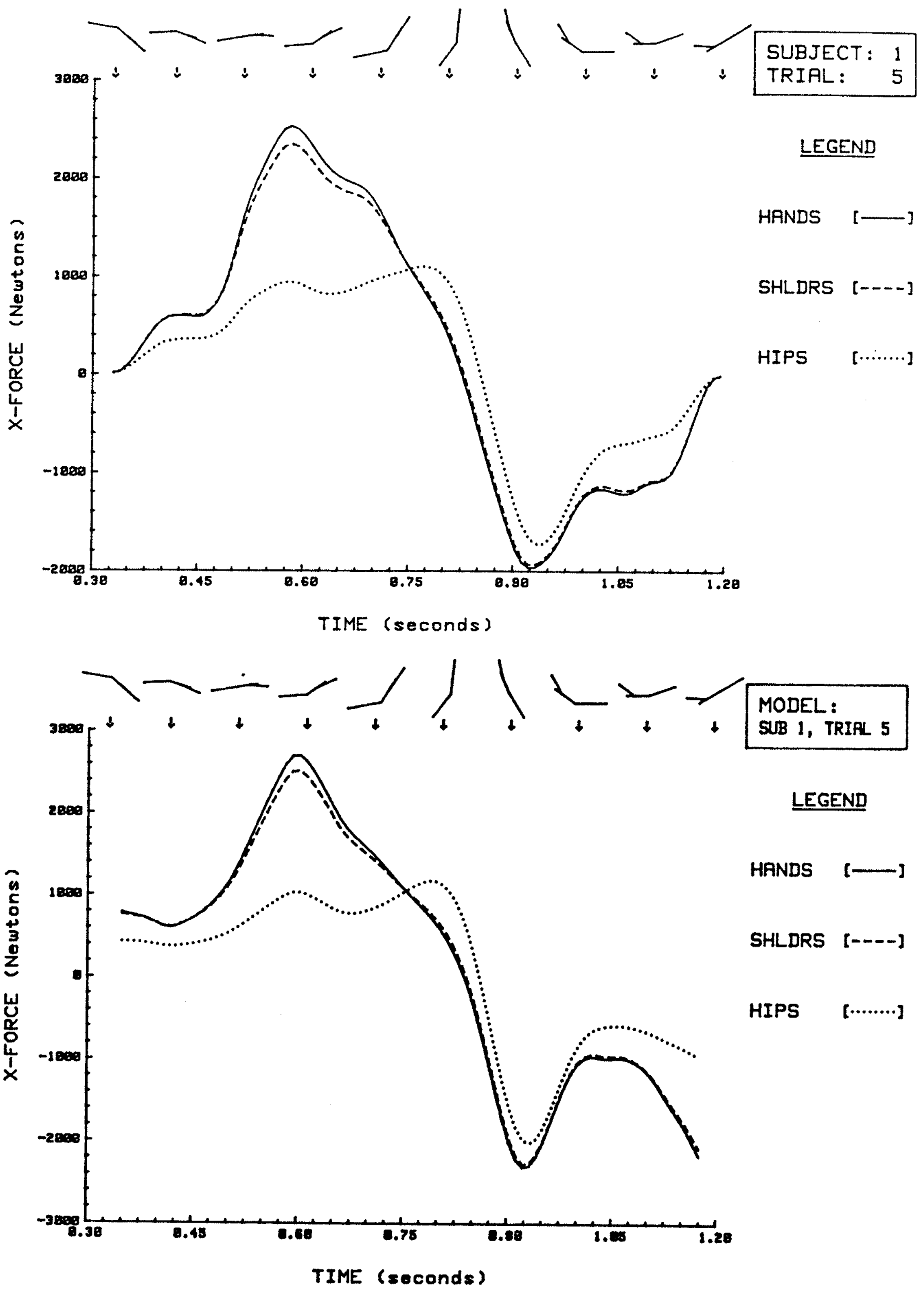


Figure 26: Modelled versus actual horizontal force

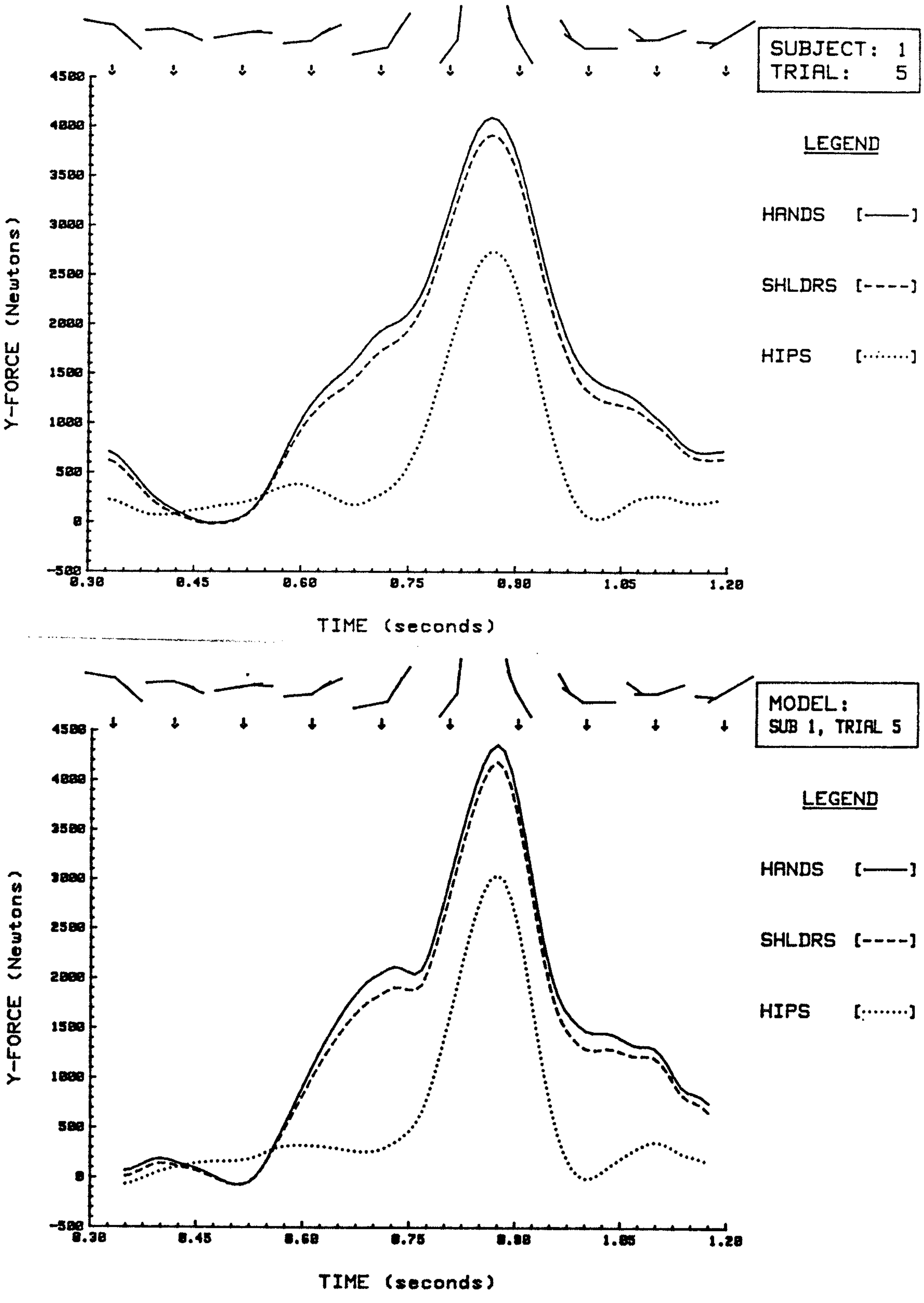


Figure 27: Modelled versus actual vertical force

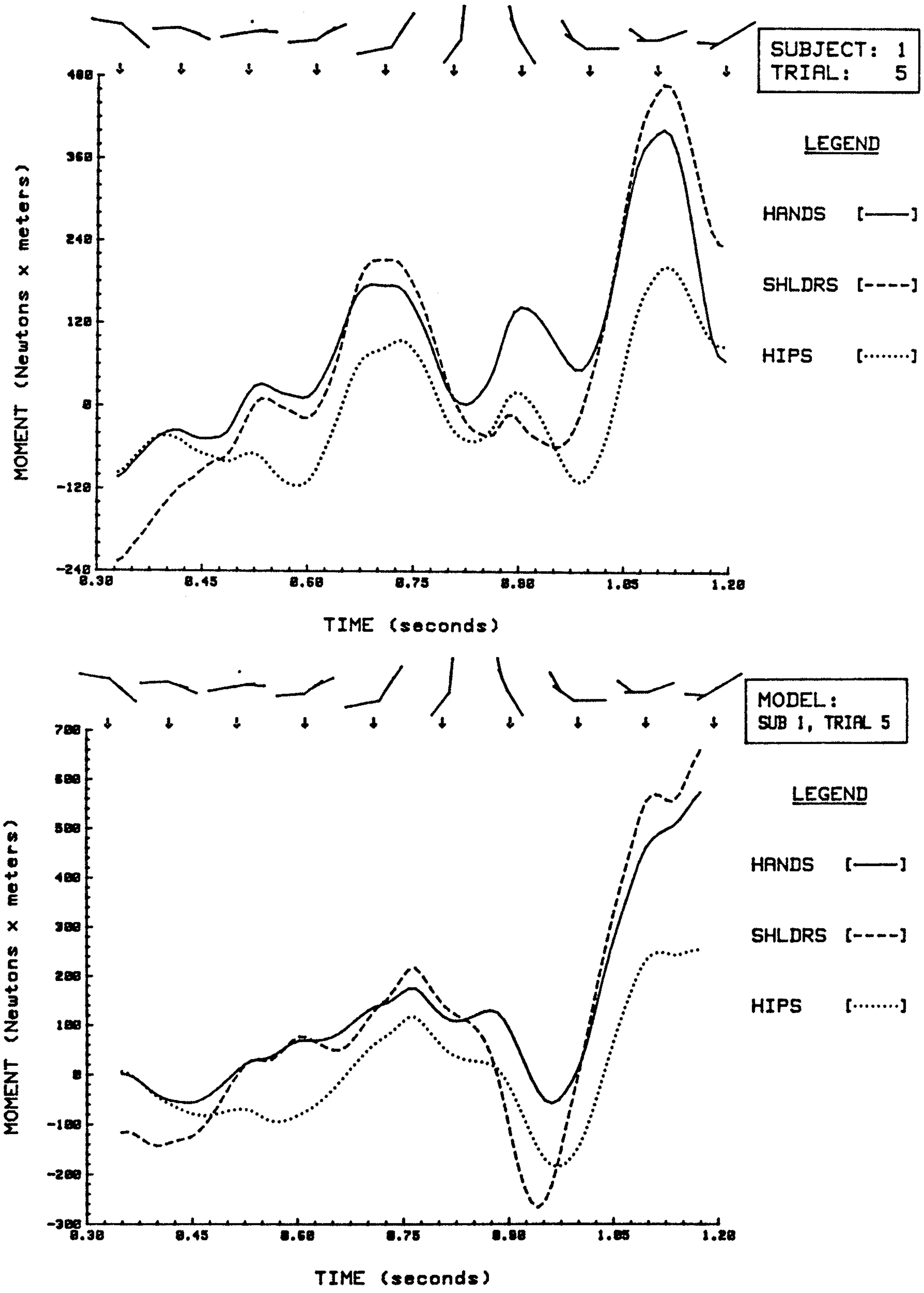


Figure 28: Modelled versus actual torque

Even though the statistical differences between the force data is non-significant it is clear that the modelled data for the first 0.15 seconds and last 0.20 seconds does differ from the actual performance data. The middle section of the skill between 0.45 seconds and 1.00 seconds appears to have been modelled quite well. This is not the case for the torque data. The modelling process smoothed out a lot of the peaks and troughs in the torque curves. Clearly the differences are significant enough to reject the torque data as being too inaccurate.

There are several reasons that the modelled data differs from the performance data. The most significant factor is that the integration procedure used is not a true inverse of the differentiating procedure used in analysing the actual performances. The differentiating technique used in the kinematic analysis is referred to as a first finite differences technique and has a weak smoothing effect on the data. The integration procedure used in the model to derive the inclination data from the angular acceleration data is not an exact inverse of the first finite differences technique. For this reason there will be some error in trying to replicate the actual data using the integration technique. This error appears to be most significant in the first 0.15 seconds and last 0.20 seconds of the modelled performance.

Another possible error-causing procedure involves the interpolation procedure used to reproduce the angular acceleration data and bar position data. Since only a few (approx 15-25) points are digitized from the original curves the interpolation subprogram must fill in much of the data for these curves. This involves a certain amount of smoothing by the algorithm to produce data that passes through all the digitized points. This smoothing effect may also contribute to any differences in the two data sets.

Related to the interpolation problems in reproducing the initial data, is the error involved in digitizing the points from the original curves. Although great care was taken to digitize points accurately, undoubtedly some error can be accounted for by the process of manually digitizing the points.

All these errors will add up to cause the differences in the modelled data. Although these errors are noticeable in the figures and statistically significant for the torque data the modelling program does appear to be accurate enough to be useful.

Using a Fixed Axis Bar

Once it was established that the model was accurate enough to be useful in studying skills, a modified procedure was used to try to determine what sort of error would be involved in the rigid bar assumptions used in previous modelling techniques.

The original modelling program was slightly modified to model the bar as a fixed axis at the origin. This was done by setting the coordinates of the bar to zero (X=0, Y=0) for each frame of film and then analysing the data as before. The position data is presented in figure 29 and the resulting force data is presented in figures 30 and 31.

Modelling the gymnast swinging on the bar using a fixed axis to represent the bar appears to cause considerable error when attempting to estimate joint forces. Note that the vertical scale for both modelled graphs is not the same as in the actual performances. Although there does not appear to be too much difference in the shapes of these curves (although there are differences) the most striking problem is that the forces are of a much smaller magnitude. The horizontal force peak is low by approximately 500 Newtons, while the vertical force peak is approximately 400 Newtons too low. The differences in the end sections of the curves also appear to be magnified, more so than in the model using a moving bar. Clearly it is more accurate to represent the bar as a moving point than to represent it as a fixed point.

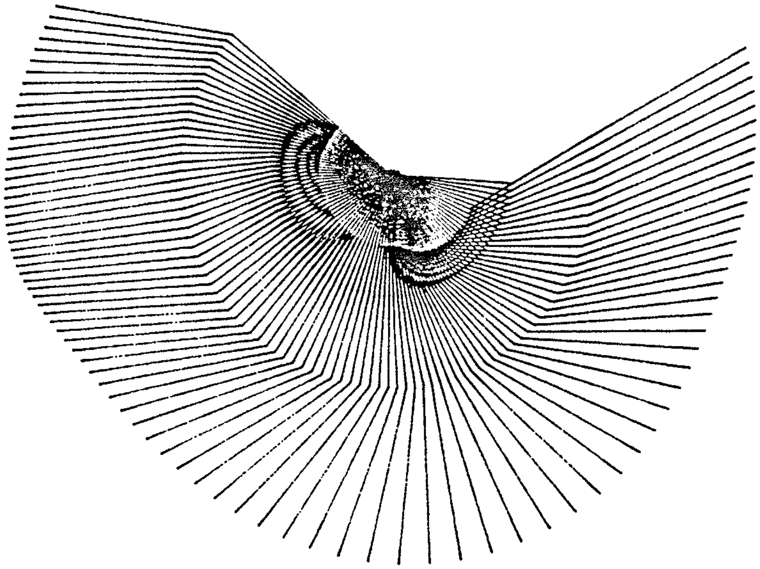


Figure 29: Body positions in a fixed bar model of subject 1, trial 5

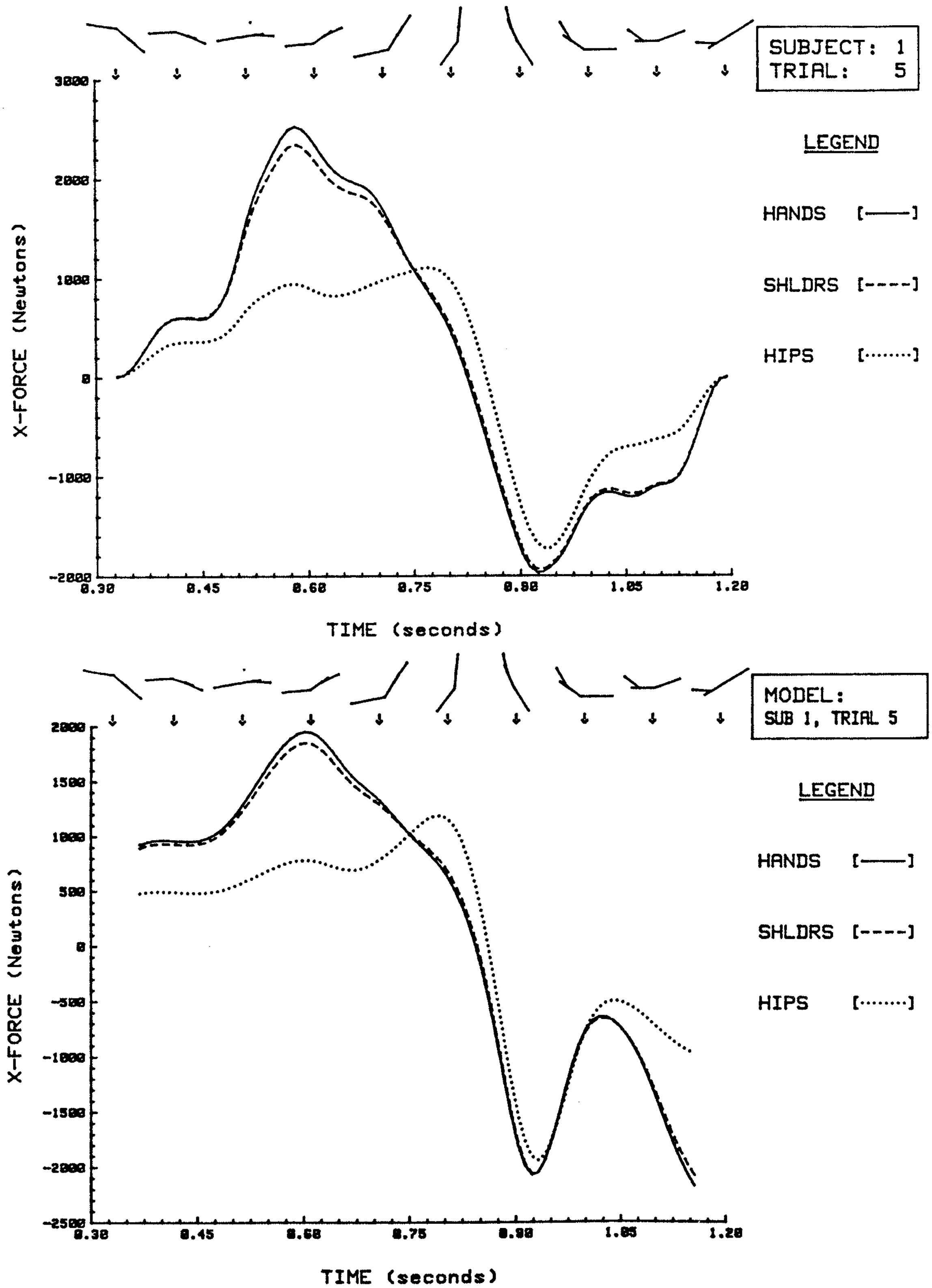


Figure 30: Fixed bar versus spring bar horizontal force data

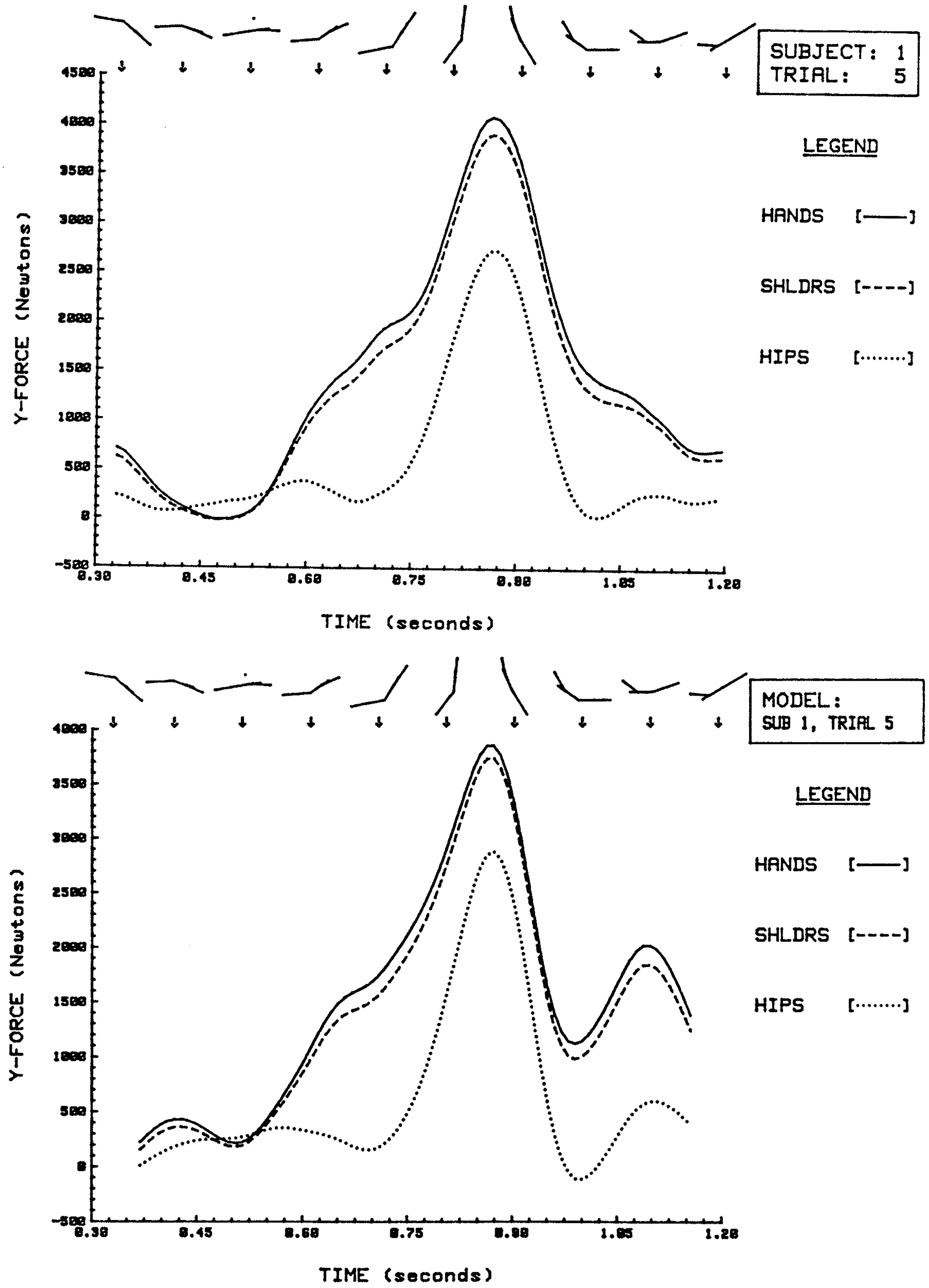


Figure 31: Fixed bar versus spring bar vertical force data

Modifying a Performance

The model was used to produce another performance that was altered slightly. In this case the bar points were input as usual and were not modified. The angular acceleration data for the leg segment was the only input data that was modified. Subject two's second trial was used, and an attempt was made to see whether a stronger hip flexion through the bottom of the swing would improve his performance.

A stronger hip flexion through the bottom was modelled by digitizing a point higher than the actual leg acceleration peak in the original performance. By digitizing a higher value and then interpolating through the higher point a new leg segment angular acceleration curve was created. All the rest of the input data, including the rest of the leg segment angular acceleration data was entered without alterations. The modified versus original angular acceleration curves are presented in figure 32. The new data was then passed through the modelling program to see whether the modification made was an improvement over the original performance.

The first and most noticeable difference in the modified performance can be seen in figure 33, which compares the body positions throughout the modified and original performances. Note how the final body position at release in the modified performance is significantly higher than the origi-

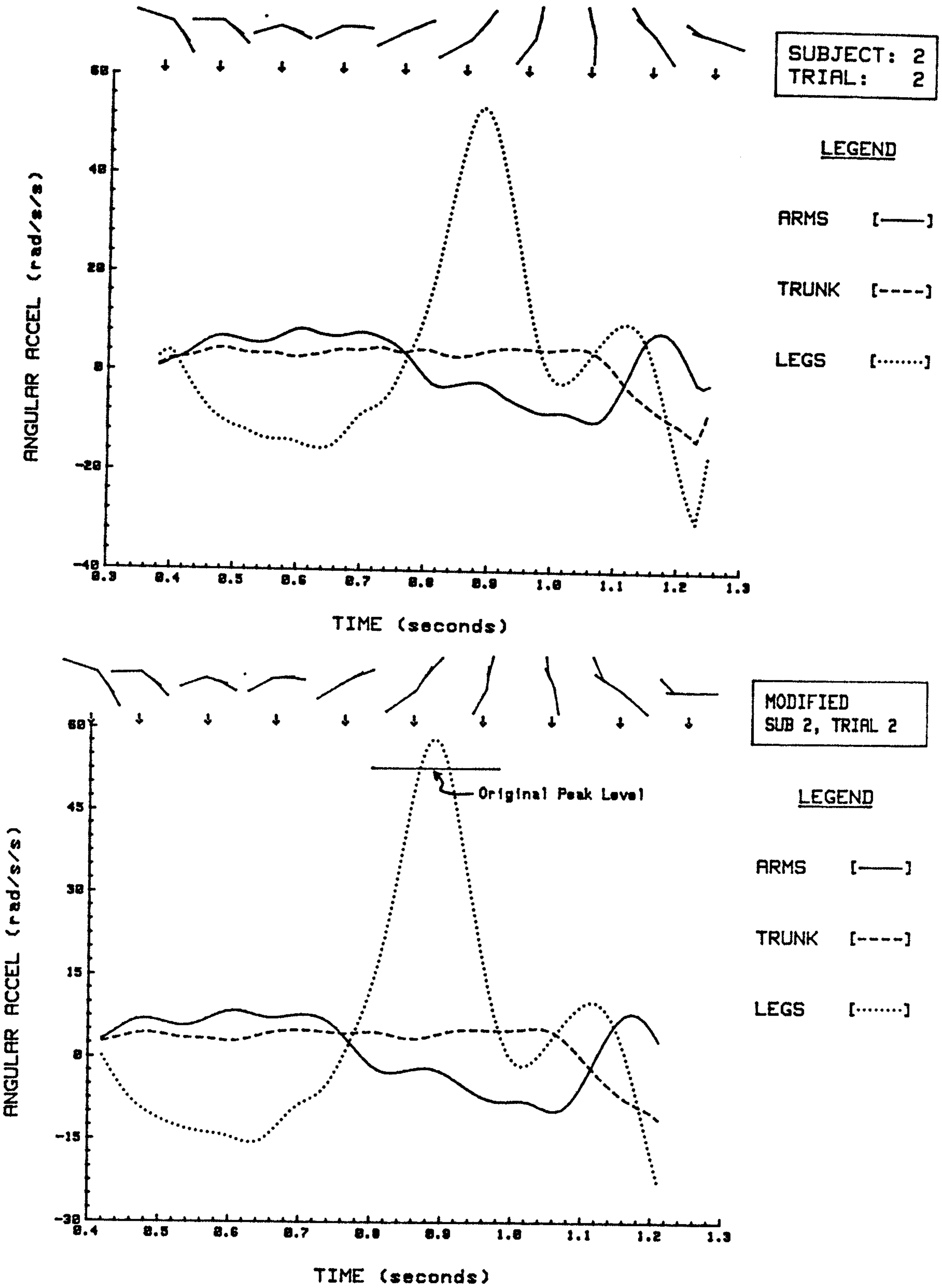
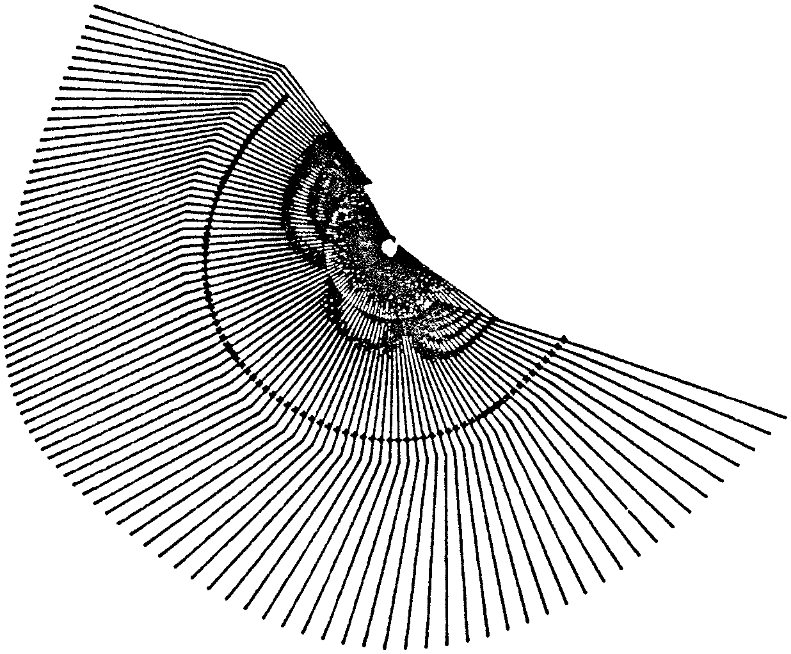


Figure 32: Modified versus actual angular acceleration curves

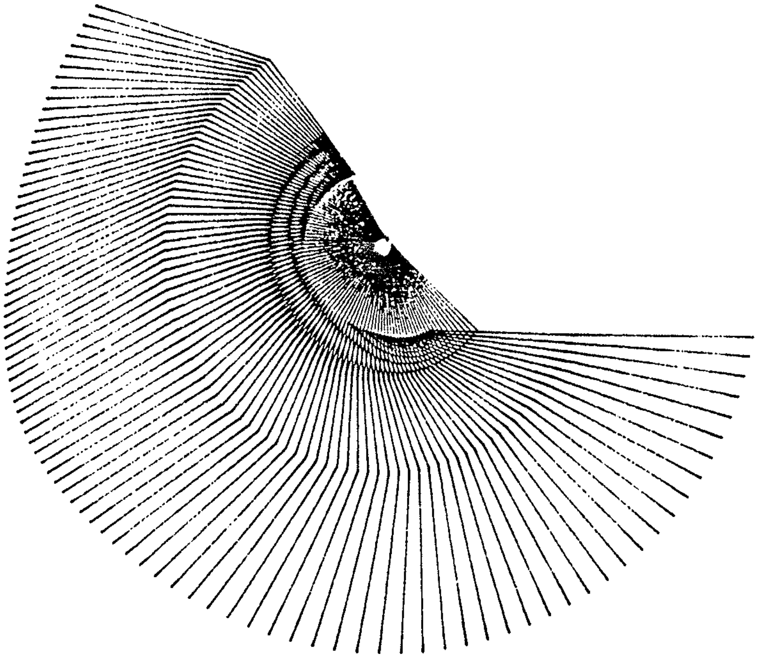
nal performance. This alone is an improvement over the original performance because by releasing with his center of gravity higher the subject would travel more vertically. One of the errors that subject two has in performing the flyaway is releasing while his center of gravity and body angle are too low. Clearly one way of correcting this error might be to hold on to the bar longer and therefore wait until the body is higher before releasing. As this modified performance shows however, another solution could be to flex harder through the bottom of the swing. This action has the same effect without altering the timing of release.

Further investigation revealed that this modified performance exerted more vertical force on the bar as well (see figure 34). This means that with even a moderate increase in the acceleration of the leg segment the forces on the bar, as well as the other joints increase significantly. No doubt there are other changes that could be investigated such as the energy changes in the segments or the velocity of the center of gravity at release, etc.

Note that the differences detected have been produced with only a modest change in the original performance. There are many other modifications to the original performance that could be attempted to see what changes help the performance further. All this can be done without the subject ever touching the bar. Such changes could be shown to the athlete using the graphing subroutine so that the gym-



SUBJECT 2, TRIAL 2



MODIFIED SUBJECT 2, TRIAL 2

Figure 33: Modified versus original body positions

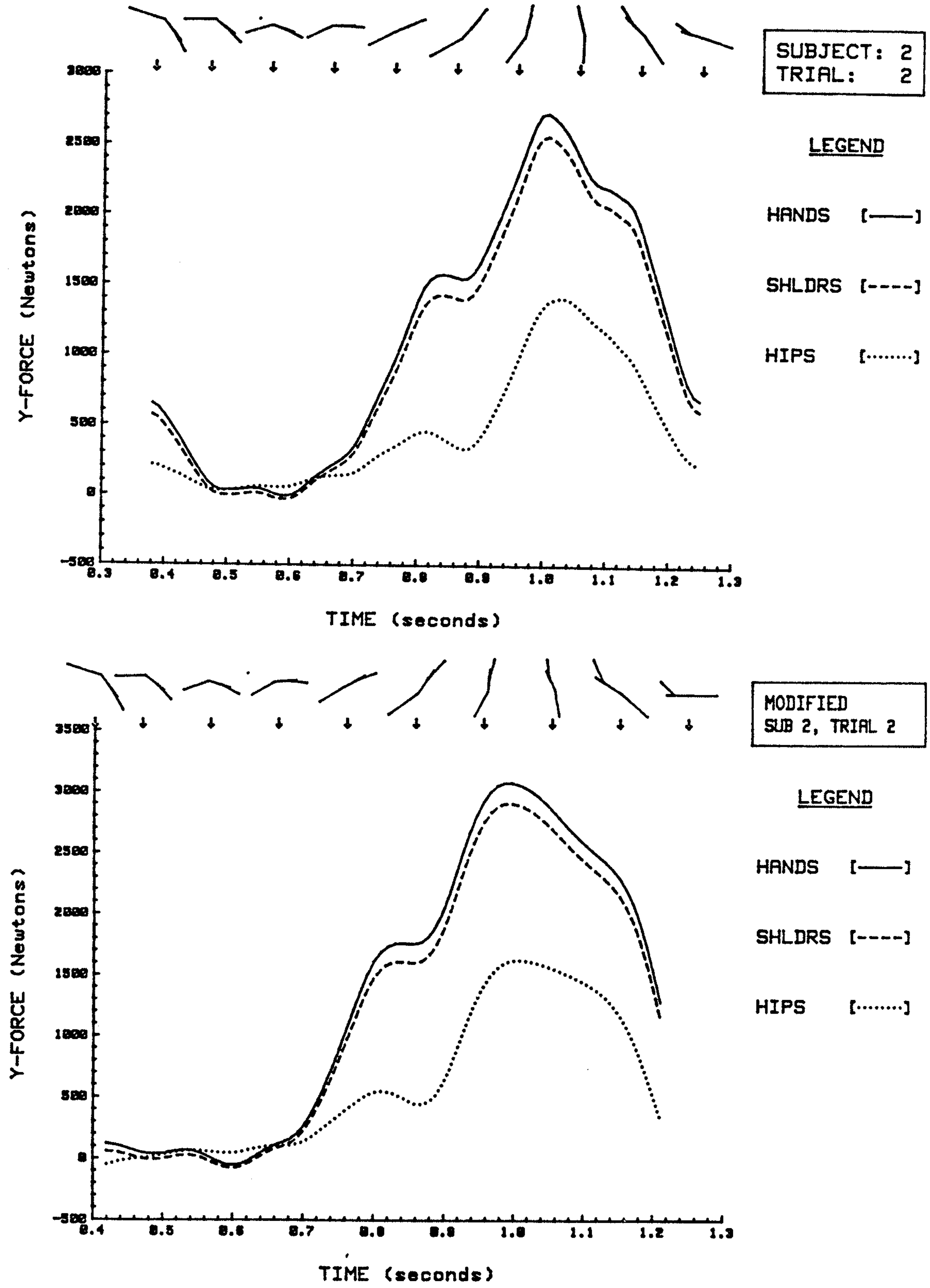


Figure 34: Modified versus original vertical force

nast could see what he is trying to achieve and how the proposed changes have helped. This would be tremendous motivation for the athlete to try the new technique. For the coach the model can be a teaching tool. For the sports scientist the model can be a "subject" that can be easily manipulated to perform test trials. This computer subject is able to make minute changes in performance without altering other factors, allowing the investigator to study very specific types of modifications to the performance in a controlled setting. These modifications could later be presented to the coach or athlete for testing.

SUMMARY AND CONCLUSIONS

Summary

The goal of this study was to develop an understanding of the interactions of the gymnast and the horizontal bar. Following a review of related literature a biomechanical analysis of accelerating giant skills was undertaken from four viewpoints. First, strain gauges were placed onto the horizontal bar to directly measure the forces on the bar. Then two subjects were filmed while performing accelerating giant swings. The films were used to derive positional data on the performances, which were in turn used to calculate the kinematic, kinetic and energy parameters of the performances. Finally a computer program was developed that was capable of modelling the gymnast/bar system.

Based on this study the execution of an accelerating giant swing prior to a flyaway can be described as having five stages. The first stage begins as the gymnast passes over the bar and is characterised by flexion at the hips and an extended position at the shoulders. The second stage consists of an extension action at the hips into a hyperextended position as the gymnast falls in the downswing. This stage is characterised by a decrease in leg segment velocity, a decrease in total force applied to the bar by the gymnast, and a transfer of energy from the legs to the trunk.

The third stage occurs as the gymnast passes under the horizontal bar and consists of a flexion action at the hips. This action is caused by an increase in hip torque and results in an increase in leg segment velocity, as well as an increase in leg segment energy and a corresponding decrease in trunk energy. This exchange of leg segment and trunk segment energy causes a pattern of first increasing and then decreasing total body energy. The flexion action also causes an increase in vertical force applied to the bar and a subsequent increase in the spring energy stored in the bar.

The fourth stage occurs in the last half of the upswing and consists of an extension action at the hips. This action results in a decrease in both the vertical and horizontal force applied to the bar and a decrease in energy stored by the bar. This energy is transferred to the gymnast resulting in an increase in total body energy as both the leg segment and trunk segment energies increase. This action also results in a net velocity of the gymnast that is nearly vertical.

The final stage is simply the release from the bar. In the better performances the gymnast released from the bar with his body nearly level with the bar, and in one case released after his body had passed above the level of the bar.

Conclusions

On the basis of this study the following conclusions appear justified:

1) The interaction of the gymnast and horizontal bar is a significant factor in the execution of accelerating giant swings.

2) The energy exchanges between the gymnast's body segments, as well as between the gymnast and bar appear to be generated by the actions at the hip joint, namely flexion and extension of the leg segment.

3) The analysis revealed a pattern of transfer of angular momentum and energy from the body segments closest to the bar down to the leg segment and then a final transfer of angular momentum and energy back up to the trunk segment just before release from the bar.

4) The gymnast should try to maximize the energy stored in the bar by applying maximum force to the bar by appropriate leg movements.

5) The frequency of the horizontal bar should be close to the forcing frequency of the gymnast to make it most responsive to the actions of the gymnast trying to store energy in the bar.

6) Computer modelling can be used to investigate the results of specific alterations in a performance to try to determine which changes would improve the performance.

Suggestions For Further Investigation

Based on this study the following suggestions are offered for further investigation:

1) Further development of the strain gauge system used in this study should be undertaken to develop a reliable method of obtaining direct measurement of stress on the bar. There will always be differences between the measured forces on the bar, and calculated forces due to the frequency differences between the gymnast and the bar. Calibration should involve forces up to five times the subjects' body weights for optimum accuracy. Also, dynamic application of force on the bar (ie. a swinging pendulum) might allow more accurate calibration.

2) Improvements in the method of representing the gymnast when analysing actual performances could be undertaken to allow for the elastic properties of the shoulder joint in particular. Since the forces on the shoulder girdle are very large in this skill there is a certain amount of lengthening and shortening of the arm segment by shoulder elevation. This movement may be very significant and should be studied in more detail.

3) There are several ways that the computer modelling algorithm could be improved. These are:

a) As with the previous suggestion (2), the elastic properties of the shoulder joint could be incorporated into the program.

b) A more efficient method of integrating the angular acceleration data might be found to derive the segment inclinations.

c) An iterative process could be employed to attempt to more accurately determine the horizontal bar positions based on the spring characteristics of the bar and the forces being applied to it.

4) More basic research is needed to study the spring characteristics of the horizontal bar. Of particular interest might be the damping effect of the cables on the bar. Also, investigations should be undertaken to see whether modifications to the bar might make it more responsive to the beating action (forcing) of the gymnasts. This responsiveness may be adjustable for each individual athlete.

5) Time should be spent to use computer models such as the one developed in this study, to systematically investigate the results of minor changes in performance. Such investigation should strive to isolate the most significant factors contributing to good performance of a skill. This process could be extended to allow the development of new techniques.

Appendix A

EQUATIONS OF MOTION

APPENDIX A

SEGMENT 3 -- Legs

```
Xforce(F,3)=Segmass(3)*Xgaccel(F,3)

Yforce(F,3)=Segmass(3)*Ygaccel(F,3)+Segwt(3)

Moment(F,3)=I(3)*Angaccel(F,3)-SIN(Incline(F,3))*Xgaccel(F,3)*Segmass(3)*Cgdist(3)
              +COS(Incline(F,3))*Ygaccel(F,3)*Segmass(3)*Cgdist(3)
              +COS(Incline(F,3))*Segwt(3)*Cgdist(3)
```

SEGMENT 2 -- Body

```
Xforce(F,2)=Segmass(2)*Xgaccel(F,2)+Xforce(F,3)

Yforce(F,2)=Segmass(2)*Ygaccel(F,2)+Segwt(2)+Yforce(F,3)

Moment(F,2)=I(2)*Angaccel(F,2)-SIN(Incline(F,2))*Xgaccel(F,2)*Segmass(2)*Cgdist(2)
              +COS(Incline(F,2))*Ygaccel(F,2)*Segmass(2)*Cgdist(2)
              +COS(Incline(F,2))*Segwt(2)*Cgdist(2)
              +COS(Incline(F,2))*Yforce(F,3)*Seglen(2)
              -SIN(Incline(F,2))*Xforce(F,3)*Seglen(2)
              +Moment(F,3)
```

SEGMENT 1 -- Arms

```
Xforce(F,1)=Segmass(1)*Xgaccel(F,1)+Xforce(F,2)

Yforce(F,1)=Segmass(1)*Ygaccel(F,1)+Segwt(1)+Yforce(F,2)

Moment(F,1)=I(1)*Angaccel(F,1)-SIN(Incline(F,1))*Xgaccel(F,1)*Segmass(1)*Cgdist(1)
              +COS(Incline(F,1))*Ygaccel(F,1)*Segmass(1)*Cgdist(1)
              +COS(Incline(F,1))*Segwt(1)*Cgdist(1)
              +COS(Incline(F,1))*Yforce(F,2)*Seglen(1)
              -SIN(Incline(F,1))*Xforce(F,2)*Seglen(1)
              +Moment(F,2)
```

VARIABLE LIST:

Xforce(F,i) = Horizontal force at proximal end of segment (i)
Yforce(F,i) = Vertical force at proximal end of segment (i)
Moment(F,i) = Torque about proximal end of segment (i)
Xgacc(F,i) = Horizontal acceleration of segment C of G (i)
Ygacc(F,i) = Vertical acceleration of segment C of G (i)
I(i) = Moment of inertia of segment (i)
Angacc(F,i) = Angular acceleration of segment (i)
Incline(F,i)= Inclination of segment (i)
Segmass(i) = Mass of segment (i)
Segwt(i) = Weight of segment (i)
Cgdist(i) = Distance of segment C of G from proximal endpoint

Appendix B

SUBJECT DATA

APPENDIX B

	SUBJECT ONE:	SUBJECT TWO:
Name:	Paul J. Thiessen	Mike Gifford
Mass (Kg):	74.84	68.04
Height (m):	1.772	1.753
Segment Lengths: (meters)		
Hand:	0.19	0.19
Forearm:	0.27	0.25
Upper:	0.28	0.28
Head & Neck:	0.30	0.37
Trunk:	0.56	0.46
Thigh:	0.39	0.42
Shank:	0.42	0.41
Foot:	0.28	0.27

Appendix C

COMPUTER PROGRAMS

```
10   ! File: ADRD2                                 Cartridge: PJT THESIS DATA
20   ! Date: Dec 22, 1982                          Author: P.J.Thiessen
30   ! Desc: This program uses assembly language to control the A to D
40   ! converter.  Data from two channels are read in at any pace, and
50   ! can be stored.
60   ! ---------------------------------------------------------------------
70   OPTION BASE 1
80   ICOM 0
90   ICOM 25000
100  IASSEMBLE A_to_d_assembly
110  DIM Time(6),Format$[180],Desc$[180]
120  DIM Yi(3),Slope(3),Corr(3),Twt(10),Sample(10)
130  INTEGER Pa,D,Numread,Pace
140  INTEGER Channel1(5000),Channel2(5000),Channel3(5000)
150  Ch1$=CHR$(127)
160  Ch2$="*"
170  Select=704
180  Pa=7
190  ! ---------------------------------------------------------------------
200  !                          M A I N L I N E
210  ! ---------------------------------------------------------------------
220  GOSUB Explain
230  GOSUB Assemble_ready
240  GOSUB Read_ad
250  GOSUB Printout
260  LINPUT "Do you want to store the data [Y/N]",S$
270  IF S$="N" THEN GOTO 290
280     GOSUB Storedata
290  DISP "Program completed"
300  END
310  ! ---------------------------------------------------------------------
320  !                        S U B R O U T I N E S
330  ! ---------------------------------------------------------------------
340 Assemble_ready:!
350        IPAUSE ON
360        IBREAK Ready GOSUB Ready        ! Assembly break when A/D is ready
370        IBREAK Break GOSUB Break        ! Assembly break when CONT'L key hit
380        D=5000                          ! Max. number of values to be read
390        RETURN
400 Explain:!
410        PRINTER IS 16
420        PRINT CHR$(27)&"E";PAGE;TAB(15);" THREE CHANNEL ANALOG TO DIGITAL CONTROL PROGRAM ";LIN(1)
430        PRINT "    This program executes a high speed data transfer from the analog to digital"
440        PRINT "converter on select code 704, to the computer.  An assembly language program is"
450        PRINT "used to transfer the A to D data into three arrays (one for each channel).  The"
460        PRINT "transfer speed can be selected from the list below.  Press the CONT'L key to"
470        PRINT "stop the transfer, otherwise 5000 transfers will be executed.";LIN(1)
480        MAT READ Time
490        DATA 5,10,20,50,100,200
500        PRINT "PACE SETTINGS:";LIN(1)
```

```
510         PRINT ,"Time","Hz","Per channel"
520         FOR I=1 TO 6
530             PRINT "(";VAL$(I);")",Time(I),1000/Time(I),
540             PRINT 1000/Time(I)/2
550         NEXT I
560         STANDARD
570         Pace=1
580         Time=Time(Pace)*2/1000
590         INPUT "Please enter the desired pace [1-6]",Pace
600         Pace$=CHR$(65+Pace)
610         OUTPUT 704 USING "#,K";"H1"&Pace$
620         OUTPUT 704 USING "#,K";"LJ"
630         RESTORE Yidata
640         READ Yi(*)
650         RESTORE Sldata
660         READ Slope(*)
670         INPUT "Do you want to calibrate [Y/N]",Cal$
680         IF Cal$()"Y" THEN GOTO 710
690             GOSUB Calibrate
700         GOTO 730
710             INPUT "Please enter the Yintercept and Slope for channel 1",Yi(1),Slope(1)
720             INPUT "Please enter the Yintercept and Slope for channel 2",Yi(2),Slope(2)
730         INPUT "Do you want to test the system [Y/N]",T$
740         IF T$()"Y" THEN GOTO 770
750             GOSUB Test
760             GOTO 730
770         RETURN
780 Yidata:DATA 0,0,0
790 Sldata:DATA 1,1,1
800 Read_ad:!
810         ICALL A_to_d_read(Pa,D,Pace,Channel1(*),Channel2(*),Numread)
820         IF Break THEN GOTO 850
830             BEEP
840             PRINT "TRANSFER COMPLETED SUCCESSFULLY ";
850         PRINT "Number of values read in:";Numread;"   Time:";(Numread-1)*Time
860         DISP
870         RETURN
880 Printout:!
890         PRINTER IS 16
900         INPUT "Do you want the output on the Screen or Printer [S/P]",Pr$
910         IF Pr$="N" THEN RETURN
920         IF Pr$="P" THEN PRINTER IS 7,0
930         IF Pr$()"P" THEN PRINT CHR$(27)&"E";CHR$(132);" I","  Time","   Channel1","   Channel2";CHR$(128);L
IN(1)
940         IF Pr$="P" THEN PRINT " I","Time","Channel1","Channel2";LIN(1)
950         DISP "Number of values read in:";Numread
960         REDIM Channel1(Numread),Channel2(Numread),Channel3(Numread)
970         FOR I=1 TO Numread
980             PRINT I,
990             FIXED 3
```

```
1000            PRINT (I-1)*Time,
1010            STANDARD
1020            PRINT Channel1(I)*Slope(1)+Yi(1),Channel2(I)*Slope(2)+Yi(2)
1030        NEXT I
1040        RETURN
1050 Storedata:!
1060        LINPUT "Please enter a name for the data file [6 characters]",File$
1070        IF File$="" THEN RETURN
1080        Numrecs=INT(((Numread+1)*8+200)/256)+2
1090        LINPUT "Please enter a description for the file",Desc$
1100        Format$="Format$,Desc$,N,Time,Channel1(N),Channel2(N),Channel3(N),Yi(3),Slope(3),Corr(3)"
1110        DISP "File: ";File$;"    Number of records:";Numrecs;"   -- Insert cartridge then CONTINUE"
1120        PAUSE
1130        ON ERROR GOTO Sterr
1140        CREATE File$,Numrecs
1150        ASSIGN #1 TO File$
1160        PRINT #1;Format$,Desc$,Numread,Time
1170        PRINT #1;Channel1(*)
1180        PRINT #1;Channel2(*)
1190        PRINT #1;Channel3(*)
1200        PRINT #1;Yi(*)
1210        PRINT #1;Slope(*)
1220        PRINT #1;Corr(*)
1230        ASSIGN * TO #1
1240        RETURN
1250 Sterr:BEEP
1260        DISP "Storing error -- ";ERRM$;" (Press CONTINUE to re-store)"
1270        PAUSE
1280        GOTO Storedata
1290 Calibrate:!
1300        PRINT PAGE;" CALIBRATION ";LIN(2)
1310        FOR Channel=1 TO 2
1320            DISP "Please enter the number of test weights to be sampled for channel ";Channel;
1330            INPUT "",Nt
1340            REDIM Twt(Nt)
1350            INPUT "Please enter the weights in order",Twt(*)
1360            FOR T=1 TO Nt
1370                DISP "Please prepare the ";VAL$(Twt(T));" weight -- then CONTINUE"
1380                PAUSE
1390                GOSUB Getavrg
1400                Sample(T)=Average
1410            NEXT T
1420            CALL Lincor(Sample(*),Twt(*),Nt,Xm,Ym,Yi(Channel),Slope(Channel),Corr(Channel))
1430            PRINT "CHANNEL";Channel;"";LIN(2);"Yi =";Yi(Channel),"Slope =";Slope(Channel),"r =";Corr(Chan
nel);LIN(2)
1440        NEXT Channel
1450        RETURN
1460 Getavrg:!
1470        OUTPUT Select USING "#,K";VAL$(Channel)
1480        OUTPUT Select USING "#,K";"J"
```

```
1490       Sm=0
1500       FOR I=1 TO 20
1510           ENTER Select USING "#,W";S
1520           Sm=Sm+S
1530           BEEP
1540       NEXT I
1550       Average=Sm/20
1560       RETURN
1570 Test: OUTPUT Select USING "#,K";"J"
1580       ON KBD GOTO Texit
1590 Loop: OUTPUT Select USING "#,K";"1"
1600       ENTER Select USING "#,W";Ch1
1610       OUTPUT Select USING "#,K";"2"
1620       ENTER Select USING "#,W";Ch2
1630       DISP Ch1*Slope(1)+Y1(1),Ch2*Slope(2)+Y1(2)
1640       PRINT USING "#,K";CHR$(27)&"&a"&VAL$(INT(Ch1/1024*80))&"C"&Ch1$
1650       PRINT USING "#,K";CHR$(27)&"&a"&VAL$(INT(Ch2/1024*80))&"C"&Ch2$
1660       PRINT
1670       GOTO Loop
1680 Texit:OFF KBD
1690       PRINT PAGE;
1700       RETURN
1710 ! ----------------------------------------------------------------------
1720 !                   SUBROUTINES USED BY ASSEMBLY PROGRAM
1730 ! ----------------------------------------------------------------------
1740 Ready:!
1750       DISP "A to D TRANSFER READY -- press CONTINUE to begin data transfer"
1760       PAUSE
1770       BEEP
1780       DISP "A to D TRANSFER EXECUTING -- press CONT’L to terminate transfer"
1790       RETURN
1800 Break:!
1810       BEEP
1820       Break=1
1830       PRINT PAGE;"TRANSFER TERMINATED PREMATURELY ";
1840       RETURN
1850 ! ----------------------------------------------------------------------
1860 !            ASSEMBLY LANGUAGE A TO D CONVERTER FAST READ PROGRAM
1870 ! ----------------------------------------------------------------------
1880 ISOURCE                    NAM A_to_d_assembly   ! MODULE NAME
1890 ! ISOURCE                  LST                   ! List assembled code (supressed)
1900 !
1910 ! EXTERNAL SUBROUTINES (MACROS):
1920 !
1930 ISOURCE                    EXT Get_value,Get_info,Put_element,Error_exit,Put_value,Printer_select,Print_
string
1940 !
1950 ! MEMORY ALLOCATION:
1960 !
1970 ISOURCE                    LIT 1000              ! Literal pool
```

```
1980 ISOURCE Data:              BSS 20010            ! Array for each channel
1990 ISOURCE Point:             BSS 1                ! Pointer for stack oper.
2000 ISOURCE Array1_info:       BSS 30               ! Array information
2010 ISOURCE Element1:          EQU Array1_info+16   ! for each channel
2020 ISOURCE Array2_info:       BSS 30               !
2030 ISOURCE Element2:          EQU Array2_info+16   !
2040 !
2050 ISOURCE Num_elements:      BSS 1                ! Array size
2060 ISOURCE Select_code:       BSS 1                ! Select code of A/D
2070 ISOURCE Highbyte:          BSS 1                ! 1st byte read in
2080 ISOURCE Lowbyte:           BSS 1                ! 2nd byte read in
2090 ISOURCE Value:             BSS 1                ! 16 bit result
2100 ISOURCE Count:             DAT 1                ! Counter
2110 ISOURCE Control:           DAT 3                ! Control key code
2120 ISOURCE Pace:              BSS 1                ! Pace of A/D
2130 ISOURCE One:               BSS 1                ! Channel 1 code
2140 ISOURCE Two:               BSS 1                !    "    2  "
2150 ISOURCE Error_message:     DAT 27,"INTERFACE NOT OPERATIONAL"
2160 ! ------------------------------------------------------------------
2170 !
2180 ! SUBROUTINE: A_to_d_read
2190 !
2200 ISOURCE                    SUB                  ! Pass parameters:
2210 ISOURCE Sc:                INT                  !     Select code
2220 ISOURCE Dim:               INT                  !     Array dimension
2230 ISOURCE Pc:                INT                  !     Pace
2240 ISOURCE Ch1:               INT (*)              !     Channel 1 array
2250 ISOURCE Ch2:               INT (*)              !        "    2  "
2260 ISOURCE Numread:           INT                  !     # of values read in
2270 !
2280 ISOURCE A_to_d_read:       LDA =Select_code     ! Get select code
2290 ISOURCE                    LDB =Sc              !
2300 ISOURCE                    JSM Get_value        !
2310 ISOURCE                    LDA Select_code      !
2320 ISOURCE                    STA Pa               ! Set peripheral address
2330 ISOURCE                    LDA =Num_elements    ! Get array dimension
2340 ISOURCE                    LDB =Dim             !
2350 ISOURCE                    JSM Get_value        !
2360 ISOURCE                    LDA =Pace            ! Get A/D pace
2370 ISOURCE                    LDB =Pc
2380 ISOURCE Setup_arrays:      LDA =Array1_info     ! Get array info on
2390 ISOURCE                    LDB =Ch1             ! each of the arrays
2400 ISOURCE                    JSM Get_info         ! so that they can be
2410 ISOURCE                    LDA =Array2_info     ! filled with the data
2420 ISOURCE                    LDB =Ch2             ! read in and passed back
2430 ISOURCE                    JSM Get_info         ! to BASIC.
2440 ISOURCE                    LDA =Data            ! Set up stack pointer
2450 ISOURCE                    ADA =-1              ! to point at bottom of
2460 ISOURCE                    STA C                ! memory alloc. for data
2470 !
```

```
2480 ISOURCE Ready:            NOP                 ! A break has been set
2490                                               ! up here to pass control
2500                                               ! to BASIC to allow
2510                                               ! manual start
2520 Input:! INPUT LOOP:
2530 !
2540 ISOURCE                   JSM Talk
2550 ISOURCE                   LDA ='J
2560 ISOURCE                   JSM Send
2570 ISOURCE Input:            JSM Listen
2580 ISOURCE                   JSM Read            ! Read in data
2590 ISOURCE                   JSM Talk            !
2600 ISOURCE                   LDA Two             ! Change to channel  2 !
2610 ISOURCE                   JSM Send            ! Send message to change
2620 ISOURCE                   JSM Listen          !
2630 ISOURCE                   JSM Read            ! Read in data
2640 ISOURCE                   JSM Talk            !
2650 ISOURCE                   LDA One             ! Change to channel  1 !
2660 ISOURCE                   JSM Send            ! Send message to change
2670 ISOURCE                   DSZ Num_elements    ! Check if last
2680 ISOURCE                       JMP Interrupt   ! No: check for interrupt
2690 ISOURCE                       JMP Exit        ! Yes: EXIT
2700 ISOURCE Next:             LDA Count           !
2710 ISOURCE                   ADA =1              ! Increment counter
2720 ISOURCE                   STA Count           !
2730 ISOURCE                   JMP Input           ! Next read
2740 !
2750 ISOURCE Exit:             NOP                 ! Exit the program
2760 ISOURCE                   JSM Passdata        ! Pass data to arrays
2770 ISOURCE                   LDA =Count          ! Return the counter
2780 ISOURCE                   LDB =Numread        !
2790 ISOURCE                   JSM Put_value       !
2800 ISOURCE                   RET 1               ! Back to BASIC
2810 ! ---------------------------------------------------------------------
2820 !                      ASSEMBLY SUBROUTINES
2830 ! ---------------------------------------------------------------------
2840 Not_oper:ISOURCE Not_oper: LDA =18            ! Choose SYSTEM display
2850 ISOURCE                   LDB =80             ! as printer
2860 ISOURCE                   JSM Printer_select  !
2870 ISOURCE                   LDA =Error_message  ! Get the error message
2880 ISOURCE                   JSM Print_string    ! and print it
2890 ISOURCE                   NOP                 !
2900 ISOURCE                   NOP                 !
2910 ISOURCE                   JMP Exit            ! Then EXIT
2920 !
2930 Talk:ISOURCE Talk:        NOP
2940 ISOURCE                   LDA ='?             ! Unlisten command
2950 ISOURCE                   SFC *               ! Wait for flag clear
2960 ISOURCE                   STA R6              ! Send unlisten
2970 ISOURCE                   LDA ='U             ! HP talker address
```

```
2980 ISOURCE                     SFC *                 ! Wait for flag clear
2990 ISOURCE                     STA R6                ! Send HP address
3000 ISOURCE                     LDA ='$               ! AD listen address
3010 ISOURCE                     SFC *                 ! Wait for flag clear
3020 ISOURCE                     STA R6                ! Send AD address
3030 ISOURCE                     RET 1
3040 !
3050 Listen:!
3060 ISOURCE Listen:             LDA ='?               ! Untalk address
3070 ISOURCE                     SFC *                 ! Wait for flag clear
3080 ISOURCE                     STA R6                ! Send untalk
3090 ISOURCE                     LDA ='5               ! HP listen address
3100 ISOURCE                     SFC *                 ! Wait for flag clear
3110 ISOURCE                     STA R6                ! Send HP listen address
3120 ISOURCE                     LDA ='D               ! AD talk address
3130 ISOURCE                     SFC *                 ! Wait for flag clear
3140 ISOURCE                     STA R6                ! Send AD talk address
3150 ISOURCE                     RET 1
3160 !
3170 Read:ISOURCE Read:          NOP
3180 ISOURCE                     SFC *                 ! Wait for flag clear
3190 ISOURCE                     LDB R4                ! Trigger handshake
3200 ISOURCE                     SFC *                 ! Wait for flag clear
3210 ISOURCE                     LDB R6                ! Complete handshake
3220 ISOURCE                     SBL 8                 ! Shift data 8 bits left
3230 ISOURCE                     STB Highbyte          ! Store as high byte
3240 ISOURCE                     SFC *                 ! Wait for flag clear
3250 ISOURCE                     LDB R4                ! Trigger 2nd handshake
3260 ISOURCE                     SFC *                 ! Wait for flag clear
3270 ISOURCE                     LDB R6                ! Read in 2nd byte
3280 ISOURCE                     STB Lowbyte           ! Store as low byte
3290 ISOURCE                     LDA Highbyte          ! Combine both bytes
3300 ISOURCE                     IOR Lowbyte           ! using Inclusive OR
3310 ISOURCE                     STA Value             ! Store value
3320 ISOURCE                     PWC A                 ! Push onto stack
3330 ISOURCE                     RET 1
3340 !
3350 Send:ISOURCE Send:          NOP
3360 ISOURCE                     SFC *                 ! Wait for flag clear
3370 ISOURCE                     STA R4                ! Send new channel
3380 ISOURCE Sent:               RET 1
3390 !
3400 Interrupt:ISOURCE Interrupt:NOP
3410 ISOURCE                     LDA =0                ! Set keyboard as
3420 ISOURCE                     STA Pa                ! peripheral address
3430 ISOURCE                     LDA R5                ! Read status
3440 ISOURCE                     CPA Control           ! Was CONT'L pressed
3450 ISOURCE Break:               JMP Exit             ! Yes: EXIT
3460 ISOURCE                     LDA Select_code       ! No: Continue with
3470 ISOURCE                     STA Pa                ! data transfer on select
```

```
3480 ISOURCE                  JMP Next            ! code
3490 !
3500 Passdata:!
3510 ISOURCE Passdata:        LDA =Data           ! Point to data location
3520 ISOURCE                  LDB Pace            ! Check the pace
3530 ISOURCE                  CPB =1              ! IF Pace=1
3540 ISOURCE                      ADA =1          ! THEN skip 1st data pt.
3550 ISOURCE                  STA Point           ! Store pointer
3560 ISOURCE                  LDA Point           ! Transfer data to
3570 ISOURCE                  LDB =Array1_info    ! channel 1 array
3580 ISOURCE                  JSM Put_element     !
3590 ISOURCE                  LDA Point           !
3600 ISOURCE                  ADA =1              ! Increment the pointer
3610 ISOURCE                  STA Point           !
3620 ISOURCE                  LDB =Array2_info    ! Transfer data to
3630 ISOURCE                  JSM Put_element     ! channel 2 array
3640 ISOURCE                  LDA Point           !
3650 ISOURCE                  ADA =1              ! Increment pointer
3660 ISOURCE                  STA Point           !
3670 ISOURCE                  LDB Element1        ! Increment array element
3680 ISOURCE                  ADB =1              ! pointers for each
3690 ISOURCE                  STB Element1        ! of the four arrays
3700 ISOURCE                  STB Element2        !
3710 ISOURCE                  CPB Count           ! Check if more data
3720 ISOURCE                  JMP Stored          ! No: RETURN
3730 ISOURCE                  JMP Passdata+4      ! Yes: Keep going
3740 ISOURCE Stored:          RET 1
3750 !
3760 ISOURCE                  END A_to_d_assembly  ! END OF MODULE
3770 End:!
3780 ! File: Lincor                Cartridge: DATA SMOOTHING
3790 ! Date: Fall, 1982            Author: P.J. Thiessen
3800 ! Desc:  Subprogram accepts two arrays (X,Y) for which it calculates the
3810 ! line of best fit, and also returns the correlation coefficient.  The line
3820 ! can be recreated using the formula Y=Slope * X + Yintercept.
3830 ! Keys: LINEAR REGRESSION,LEAST SQUARES LINE,STATS,CORRELATION,NUMANL,SUB
3840 ! -----------------------------------------------------------------------
3850 SUB Lincor(X(*),Y(*),N,X_mean,Y_mean,Yintercept,Slope,Correlation)
3860 Sum_xy=Sum_x=Sum_y=Sum_xsqr=0
3870 FOR I=1 TO N
3880     Sum_xy=Sum_xy+X(I)*Y(I)
3890     Sum_x=Sum_x+X(I)
3900     Sum_y=Sum_y+Y(I)
3910     Sum_xsqr=Sum_xsqr+X(I)^2
3920     Sum_ysqr=Sum_ysqr+Y(I)^2
3930 NEXT I
3940 Ss_x=Sum_xsqr-Sum_x^2/N
3950 Ss_y=Sum_ysqr-Sum_y^2/N
3960 Ss_xy=Sum_xy-Sum_x*Sum_y/N
3970 X_mean=Sum_x/N
```

```
3980 Y_mean=Sum_y/N
3990 Slope=Ss_xy/Ss_x
4000 Yintercept=Y_mean-Slope*X_mean
4010 Correlation=Ss_xy/SQR(Ss_x*Ss_y)
4020 SUBEND
```

```
5    ! File: HBKIN2                  Cartridge: PJT THESIS PROGRAMS (3)
10   ! Date: June, 1983              Author: P.J.Thiessen
15   ! Desc:  This program calculates the kinematic, kinetic and energy data
20   ! of a three segment rigid body model of a gymnast using smoothed coord.
25   ! Keys: KINET,KINMAT,ENERGY,DYNAMIC,HIGH BAR,PJT
30   ! -----------------------------------------------------------------------
35   DIM Format$[180],Descrfile$[180],File$[6]
40   STANDARD
45   PRINT CHR$(27)&"E";PAGE;"";TAB(18);" HORIZONTAL BAR DYNAMIC ANALYSIS PROGRAM ";TAB(80);""
50   INPUT "Please enter the name of the data file ",File$
55   DISP "Please insert the data cartridge -- then CONTINUE"
60   PAUSE
65   ASSIGN #1 TO File$,Rerr
70   IF NOT Rerr THEN GOTO 95
75      BEEP
80      DISP " ERROR :  File ";File$;" not listed on this cartridge"
85      WAIT 2000
90      GOTO 60
95   READ #1;Format$,Descrfile$,N
100  Subject=VAL(File$[3;1])
105  Film=VAL(File$[4;1])
110  Skill=VAL(File$[5;1])
115  Trial=VAL(File$[6;1])
120  IF (Skill=2) AND (Subject=1) THEN Trial=5
125  PRINT "File  : ";File$,"   Subject:";Subject;"   Trial:";Trial;""
130  IF LEN(Format$)<70 THEN GOTO 145
135     PRINT "Format: ";Format$[1;70]
140  GOTO 150
145     PRINT "Format: ";Format$
150  PRINT "Desc  : ";Descrfile$
155  PRINT "Frames:";N;
160  F=1
165  L=N
170  DISP "Allocating memory (N=";N;")"
175  CALL Hbkin(File$,#1,Format$,Descrfile$,N,Subject,Trial)
180  END
185  ! -----------------------------------------------------------------------
190 Hbkin:SUB Hbkin(File$,#1,Format$,Descrfile$,N,Subject,Trial)
195  OPTION BASE 1
200  DIM Name$[40],Seglen(1:8)
205  DIM Xpt(N,5),Ypt(N,5)
210  DIM Xg(N,3),Yg(N,3),Xtg(N,1),Ytg(N,1)
215  DIM Xvel(N,5),Yvel(N,5),Xacc(N,5),Yacc(N,5)
220  DIM Xgvel(N,3),Ygvel(N,3),Xgacc(N,3),Ygacc(N,3)
225  DIM Xtgvel(N,1),Ytgvel(N,1),Xtgacc(N,1),Ytgacc(N,1)
230  DIM Incline(N,3),Angvel(N,3),Angacc(N,3)
235  SHORT Segpercent(1:3),Radgyration(1:3),Cgdist(1:3)
240  SHORT Segmass(1:3),Segwt(1:3),I(1:3)
245  DIM Xforce(N,4),Yforce(N,4),Moment(N,4),Energy(N,3),Tot_e(N,1),Bar_e(N,1)
250  DIM Scale(4),Loc(4),Opt$[40],Leg$(5)[40],Xaxis$[40],Yaxis$[40],Title$[100]
```

```
255  DIM X(N,5),Y(N,5),Time(N,5),Foot$[100],Var(5)
260  INTEGER F(10)
265 Km: PRINTER IS 16 ! (Screen)
270     Cutoff=.5
275     Check=0
280     GOSUB Coord_data
285     GOSUB Sub_data
290     GOSUB Calc_seg_inc
295     GOSUB Calc_seg_cg
300     GOSUB Calc_tot_cg
305     GOSUB Kinematics
310 Kn: GOSUB Getinertias
315     GOSUB Kinetics
320 E:  GOSUB Energy
325 Grf:GOSUB Graphdata
330     INPUT "Do you want the data printed out [Y/N]",Print$
335     IF Print$<>"Y" THEN GOTO 355
340     GOSUB Printkinematics
345     GOSUB Printkinetics
350     GOSUB Printenergy
355     DISP "Analysis Completed."
360     PAUSE
365     GOTO 355
370  SUBEND
375 Sub_data:IF Subject=1 THEN RESTORE Pjt
380          IF Subject=2 THEN RESTORE Mg
385          READ Name$,Mass,Height,Seglen(*)
390          RETURN
395 Coord_data:RESTORE Ordpts
400          Numfrms=N
405          READ #1;Fr,Initime,Numpts,Cfact,Time
410          PRINT "(";VAL$(Fr);" to ";VAL$(N+Fr-1);")"
415          PRINT "Points:";Numpts
420          PRINT "Cfact :";Cfact;LIN(1);"Time  : Initial=";Initime,"Per frame=";Time;LIN(1);"";TAB(80);"
"
425          PRINT LIN(1);"Operations Completed:";LIN(1);CHR$(27)&"l";PAGE
430          DISP "Reading in coordinate data"
435          READ #1;Xpt(*)
440          READ #1;Ypt(*)
445          PRINT "o  Coordinate data read in."
450          DISP "Creating time array"
455          FOR F=1 TO N
460              FOR S=1 TO 5
465                  Time(F,S)=Initime+(F-1)*Time
470              NEXT S
475          NEXT F
480          PRINT "o  Time array created."
485          DISP
490          RETURN
495 Alarm: FOR B=1 TO 150
```

```
500             BEEP
505         NEXT B
510         RETURN
515 Calc_seg_cg:DISP "Calculating segment C of G coordinates"
520         RESTORE Cgdist
525         READ Cgdist(1),Cgdist(2),Cgdist(3)
530         RESTORE Endpts
535         FOR S=1 TO 3
540             READ Prox,Distal
545             FOR F=1 TO N
550                 Xg(F,S)=(Xpt(F,Distal)-Xpt(F,Prox))*Cgdist(S)+Xpt(F,Prox)
555                 Yg(F,S)=(Ypt(F,Distal)-Ypt(F,Prox))*Cgdist(S)+Ypt(F,Prox)
560             NEXT F
565         NEXT S
570         PRINT "o  Segment C of G coordinates calculated."
575         DISP
580         RETURN
585 Calc_tot_cg: DISP "Calculating total body C of G coordinates"
590         RESTORE Segperc
595         READ Segpercent(*)
600         FOR F=1 TO N
605             Xtg(F,1)=Ytg(F,1)=0
610             FOR S=1 TO 3
615                 Xtg(F,1)=Xtg(F,1)+Xg(F,S)*Segpercent(S)
620                 Ytg(F,1)=Ytg(F,1)+Yg(F,S)*Segpercent(S)
625             NEXT S
630         NEXT F
635         PRINT "o  Total body C of G coordinates calculated."
640         DISP
645         RETURN
650 Kinematics:!
655         FOR I=1 TO 5
660             DISP "Differentiating I=";I;""
665             CALL Velacc(Xpt(*),Xvel(*),Xacc(*),Numfrms,I,Time)
670             CALL Velacc(Ypt(*),Yvel(*),Yacc(*),Numfrms,I,Time)
675             IF I>3 THEN GOTO 695
680                 CALL Velacc(Xg(*),Xgvel(*),Xgacc(*),Numfrms,I,Time)
685                 CALL Velacc(Yg(*),Ygvel(*),Ygacc(*),Numfrms,I,Time)
690                 CALL Velacc(Incline(*),Angvel(*),Angacc(*),Numfrms,I,Time)
695         NEXT I
700         DISP "Differentiating total body C of G"
705         CALL Velacc(Xtg(*),Xtgvel(*),Xtgacc(*),Numfrms,1,Time)
710         CALL Velacc(Ytg(*),Ytgvel(*),Ytgacc(*),Numfrms,1,Time)
715         PRINT "o  Kinematic analysis completed."
720         DISP
725         RETURN
730 Calc_seg_inc:!
735         DISP "Calculating segment inclinations"
740         RESTORE Endpts
745         FOR S=1 TO 3
```

```
750            READ Prox,Distal
755            CALL Incline(N,Xpt(*),Ypt(*),Incline(*),Prox,Distal,S,0)
760        NEXT S
765        PRINT "o  Segment inclinations calculated."
770        DISP
775        RETURN
780 Getprintereody: BEEP
785        PRINTER IS 7,0,WIDTH(132)
790        OUTPUT 700;CHR$(27)&"n"
795        Status=PPOLL(7)
800        IF BIT(Status,7) THEN GOTO 820
805            BEEP
810            DISP "Please turn printer ON-LINE"
815            GOTO 795
820        DISP
825        RETURN
830 Printfiledata: PRINT Time$;LIN(2)
835        PRINT "File: ";File$
840        PRINT "Desc: ";Descrfile$
845        PRINT "Frames:";Fr;"to";L
850        PRINT "Time:";Time
855        PRINT "Spline Cutoff: ";Cutoff
860        PRINT LIN(2)
865        RETURN
870 Printkinematics: GOSUB Getprintereody
875        DISP "Printing Kinematics"
880        PRINT "KINEMATIC DATA  (Linear Units  = meters,  m/sec,   m/s/s)"
885        PRINT RPT$(CHR$(127),14);"  (Angular Units = radians, rad/sec, rad/s/s)";LIN(2)
890        OUTPUT 9;"R"
895        ENTER 9;Time$
900        GOSUB Printfiledata
905        FOR P=1 TO 5
910            PRINT "POINT ";P;LIN(1);"Frame","Point (X,Y)","Velocity (X,Y)","Accel (X,Y)"
915            FOR F=1 TO N
920                PRINT F+Fr-1;
925                FIXED 5
930                PRINT Time(F,1),Xpt(F,P);Ypt(F,P),Xvel(F,P);Yvel(F,P),Xacc(F,P);Yacc(F,P)
935                STANDARD
940            NEXT F
945            PRINT LIN(1)
950        NEXT P
955        PRINT LIN(2)
960        FOR S=1 TO 3
965            PRINT "SEG CG";S;LIN(1);"Frame","Point (X,Y)","Velocity (X,Y)","Accel (X,Y)"
970            FOR F=1 TO N
975                PRINT F+Fr-1;
980                FIXED 5
985                PRINT Time(F,1),Xg(F,S);Yg(F,S),Xgvel(F,S);Ygvel(F,S),Xgacc(F,S);Ygacc(F,S)
990                STANDARD
995            NEXT F
```

```
1000            PRINT LIN(1)
1005        NEXT S
1010        PRINT LIN(2)
1015        FOR S=1 TO 3
1020            PRINT "SEG INCLINE";S;LIN(1);"Frame","Incline","Ang Velocity","Ang Acceleration"
1025            FOR F=1 TO N
1030                PRINT F+Fr-1;
1035                PRINT Time(F,1),Incline(F,S),Angvel(F,S),Angacc(F,S)
1040            NEXT F
1045            PRINT LIN(1)
1050        NEXT S
1055        PRINT LIN(2)
1060        PRINT "TOTAL CG";LIN(1);"Frame","Point (X,Y)","Velocity (X,Y)","Accel (X,Y)"
1065        FOR F=1 TO N
1070            PRINT F;
1075            FIXED 5
1080            PRINT Time(F,1),Xtg(F,1);Ytg(F,1),Xtgvel(F,1);Ytgvel(F,1),Xtgacc(F,1);Ytgacc(F,1)
1085            STANDARD
1090        NEXT F
1095        PRINT LIN(10)
1100        PRINTER IS 16
1105        RETURN
1110 Plotpoints:DISP "Scaling the plotter"
1115        PLOTTER IS 7,5,"9872A"
1120        LOCATE 20,110,10,100
1125        Xx=Yx=-9E99
1130        Xm=Ym=9E99
1135        FOR F=1 TO N
1140            FOR P=1 TO 5
1145                Xx=MAX(Xx,Xpt(F,P))
1150                Yx=MAX(Yx,Ypt(F,P))
1155                Xm=MIN(Xm,Xpt(F,P))
1160                Ym=MIN(Ym,Ypt(F,P))
1165            NEXT P
1170        NEXT F
1175        BEEP
1180        FIXED 6
1185        DISP "READY -- press CONTINUE (";Xm;Xx;Ym;Yx;")"
1190        STANDARD
1195        SHOW Xm,Xx,Ym,Yx
1200        PAUSE
1205        DISP "Plotting the coordinate points"
1210        FOR F=1 TO N
1215            RESTORE Plotpts
1220            READ Numplot
1225            FOR I=1 TO Numplot
1230                READ Pt
1235                IF Pt>=0 THEN PLOT Xpt(F,Pt),Ypt(F,Pt)
1240                IF Pt<0 THEN PENUP
1245            NEXT I
```

```
1250            PENUP
1255            CSIZE 1.5
1260            LORG 5
1265            IF SUM(Xg)=0 THEN GOTO 1280
1270            MOVE Xtg(F,1),Ytg(F,1)
1275            LABEL "+"
1280        NEXT F
1285        SETGU
1290        CSIZE 3
1295        MOVE 65,7
1300        LORG 6
1305        LABEL "SUBJECT ";VAL$(Subject);", TRIAL ";VAL$(Trial)
1310        DISP
1315        RETURN
1320 Plotpts:DATA 7,1,2,3,-1,2,4,5
1325 Getinertias:DISP "Calculating the inertia values"
1330        Gravity=9.81
1335        RESTORE Radgyr
1340        REDIM Radgyration(1:3)
1345        READ Radgyration(*)
1350        FOR S=1 TO 3
1355            Segmass(S)=Mass*Segpercent(S)
1360            Segwt(S)=Segmass(S)*Gravity
1365            I(S)=Radgyration(S)^2*Segmass(S)   ! I=k^2m
1370        NEXT S
1375        DISP
1380        RETURN
1385 Kinetics:!
1390        FOR F=1 TO Numfrms
1395            DISP "Calculating segment kinetics for frame";F;""
1400            !  SEGMENT 3 -- Legs
1405            Xforce(F,3)=Segmass(3)*Xgacc(F,3)
1410            Yforce(F,3)=Segmass(3)*Ygacc(F,3)+Segwt(3)
1415            Moment(F,3)=I(3)*Angacc(F,3)-SIN(Incline(F,3))*Xgacc(F,3)*Segmass(3)*Cgdist(3)
1420            Moment(F,3)=Moment(F,3)+COS(Incline(F,3))*Ygacc(F,3)*Segmass(3)*Cgdist(3)
1425            Moment(F,3)=Moment(F,3)+COS(Incline(F,3))*Segwt(3)*Cgdist(3)
1430            !  SEGMENT 2 -- Body
1435            Xforce(F,2)=Segmass(2)*Xgacc(F,2)+Xforce(F,3)
1440            Yforce(F,2)=Segmass(2)*Ygacc(F,2)+Segwt(2)+Yforce(F,3)
1445            Moment(F,2)=I(2)*Angacc(F,2)-SIN(Incline(F,2))*Xgacc(F,2)*Segmass(2)*Cgdist(2)
1450            Moment(F,2)=Moment(F,2)+COS(Incline(F,2))*Ygacc(F,2)*Segmass(2)*Cgdist(2)
1455            Moment(F,2)=Moment(F,2)+COS(Incline(F,2))*Segwt(2)*Cgdist(2)
1460            Moment(F,2)=Moment(F,2)+COS(Incline(F,2))*Yforce(F,3)*Seglen(2)
1465            Moment(F,2)=Moment(F,2)-SIN(Incline(F,2))*Xforce(F,3)*Seglen(2)
1470            Moment(F,2)=Moment(F,2)+Moment(F,3)
1475            !  SEGMENT 1 -- Arms
1480            Xforce(F,1)=Segmass(1)*Xgacc(F,1)+Xforce(F,2)
1485            Yforce(F,1)=Segmass(1)*Ygacc(F,1)+Segwt(1)+Yforce(F,2)
1490            Moment(F,1)=I(1)*Angacc(F,1)-SIN(Incline(F,1))*Xgacc(F,1)*Segmass(1)*Cgdist(1)
1495            Moment(F,1)=Moment(F,1)+COS(Incline(F,1))*Ygacc(F,1)*Segmass(1)*Cgdist(1)
```

```
1500            Moment(F,1)=Moment(F,1)+COS(Incline(F,1))*Segwt(1)*Cgdist(1)
1505            Moment(F,1)=Moment(F,1)+COS(Incline(F,1))*Yforce(F,2)*Seglen(1)
1510            Moment(F,1)=Moment(F,1)-SIN(Incline(F,1))*Xforce(F,2)*Seglen(1)
1515            Moment(F,1)=Moment(F,1)+Moment(F,2)
1520        NEXT F
1525        PRINT "o  Segment kinetics calculated."
1530        DISP
1535        RETURN
1540 Printkinetics:GOSUB Getprinteready
1545        DISP "Printing Kinetics"
1550        PRINT "KINETIC DATA  (Units = Newtons & Newton x meters)"
1555        PRINT RPT$(CHR$(127),12);LIN(2)
1560        GOSUB Printfiledata
1565        FOR S=1 TO 3
1570            PRINT "SEGMENT";S;LIN(1);"Frame","Xforce","Yforce","Moment"
1575            FOR F=1 TO Numfrms
1580                PRINT F+Fr-1;Time(F,1),Xforce(F,S),Yforce(F,S),Moment(F,S)
1585            NEXT F
1590            PRINT LIN(1)
1595        NEXT S
1600        PRINT LIN(3);"SUBJECT DATA:";LIN(1);RPT$(CHR$(127),12);LIN(2)
1605        PRINT LIN(1);"Radius of Gyration:";Radgyration(*);
1610        PRINT LIN(2);"Segment Masses:    ";Segmass(*);
1615        PRINT LIN(2);"Segment Weights:   ";Segwt(*);
1620        PRINT LIN(2);"CofG Distances:    ";Cgdist(*);
1625        PRINT LIN(2);"Moment of Inertias:";I(*);LIN(10)
1630        PRINTER IS 16
1635        RETURN
1640 Energy:DISP "Calculating the energy data"
1645        FOR F=1 TO N
1650            DISP "Calculating the energy data F=";F;""
1655            FOR S=1 TO 3
1660                Potential=Segmass(S)*9.81*Yg(F,S)+2.59  ! P.E. = mgh
1665                Linvel=SQR(Xgvel(F,S)^2+Ygvel(F,S)^2)
1670                Translate_ke=Segmass(S)*Linvel^2/2      ! K.E.t = (mv^2)/2
1675                Rotate_ke=I(S)*Angvel(F,S)^2/2          ! K.E.r = (Iw^2)/2
1680                Energy(F,S)=Potential+Translate_ke+Rotate_ke
1685                Tot_e(F,1)=Tot_e(F,1)+Energy(F,S)
1690            NEXT S
1695            Bar_ex=28238*Xpt(F,1)^2/2                   ! S.E.x = (Kx^2)/2
1700            Bar_ey=28238*Ypt(F,1)^2/2                   ! S.E.y = (Ky^2)/2
1705            Bar_e(F,1)=SQR(Bar_ex^2+Bar_ey^2)             ! S.E. total
1710        NEXT F
1715        PRINT "o  Energy analysis completed."
1720        RETURN
1725 Printenergy:GOSUB Getprinteready
1730        DISP "Printing Energy data'
1735        PRINT "ENERGY ANALYSIS (Units = joules)"
1740        PRINT RPT$(CHR$(127),15);LIN(2)
1745        GOSUB Printfiledata
```

```
1750       PRINT "Frame,Time","Segment 1","Segment 2","Segment 3","Total"
1755       FOR F=1 TO N
1760           PRINT F+Fr-1;Time(F,1),
1765           FOR S=1 TO 3
1770               PRINT Energy(F,S),
1775           NEXT S
1780           PRINT Tot_e(F,1)
1785       NEXT F
1790       PRINT LIN(2);"SPRING ENERGY"
1795       PRINT "Frame,Time","Bar Energy"
1800       FOR F=1 TO N
1805           PRINT F+Fr-1;Time(F,1),Bar_e(F,1)
1810       NEXT F
1815       PRINT LIN(5)
1820       PRINTER IS 16
1825       RETURN
1830 Graphdata:FOR S=1 TO 5
1835           Var(S)=S
1840       NEXT S
1845       ON ERROR GOTO Getline
1850           F=-1
1855           GOSUB Xaxis
1860           Xline$=VAL$(ERRL)
1865           GOSUB Yaxis
1870           Yline$=VAL$(ERRL)
1875       OFF ERROR
1880       PRINT CHR$(27)&"E";PAGE;"";TAB(29);"DATA GRAPHING PROCEDURE";TAB(80);"";LIN(1)
1885       PRINT "Please choose one of the following sets of data by entering the appropriate"
1890       PRINT "number (Note: 0=EXIT, 29=Plot stick figures)";LIN(1)
1895       RESTORE Grfdata
1900       FOR Opt=0 TO 29
1905           READ Opt$
1910           Optn$=" "&VAL$(Opt)&" "
1915           IF LEN(Optn$)=3 THEN Optn$=" "&Optn$
1920           IF Opt<10 THEN PRINT CHR$(27);"&a0C";Optn$;" ";Opt$
1925           IF (Opt>9) AND (Opt<20) THEN PRINT CHR$(27);"&a30C";Optn$;" ";Opt$
1930           IF Opt>19 THEN PRINT CHR$(27);"&a60C";Optn$;" ";Opt$
1935           IF (Opt=9) OR (Opt=19) THEN PRINT CHR$(27);"&a1c4R"
1940       NEXT Opt
1945       PRINT "";RPT$(" ",78);"";LIN(1);CHR$(27)&"1"
1950 Regraph:PRINT PAGE;LIN(1);
1955       GOSUB Alarm
1960       Ax$="X"
1965       Nt=0
1970       FOR I=1 TO 2
1975           DISP "Please enter the number of the data set for the ";Ax$;"-AXIS";" (0=EXIT)";
1980           INPUT "",Set
1985           IF (I=1) AND (Set<>1) THEN Nt=1
1990           IF Set=0 THEN RETURN
1995           IF Set<>29 THEN GOTO 2010
```

```
2000              GOSUB Plotpoints
2005              GOTO Regraph
2010          RESTORE Axlabel
2015          FOR J=1 TO Set
2020              IF Ax$="X" THEN READ Xaxis$
2025              IF Ax$="Y" THEN READ Yaxis$
2030          NEXT J
2035          PRINT Ax$;"-axis:  ";
2040          IF Ax$="X" THEN PRINT Xaxis$;
2045          IF Ax$="Y" THEN PRINT Yaxis$;
2050          IF (Set=1) OR (Set>18) THEN RESTORE Seg1
2055          IF (Set>1) AND (Set<8) THEN RESTORE Seg2
2060          IF (Set>7) AND (Set<18) THEN RESTORE Seg3
2065          IF (Set>17) AND (Set<21) THEN RESTORE Seg4
2070          IF Set>20 THEN RESTORE Seg5
2075          READ Nv
2080          IF Nv>1 THEN GOTO 2095
2085              Leg$(1)=""
2090          GOTO 2145
2095              DISP "Variables=";Nv;"  Enter a new value or press CONTINUE";
2100              INPUT "",Nv
2105              FOR S=1 TO Nv
2110                  READ Leg$(S)
2115              NEXT S
2120 Seg1:    DATA 1,""
2125 Seg2:    DATA 5,HANDS,SHLDRS,HEAD,HIPS,TOES
2130 Seg3:    DATA 3,ARMS,TRUNK,LEGS
2135 Seg4:    DATA 3,HANDS,SHLDRS,HIPS
2140 Seg5:    DATA 1,COFG
2145          PRINT TAB(37);Nv;"Data sets: ";
2150          FOR S=1 TO Nv
2155              PRINT Leg$(S);",";
2160              IF S=Nv THEN PRINT "";
2165          NEXT S
2170          PRINT LIN(1);
2175          RESTORE Grfdata
2180          FOR Opt=0 TO Set
2185             READ Opt$
2190          NEXT Opt
2195          IF I=1 THEN Opt$=Xline$&" Xaxis:       X(F,S)="&Opt$&"(F,S)"
2200          IF I=2 THEN Opt$=Yline$&" Yaxis:       Y(F,S)="&Opt$&"(F,S)"
2205          EDIT "Please press  STORE  then  CONTINUE  ....",Opt$
2210          Ax$="Y"
2215      NEXT I
2220      EDIT "Please enter a title for the graph",Title$
2225      EDIT "Please enter a footnote for the graph",Foot$
2230      INPUT "Enter the graphing option [0=Auto,1=Manual scale,2=Pause,3=Manual & Pause]",Option
2235      FOR F=1 TO N
2240          FOR S=1 TO Nv
2245 Xaxis:       X(F,S)=Time(F,S)
```

```
2250 Yaxis:       Y(F,S)=Xpt(F,S)
2255            NEXT S
2260        NEXT F
2265 Callgrf:CALL Autograph(N,Nv,X(*),Y(*),Var(*),Scale(*),Loc(*),Xaxis$,Yaxis$,Leg$(*),Title$,Foot$,Option)
2270        GOSUB Labelsub
2275        IF Nt OR (Title$<>"") THEN GOTO Regraph
2280 Tracings:RESTORE 2290
2285        READ F(*)
2290        DATA 1,10,20,30,40,50,60,70,80,90
2295 Callgt:CALL Graphtrace(Xpt(*),Ypt(*),Time(*),Scale(*),Loc(*),Numfrms,5,10,F(*))
2300        GOTO Regraph
2305        RETURN
2310 Labelsub:PLOTTER IS "9872A"
2315        MOVE 116,95
2320        LORG 3
2325        LABEL "SUBJECT:";Subject
2330        LABEL "TRIAL:  ";Trial
2335        LOCATE 114,137,88,97
2340        FRAME
2345        RETURN
2350 Getline:RETURN
2355 ! -------------------- D A T A   S T A T E M E N T S -----------------
2360 !              1    2    3   ! Segments (Arms, Head & trunk, Legs)
2365 Ordpts: DATA  0,3,4,5,7      ! Endpts from data file
2370 Endpts: DATA  2,1, 2,4, 4,5  ! Segment endpoint (Prox,Dist)
2375 Cgdist: DATA .512,.280,.434  ! Distance of seg CG from prox. end
2380 Segperc:DATA .117,.554,.329  ! Segment % weightings
2385 Radgyr: DATA .183,.188,.257  ! Radius of gyration
2390 Pjt:    DATA P.J.THIESSEN,74.84,1.772        ! Name,mass,height
2395         DATA .19,.27,.28,.3,.56,.39,.42,.28  ! Segment lengths
2400 Mg:     DATA M.GIFFORD,68.04,1.753
2405         DATA .188,.251,.279,.368,.457,.424,.414,.267
2410 Grfdata:DATA "EXIT",Time,Xpt,Ypt,Xvel,Yvel,Xacc,Yacc,Xg,Yg,Xgvel,Ygvel,Xgacc,Ygacc
2415         DATA Incline,Angvel,Angacc,Energy,Xforce,Yforce,Moment
2420         DATA Xtg,Ytg,Xtgvel,Ytgvel,Xtgacc,Ytgacc,Tot_e,Bar_e,Plot
2425 Axlabel:DATA TIME (seconds),X-POINT (meters),Y-POINT (meters)
2430         DATA X-VELOCITY (meters/sec),Y-VELOCITY (meters/sec)
2435         DATA X-ACCELERATION (m/s/s),Y-ACCELERATION (m/s/s)
2440         DATA SEG CG X-POINT (meters),SEG CG Y-POINT (meters)
2445         DATA SEG CG X-VEL (meters/sec),SEG CG Y-VEL (meters/sec)
2450         DATA SEG CG X-ACCEL (m/s/s),SEG CG Y-ACCEL (m/s/s)
2455         DATA INCLINATION (radians),ANGULAR VELOCITY (rad/sec),ANGULAR ACCEL (rad/s/s)
2460         DATA ENERGY (Joules)
2465         DATA X-FORCE (Newtons),Y-FORCE (Newtons),MOMENT (Newtons x meters)
2470         DATA TOT CG X-POINT (meters),TOT CG Y-POINT (meters)
2475         DATA TOT CG X-VEL (meters/sec),TOT CG Y-VEL (meters/sec)
2480         DATA TOT CG X-ACCEL (m/s/s),TOT CG Y-ACCEL (m/s/s)
2485         DATA TOTAL ENERGY (Joules),SPRING ENERGY (Joules)
2490 ! -------------------------------------------------------------------
2495 End:!
```

```
2500 ! File: Inclin                Cartridge: DATA SMOOTHING
2505 ! Date: March, 1983           Author: P.J.Thiessen
2510 ! Desc: This subprogram calculates the inclination of a segment given the
2515 ! two endpoints of the segment.  It keeps track of revolutions (ie angles
2520 ! greater than 360 deg.) provided the transition is from the 4th quadrant
2525 ! to the first quadrant.
2530 ! Keys: INCLINATION,INCLINE,ANGLE,SLOPE,SUB
2535 ! ----------------------------------------------------------------------
2540 Incline:SUB Incline(N,Xpt(*),Ypt(*),Incline(*),Prox,Dist,Numv,Prnt)
2545 DEFAULT ON
2550 Rev=Previ=0
2555 IF Prnt THEN PRINT "### Incline","Adjusted","Revolution";LIN(1)
2560 FOR F=1 TO N
2565     GOSUB Getincline
2570     GOSUB Adjustrevs
2575     IF Prnt THEN PRINT F;Incline,Incline(F,Numv),Rev
2580 NEXT F
2585 SUBEND
2590 Getincline:Y=Ypt(F,Dist)-Ypt(F,Prox)
2595       X=Xpt(F,Dist)-Xpt(F,Prox)
2600       Incline=ATN(Y/X)+PI*(X<0)+2*PI*((X>=0) AND (Y<0))
2605       RETURN
2610 Adjustrevs:IF (Previ>3/2*PI) AND (Incline<PI) THEN Rev=Rev+1
2615       IF Previ AND (Previ<PI/2) AND (Incline>PI) THEN Rev=Rev-1
2620       Incline(F,Numv)=Incline+2*PI*Rev
2625       Previ=Incline
2630       RETURN
2635 End:!
2640 ! File: Velaci                 Cartridge: DATA SMOOTHING
2645 ! Date: 1980?                  Author: P.J.Thiessen
2650 ! Desc: This subprogram calculates the first and second derivatives of an
2655 ! array.  A first finite differences technique is used.  The array must be
2660 ! two dimensional.  The velocity and acceleration arrays are also passed.
2665 ! Keys: DIFFER,NUMANL,FINITE DIFFERENCES,1ST,SMOOTH,VELOCITY,ACCEL,SUB
2670 ! ----------------------------------------------------------------------
2675 SUB Velacc(S(*),V(*),A(*),N,V,Time)
2680 !
2685 ! Calculate Velocity:
2690 !
2695 V(1,V)=(S(2,V)-S(1,V))/Time
2700 FOR C=2 TO N-1
2705     V(C,V)=(S(C+1,V)-S(C-1,V))/(2*Time)
2710 NEXT C
2715 V(N,V)=(S(N,V)-S(N-1,V))/Time
2720 !
2725 ! Calculate Acceleration:
2730 !
2735 A(1,V)=(V(2,V)-V(1,V))/Time
2740 FOR C=2 TO N-1
2745     A(C,V)=(V(C+1,V)-V(C-1,V))/(2*Time)
```

```
2750 NEXT C
2755 A(N,V)=(V(N,V)-V(N-1,V))/Time
2760 SUBEND
2765 End:!
2770 ! File: Autgrf                  Cartridge: GRAPHICS (1)
2775 ! Date: June 22/83 (Update)     Author: P.J. Thiessen
2780 ! Desc: This subprogram graphs a set of data points automatically. X and
2785 ! Y two dimensional arrays are passed by the main program.  As many as 10
2790 ! subsets (2nd dimension) can be passed.  The subprog calculates the SCALE,
2795 ! LINE TYPE and LABELing parameters automatically.
2800 ! Note: Option=1 -- Manual Scale
2805 !       Option=2 -- Pause between operations (for pen change)
2810 !       Option=3 -- Manual Scale and Pause
2815 ! Keys: GRAPHICS,PLOT,CURVE,AUTOMATIC,SUB
2820 ! ------------------------------------------------------------------------
2825 Autograph:SUB Autograph(N,Nv,X(*),Y(*),Var(*),Scale(*),Loc(*),Xaxis$,Yaxis$,Legend$(*),Title$,Foot$,Optio
n)
2830 PLOTTER IS 7,5,"9872A"
2835 PRINTER IS 16
2840 DEG
2845 GOSUB Getmaxmins
2850 GOSUB Scale
2855 GOSUB Plotdata
2860 GOSUB Axislabel
2865 GOSUB Legend
2870 GOSUB Title_foot
2875 SETGU
2880 MOVE 138.8888,100  ! Move pen to top right
2885 SUBEND
2890 Out:DISP " Autograph Subprogram completed "
2895 WAIT 1000
2900 SUBEND
2905 Getmaxmins:Xmax=Ymax=-9E99
2910       Xmin=Ymin=9E99
2915       FOR I=1 TO N
2920           FOR J=1 TO Nv
2925               Xmax=MAX(Xmax,X(I,Var(J)))
2930               Ymax=MAX(Ymax,Y(I,Var(J)))
2935               Xmin=MIN(Xmin,X(I,Var(J)))
2940               Ymin=MIN(Ymin,Y(I,Var(J)))
2945           NEXT J
2950       NEXT I
2955       RETURN
2960 Scale:IF NOT SUM(Loc)=0 THEN GOTO 2980
2965           Loc(1)=Loc(3)=20
2970           Loc(2)=110
2975           Loc(4)=90
2980       LOCATE Loc(1),Loc(2),Loc(3),Loc(4)
2985       IF (Option<>1) AND (Option<>3) THEN GOTO 3050
2990           BEEP
```

```
2995            DISP "Enter Xmin,Xmax,Xmajor,Xminor (";Xmin;",";Xmax;")";
3000            INPUT "",Xm,Xx,Xminor,Xmajor
3005            Xminor=(Xx-Xm)/(Xmajor*Xminor)
3010            Xstep=Xminor*Xmajor
3015            Xformat$=FNFormat$(Xm,Xx,Xstep)
3020            DISP "Enter Ymin,Ymax,Ymajor,Yminor (";Ymin;",";Ymax;")";
3025            INPUT "",Ym,Yx,Yminor,Ymajor
3030            Yminor=(Yx-Ym)/(Ymajor*Yminor)
3035            Ystep=Yminor*Ymajor
3040            Yformat$=FNFormat$(Ym,Yx,Ystep)
3045        GOTO 3060
3050            CALL Minmax(Xmin,Xmax,Xm,Xx,Xstep,Xmajor,Xminor,Xformat$)
3055            CALL Minmax(Ymin,Ymax,Ym,Yx,Ystep,Ymajor,Yminor,Yformat$)
3060        SCALE Xm,Xx,Ym,Yx
3065        DISP "X-Scale:";Xm;Xx;Xstep;"(";Xformat$;")","Y-Scale:";Ym;Yx;Ystep;"(";Yformat$;")"
3070        IF Option<2 THEN GOTO 3085
3075            DISP " Pen Change  -- Ready to plot Axes, press CONTINUE"
3080            PAUSE
3085        GOSUB Plotter_ok
3090        DISP "X-Scale:";Xm;Xx;Xstep;"(";Xformat$;")","Y-Scale:";Ym;Yx;Ystep;"(";Yformat$;")"
3095        Majticwidth=1.5
3100        AXES Xminor,Yminor,Xm,Ym,Xmajor,Ymajor,Majticwidth
3105        Scale(1)=Xm
3110        Scale(2)=Xx
3115        Scale(3)=Ym
3120        Scale(4)=Yx
3125        RETURN
3130 Plotdata:!
3135        RESTORE Linetypes
3140        FOR J=1 TO Nv
3145            V=Var(J)
3150            READ Lt,Ll
3155            LINE TYPE Lt,Ll
3160            IF Option<2 THEN GOTO 3180
3165                BEEP
3170                DISP " Pen Change  -- Ready to plot data set";V;"(LINE TYPE ";VAL$(Lt);",";VAL$(Ll);")"
3175                PAUSE
3180            FOR I=1 TO N
3185                PLOT X(I,V),Y(I,V)
3190            NEXT I
3195            PENUP
3200            IF NOT J MOD 10 THEN RESTORE Linetypes
3205        NEXT J
3210        RETURN
3215 Linetypes:DATA 1,4,4,1,3,.5,6,3,7,4,8,4,5,2,9,4,10,4,2,1
3220 Axislabel:IF Option<2 THEN GOTO 3240
3225            BEEP
3230            DISP " Pen Change  -- Ready to label the X axis"
3235            PAUSE
3240        LINE TYPE 1,4
```

```
3245        CSIZE 2
3250        LORG 6
3255        FOR L=Xm TO Xx STEP Xstep
3260            MOVE L,Ym
3265            SETGU
3270            CURSOR X,Y
3275            MOVE X,Y-1
3280            LABEL USING Xformat$;L
3285            SETUU
3290        NEXT L
3295        SETGU
3300        Xin=3*2.25  ! 3 times the character size of the axis labels
3305        MOVE Loc(1)+(Loc(2)-Loc(1))/2,Loc(3)-Xin
3310        CSIZE 3
3315        LABEL Xaxis$
3320        SETUU
3325        IF Option<2 THEN GOTO 3345
3330            BEEP
3335            DISP " Pen Change  -- Ready to label the Y axis"
3340            PAUSE
3345        LORG 8
3350        CSIZE 2
3355        FOR L=Ym TO Yx STEP Ystep
3360            MOVE Xm,L
3365            SETGU
3370            CURSOR X,Y
3375            MOVE X-1,Y
3380            LABEL USING Yformat$;L
3385            SETUU
3390        NEXT L
3395        SETGU
3400        LORG 4
3405        LDIR 90
3410        Yin=LEN(Format$)*.6+10
3415        MOVE Loc(1)-Yin,Loc(3)+(Loc(4)-Loc(3))/2
3420        CSIZE 3
3425        LABEL Yaxis$
3430        SETUU
3435        RETURN
3440 Legend:IF Option<2 THEN GOTO 3460
3445            BEEP
3450            DISP " Pen Change  -- Ready to plot the Legend"
3455            PAUSE
3460        Lx=0
3465        FOR J=1 TO Nv
3470            Lx=MAX(Lx,LEN(Legend$(Var(J))))
3475        NEXT J
3480        IF Lx=0 THEN RETURN
3485        IF Lx>10 THEN Lx=10
3490        Lwidth=.4*(10/Lx)
```

```
3495       IF Lwidth>.6 THEN Lwidth=.6
3500       SETGU
3505       MOVE 126,80
3510       CSIZE 3,.6
3515       LORG 4
3520       LDIR 0
3525       LABEL "LEGEND"
3530       MOVE 120.8,79.4    ! Underline
3535       DRAW 131.1,79.4
3540       LORG 1
3545       RESTORE Linetypes
3550       Mult=5
3555       IF Nv<6 THEN Mult=10
3560       FOR J=1 TO Nv
3565           V=Var(J)
3570           Y=80-Mult-(J-1)*Mult
3575           MOVE 115,Y
3580           CSIZE 3,Lwidth
3585           IF Option<2 THEN GOTO 3605
3590               BEEP
3595               DISP " Pen Change  -- Ready to label ";Legend$(V);""
3600               PAUSE
3605           IF LEN(Legend$(V))<10 THEN LABEL Legend$(V)
3610           IF NOT (LEN(Legend$(V))<10) THEN LABEL Legend$(V)[1;10]
3615           MOVE 128.2,Y
3620           CSIZE 3,.375
3625           LABEL "[      ]"
3630           MOVE 129.5,Y+.75
3635           READ Lt,L1
3640           IF L1=4 THEN L1=3
3645           LINE TYPE Lt,L1
3650           DRAW 135.5,Y+.75
3655           PENUP
3660           LINE TYPE 1,4
3665       NEXT J
3670       PENUP
3675       RETURN
3680 Title_foot:CSIZE 3.3,.6
3685       SETGU
3690       LDIR 0
3695       LORG 6
3700       IF Foot$="" THEN GOTO 3735
3705       MOVE Loc(1)+(Loc(2)-Loc(1))/2,Loc(3)-(Loc(4)-Loc(3))*.2
3710       IF Option<2 THEN GOTO 3730
3715           BEEP
3720           DISP " Pen Change  -- Ready to plot footnote ";Foot$;""
3725           PAUSE
3730       LABEL Foot$
3735       LORG 4
3740       IF Title$="" THEN GOTO 3775
```

```
3745       MOVE Loc(1)+(Loc(2)-Loc(1))/2,Loc(4)+(Loc(4)-Loc(3))*.05
3750       IF Option<2 THEN GOTO 3770
3755          BEEP
3760          DISP " Pen Change  -- Ready to plot title ";Title$;""
3765          PAUSE
3770       LABEL Title$
3775       RETURN
3780 Plotter_ok:STATUS 7,5;Status
3785       IF NOT BIT(Status,7) THEN RETURN
3790       BEEP
3795       DISP "Please turn PLOTTER chart load button OFF"
3800       STATUS 7,5;Status
3805       IF BIT(Status,7) THEN GOTO 3790
3810       DISP
3815       RETURN
3820 ! File: Minmax                  Cartridge: GRAPHICS
3825 ! Date: May, 1983               Author: P.J.Thiessen
3830 ! Desc: This subprogram determines the parameters necessary for plotting
3835 ! an axis.  It determines the min,max,step, and minor tic values as well
3840 ! as the format needed for the labels.  Implementation of the subprogram
3845 ! for graphing could allow more automatic plotting and labelling of the
3850 ! axes as well as scaling the area defined by a LOCATE statement.
3855 ! Keys: MIN,MAX,AXIS,AXES,GRAPHICS,PLOT,LABEL,SCALE
3860 ! ----------------------------------------------------------------------
3865 Minmax:SUB Minmax(Oldmin,Oldmax,Newmin,Newmax,Step,Major,Minor,Format$)
3870 DIM F$[15]
3875 Rs:Okay=0
3880 IF Oldmin<Oldmax THEN 3900
3885     Hold=Oldmin
3890     Oldmin=Oldmax
3895     Oldmax=Hold
3900 GOSUB Integer
3905 GOSUB Getmaxmin
3910 GOSUB Convertback
3915 GOSUB Ticspacing
3920 Format$=FNFormat$(Newmin,Newmax,Step)
3925 SUBEND
3930 Integer:!
3935       Oldiff=Oldmax-Oldmin
3940       P1=FNPower(Oldmax)
3945       P2=FNPower(Oldmin)
3950       P3=FNPower(Olddiff)
3955       Power=MAX(P1,P2,P3)
3960       Min=Oldmin*10^(-(Power-1))
3965       Max=Oldmax*10^(-(Power-1))
3970       IF (ABS(Min))>=10) OR (ABS(Max))>=10) THEN GOTO 3985
3975          Power=Power-1
3980          GOTO 3960
3985       Om=Min
3990       Om=Min
```

```
3995        Ox=Max
4000        Min=PROUND(Min,0)
4005        IF Min<=Om THEN GOTO 4020
4010            Min=Om-1
4015            GOTO 4000
4020        Max=PROUND(Max,0)
4025        IF Max>=Ox THEN GOTO 4040
4030            Max=Ox+1
4035            GOTO 4020
4040        Diff=Max-Min
4045        Decmin=Min
4050        Decmax=Max
4055        RETURN
4060 Getmaxmin:RESTORE Nearest_div
4065        Oldecmin=Decmin
4070        Oldecmax=Decmax
4075 Top:   Decdiff=Decmax-Decmin
4080        GOSUB Getcommondiv
4085        GOTO 4110
4090        PRINT "Orig:";Oldmin;Oldmax
4095        PRINT "Min:";Decmin;"Max:";Decmax;"Diff";Decdiff
4100        PRINT "GCdec:";Gcdec;"GCD:";Gcd
4105        PRINT "----------------------------------------------------"
4110 !      IF NOT (Gcd>1) THEN GOTO 4095
4115            Numdiv=Decdiff/Gcd
4120            IF (Numdiv<11) AND (Numdiv>2) AND (Gcd<>11) THEN GOTO 4170
4125            IF (Gcd<>Decdiff) AND (Gcd<>Decmin) AND (Gcd<>Decmax) THEN GOTO 4175
4130                IF Gcd>10 THEN GOTO 4145
4135                    Gcd=1
4140                GOTO 4115
4145                    Newgcd=FNGcd(0,Decdiff)
4150                    IF (Newgcd=Gcd) OR (Newgcd=0) THEN GOTO 4175
4155                    Gcd=Newgcd
4160                GOTO 4115
4165            GOTO 4175
4170                Okay=1
4175        IF Okay THEN RETURN
4180            IF Near<>Decdiff THEN GOTO 4200
4185                Power=Power-1
4190                GOSUB 3960   ! Get a new set of min,max's
4195                GOTO Getmaxmin
4200            READ Near
4205                Decmin=Oldecmin
4210                Decmax=Oldecmax
4215                GOSUB Minear
4220                GOSUB Maxnear
4225                Gcd=Near
4230                GOTO Top
4235        RETURN
4240 Nearest_div:DATA 2,5,10,20
```

```
4245 Getcommondiv:Gcd=Gdmin=Gdmax=0
4250       Gcdec=FNGcd(Decmin,Decmax)
4255       Gcd=FNGcd(Gcdec,Decdiff)
4260       RETURN
4265 Minear:IF NOT (Decmin MOD Near) THEN RETURN
4270       Decmin=Decmin-Decmin MOD Near
4275       RETURN
4280 Maxnear:IF NOT (Decmax MOD Near) THEN RETURN
4285       Decmax=Decmax+(Near-Decmax MOD Near)
4290       RETURN
4295 Convertback:!
4300       Newmin=Decmin*10^(Power-1)
4305       Newmax=Decmax*10^(Power-1)
4310       Step=Gcd*10^(Power-1)
4315       IF NOT Near THEN GOTO 4335
4320           IF Near=20 THEN Minortics=2
4325           IF Near<>20 THEN Minortics=5
4330       GOTO 4350
4335           Minortics=Gcd
4340           IF (Minortics=10) OR (Minortics=1) THEN Minortics=5
4345           IF Minortics>10 THEN Minortics=1
4350       RETURN
4355 Ticspacing:IF Near=0 THEN Near=1
4360       IF Numdiv>4 THEN GOTO 4380
4365           Numdiv=Numdiv*2
4370           Gcd=Gcd*2
4375           Step=Step/2
4380       Minor=(Newmax-Newmin)/(Numdiv*Gcd)
4385       Major=Gcd
4390       IF Major<10 THEN GOTO 4415
4395           Dd=FNGcd(Major,0)
4400           Major=Major/Dd
4405           Minor=Minor*Dd
4410           GOTO 4390
4415       IF Major>1 THEN GOTO 4430
4420           Major=Major*5
4425           Minor=Minor/5
4430       RETURN
4435 ! ------------------------------------------------------------------
4440 ! Function Power finds the power of a value as expressed in floating point
4445 ! notation.  (ie. 3.210987654E-04 would yield -4)
4450 ! ------------------------------------------------------------------
4455 Power:DEF FNPower(N)
4460 DIM N$[18]
4465 FLOAT 11                       ! Force floating point notation
4470 N$=VAL$(N)                     ! Use string version of number
4475 Power=VAL(N$[POS(N$,"E")+1])   ! Strip off the power value
4480 STANDARD
4485 RETURN Power
4490 ! ------------------------------------------------------------------
```

```
4495 ! FNGcd: Finds the greatest common divisor of two numbers unless one of
4500 ! them is zero.  For zero it tries to return a divisor between 1 and 10 for
4505 ! the non-zero number.
4510 ! -------------------------------------------------------------------
4515 Gcd:DEF FNGcd(A,B)
4520 INTEGER G,R,Gprime,Rprime
4525 G=ABS(A)
4530 R=ABS(B)
4535 IF (G=0) OR (R=0) THEN GOTO Find_div
4540 IF R<=0 THEN RETURN G
4545    Gprime=G DIV R
4550    Rprime=INT(G-Gprime*R)
4555    G=R
4560    R=Rprime
4565 GOTO 4540
4570 Find_div:! Find a divisor between 1 and 10 for the non-zero value
4575 IF (R=0) AND (G<>0) THEN N=G   ! Choose the non zero value
4580 IF (G=0) AND (R<>0) THEN N=R   ! to work with.
4585 IF N=0 THEN RETURN 0           ! If both are zero return 0.
4590 IF NOT (N MOD 10) AND (N<>10) THEN Div=1   ! If N is divisible by ten
4595 IF Div THEN N=N/10             ! Then use N/10 (ie. 120 = 12)
4600 IF NOT Div THEN Try=1
4605 Try=Try+1                      ! Start with 2
4610 IF NOT (Try>10) THEN 4625      ! Stop at 9
4615    IF Div THEN N=N*10          ! If you divided then return N*10
4620    RETURN N
4625 IF N MOD Try THEN 4605         ! Remainder?  If yes then try again.
4630 IF (N/Try>10) OR (N/Try<3) THEN GOTO 4605! No!  Is N a good value?
4635 IF Div THEN Try=Try*10         ! Yes! If you divided then return Try*10
4640 RETURN Try                     ! Return the divisor.
4645 ! -------------------------------------------------------------------
4650 ! FNFormat: Given the min,max,and step of a data set this function returns
4655 ! a string that can be used to format the output.
4660 ! -------------------------------------------------------------------
4665 Frmt:DEF FNFormat$(Min,Max,Step)
4670 Format$=""
4675 STANDARD
4680 S=P=D=F=0
4685 I$=VAL$(Min)
4690 GOSUB Count
4695 I$=VAL$(Min+Step)
4700 GOSUB Count
4705 I$=VAL$(Max)
4710 GOSUB Count
4715 IF S THEN Format$="M"
4720 IF D THEN Format$=Format$&RPT$("D",D-1)&"Z"
4725 IF F THEN Format$=Format$&"."&RPT$("D",F)
4730 RETURN Format$
4735 Count:! Count digits before and after decimal point & check for sign
4740      IF NOT POS(I$,"-") THEN GOTO 4755
```

```
4745          S=1
4750          I$=I$[2]
4755      P=POS(I$,".")
4760      IF NOT P THEN GOTO 4795
4765          IF P=1 THEN 4785
4770              D=MAX(D,POS(I$,".")-1)
4775              F=MAX(F,LEN(I$[POS(I$,".")+1]))
4780          GOTO 4790
4785              F=MAX(F,LEN(I$)-1)
4790      GOTO 4800
4795          D=MAX(D,LEN(I$))
4800      RETURN
4805 End:!
4810 ! File: HBGtrc                Cartridge: GRAPHICS (1)
4815 ! Date: March, 1983 (Update)    Author: P.J.Thiessen
4820 ! Desc: This subprogram will plot stick figures over a graph that has been
4825 ! previously plotted, in the same way as subprogram "Grftrc", except that
4830 ! it has been designed for plotting a three segment representation of a
4835 ! gymnast on the Horizontal bar. (For PJT's thesis)
4840 ! Keys: GRAPH,STICK,PLOT,TRACE,OVER TOP,SUB,PJT
4845 ! ----------------------------------------------------------------------
4850 Graphtrace:SUB Graphtrace(X(*),Y(*),T(*),S(*),L(*),Numfrms,Numpts,Nf,INTEGER F(*))
4855 DIM Jnt(100),Lt(100),L1(100)
4860 LOCATE L(1),L(2),L(3),L(4)
4865 SCALE S(1),S(2),S(3),S(4)
4870 PRINTER IS 16
4875 GOSUB Getinitialpos
4880 GOSUB Plotter_ok
4885 FOR C=1 TO Nf
4890     GOSUB Getmaxmin
4895     GOSUB Plotracing
4900     IF C<Nf THEN GOSUB Getnewpos
4905 NEXT C
4910 IF Flip$="Y" THEN MAT X=(17400)-X    ! Flip back to original form
4915 DISP " Tracing Subprogram completed "
4920 SUBEND
4925 Getinitialpos:GOSUB Plotter_ok
4930       LOCATE L(1),L(2),L(3),L(4)
4935       SCALE S(1),S(2),S(3),S(4)
4940       MOVE T(F(1),1),S(4)
4945       SETGU
4950       CURSOR Xc,A
4955       Ymin=92
4960       MOVE Xc,Ymin
4965       W=H=8
4970       Xmin=Xc-W/2
4975       Xmax=Xc+W/2
4980       Ymax=Ymin+H
4985       LOCATE Xmin,Xmax,Ymin,Ymax
4990       RETURN
```

```
4995 Getnewpos:LOCATE L(1),L(2),L(3),L(4)
5000       SCALE S(1),S(2),S(3),S(4)
5005       MOVE T(F(C+1),1),S(4)
5010       SETGU
5015       CURSOR Xc,A
5020       Xmin=Xc-W/2
5025       Xmax=Xc+W/2
5030       LOCATE Xmin,Xmax,Ymin,Ymax
5035       RETURN
5040 Getmaxmin:Xsmax=Ysmax=-9E99
5045       Xsmin=Ysmin=9E99
5050       FOR P=1 TO Numpts
5055           IF X(F(C),P)>Xsmax THEN Xsmax=X(F(C),P)
5060           IF Y(F(C),P)>Ysmax THEN Ysmax=Y(F(C),P)
5065           IF X(F(C),P)<Xsmin THEN Xsmin=X(F(C),P)
5070           IF Y(F(C),P)<Ysmin THEN Ysmin=Y(F(C),P)
5075       NEXT P
5080       MOVE Xc,Ymin-.5
5085       DRAW Xc,Ymin-1
5090       CSIZE 1.75
5095       LORG 4
5100       LDIR PI
5105       LABEL "^"
5110       SETUU
5115       SHOW Xsmin,Xsmax,Ysmin,Ysmax
5120       RETURN
5125 Plotracing:!
5130       RESTORE Order1
5135       DISP "Plotting frame ";CHR$(129);F(C);CHR$(128)
5140       LINE TYPE 1,4
5145       FOR I=1 TO 8
5150           READ P
5155           IF P=-1 THEN GOTO 5170
5160               PLOT X(F(C),P),Y(F(C),P)
5165           GOTO 5175
5170               PENUP
5175       NEXT I
5180       PENUP
5185       RETURN
5190 Order1:DATA 1,2,3,-1,2,4,5,-1
5195 Plotter_ok:STATUS 7,5;Status
5200       IF NOT BIT(Status,7) THEN RETURN
5205       BEEP
5210       DISP "Please turn PLOTTER chart load button off"
5215       STATUS 7,5;Status
5220       IF NOT BIT(Status,7) THEN GOTO 5230
5225       GOTO 5205
5230       DISP
5235       RETURN
```

```
10   ! File: MODEL                  Cartridge: P.T. THESIS PROGRAMS (2)
20   ! Date: Spring, 1983           Author: P.J.Thiessen
30   ! ------------------------------------------------------------------
40   PRINTER IS 16
50   PRINT PAGE;TAB(26);" GYMNAST MODELLING PROGRAM "
60   OPTION BASE 1
70   DIM L$[180]
80 D:DIM T(90,5),Angacc(90,3),Old_t(90),New_t(90),N(3)
90   DIM Angvel(90,3),Incline(90,3),Format$[160],Descrfile$[160]
100  DIM Xpt(90,5),Ypt(90,5)
110  DIM Xg(90,3),Yg(90,3),Xtg(90,1),Ytg(90,1)
120  DIM Xvel(90,5),Yvel(90,5),Xacc(90,5),Yacc(90,5)
130  DIM Xgvel(90,3),Ygvel(90,3),Xgacc(90,3),Ygacc(90,3)
140  DIM Xtgvel(90,1),Ytgvel(90,1),Xtgacc(90,1),Ytgacc(90,1)
150  DIM Xforce(90,4),Yforce(90,4),Moment(90,4)
160  DIM Scale(4),Loc(4),Opt$[40],Leg$(5)[40],Xaxis$[40],Yaxis$[40],Title$[100]
170  DIM Foot$[100],Var(5),Name$[40]
180  DIM X(90,5),Y(90,5),S$[160]
190  SHORT Segpercent(1:3),Radgyration(1:3),Seglen(1:8)
200  SHORT Segmass(1:3),Segwt(1:3),I(1:3)
210  INTEGER F(1:10)
220  READ F(*)
230  DATA 1,10,20,30,40,50,60,70,80,90
240  OUTPUT 9;"Request time"
250  ENTER 9;T$
260  Date$=T$[1;5]
270  Dig=706
280  PRINTER IS 16
290  Iter=0
300  INPUT "Do you want automatic iterating [Y/N]",Auto$
310  IF Auto$="Y" THEN INPUT "Please enter the maximum iteration",Maxiter
320 Start:GOSUB Init
330      IF Op$="R" THEN GOTO 390
340          GOSUB Getsubs
350          GOSUB Getaa
360          GOSUB Getxpos
370          GOSUB Getypos
380          GOSUB Saveinput
390      GOSUB Integrate
400 Iterate:!
410      GOSUB Getpos
420      GOSUB K_analysis
430      IF (Auto$="Y") AND (Iter<Maxiter) THEN GOTO 490
440          GOSUB Graphdata
450          INPUT "Do you want the data printed out [Y/N]",Pr$
460          IF Pr$="Y" THEN GOSUB Pr
470          INPUT " R e-iterate,  N ew model, or  E nd [S/R/N/E]",W$
480          IF W$<>"R" THEN GOTO 510
490      PRINT "o  Iteration #";VAL$(Iter);" completed."
492      GOSUB Calc_new_barpos
```

```
500  GOTO 410
510  IF W$<>"E" THEN GOTO Start
520  DISP "Program MODEL ended."
530  PAUSE
540  GOTO 520
550  SUBEND
560 Init:  INPUT "Please enter a the subject and trial number to be modelled",Subject,Trial
570        LINPUT "Do you want to read in the input data or enter it by hand [R/E]",Op$
580        IF Op$="E" THEN GOTO 610
590            GOSUB Readinput
600            GOTO 680
610        FOR S=1 TO 3
620            DISP "Please enter the inclination and angular velocity for segment ";S;"";
630            INPUT "",Incline(1,S),Angvel(1,S)
640        NEXT S
650        INPUT "Please enter the time between the model frames (for interpolation)",Time
660        INPUT "Please enter the initial time",T(1,1)
670        INPUT "Please enter the error tolerance for interpolation",Errtol
680        RESTORE Pjt
690        READ Name$,Mass,Height
700        READ Seglen(*)
710        Length(1)=Seglen(1)+Seglen(2)+Seglen(3)
720        Length(2)=Seglen(4)
730        Length(3)=Seglen(5)
740        Length(4)=Seglen(6)+Seglen(7)+Seglen(8)
750        RETURN
760 Dropends:! The 1st two and last two data points will temporarily be dropped.
770        N=N-8
780        S=-3
790        GOSUB Redimension
800        RETURN
810 Pickupends:!
820        N=N+8
830        S=1
840        GOSUB Redimension
850        RETURN
860 Redimension:REDIM T(S:N,5),Angacc(S:N,3)
870        REDIM Angvel(S:N,3),Incline(S:N,3),Xpt(S:N,5),Ypt(S:N,5)
880        REDIM Xg(S:N,3),Yg(S:N,3),Xtg(S:N,1),Ytg(S:N,1)
890        REDIM Xvel(S:N,5),Yvel(S:N,5),Xacc(S:N,5),Yacc(S:N,5)
900        REDIM Xgvel(S:N,3),Ygvel(S:N,3),Xgacc(S:N,3),Ygacc(S:N,3)
910        REDIM Xtgvel(S:N,1),Ytgvel(S:N,1),Xtgacc(S:N,1),Ytgacc(S:N,1)
920        REDIM Xforce(S:N,4),Yforce(S:N,4),Moment(S:N,4)
930        RETURN
940 Getaa: OUTPUT Dig;"IN;SG;BP"
950        PRINT PAGE;LIN(5);TAB(29);"ANGULAR ACCELERATIONS"
960        CALL Digdisplay(Dig,"ANG ACCELS",0)
970        WAIT 1000
980        GOSUB Scale
990        FOR S=1 TO 3
```

```
1000            GOSUB Digitize
1010        NEXT S
1020        FOR S=1 TO 3
1030            GOSUB Interpolate
1040        NEXT S
1050        Ns=3
1060        GOSUB Plotcurves
1070        INPUT "Are these curves acceptable [Y/N]",Accept$
1080        IF Accept$="N" THEN GOTO Getaa
1090        L$="ANG. ACCEL."
1100        GOSUB Labelcurve
1110        FOR S=1 TO 3
1120            FOR F=1 TO N
1130                Angacc(F,S)=Y(F,S)
1140            NEXT F
1150        NEXT S
1160        RETURN
1170 Getxpos:OUTPUT Dig;"IN;SG;BP"
1180        PRINT PAGE;LIN(5);TAB(32);"X-HAND POSITION"
1190        CALL Digdisplay(Dig,"HAND HOR. POS.",0)
1200        WAIT 1000
1210        GOSUB Scale
1220        S=1
1230        GOSUB Digitize
1240        GOSUB Interpolate
1250        Ns=1
1260        GOSUB Plotcurves
1270        INPUT "Is this curve acceptable [Y/N]",Accept$
1280        IF Accept$="N" THEN GOTO Getxpos
1290        L$="X-POS"
1300        GOSUB Labelcurve
1310        FOR F=1 TO N
1320            Xpt(F,1)=Y(F,1)
1330        NEXT F
1340        RETURN
1350 Getypos:OUTPUT Dig;"IN;SG;BP"
1360        PRINT PAGE;LIN(5);TAB(32);"Y-HAND POSITION"
1370        CALL Digdisplay(Dig,"HAND Y-POS.",0)
1380        WAIT 1000
1390        GOSUB Scale
1400        S=1
1410        GOSUB Digitize
1420        GOSUB Interpolate
1430        Ns=1
1440        GOSUB Plotcurves
1450        INPUT "Is this curve acceptable [Y/N]",Accept$
1460        IF Accept$="N" THEN GOTO Getypos
1470        L$="Y-POS"
1480        GOSUB Labelcurve
1490        FOR F=1 TO N
```

```
1500            Ypt(F,1)=Y(F,1)
1510        NEXT F
1520        RETURN
1530 Readinput:INPUT "Please enter the name of the input file",Save$
1540        DISP "Please insert the data cartridge -- then press CONTINUE"
1550        PAUSE
1560        ASSIGN #1 TO Save$,Rerr
1570        IF NOT Rerr THEN GOTO 1620
1580            BEEP
1590            DISP "File ";Save$;" cannot be located on this cartridge"
1600            WAIT 2000
1610            GOTO Readinput
1620        DISP "Reading input from file ";Save$;""
1630        READ #1;S$,S$
1640        READ #1;N,Time,Initime
1650        READ #1;Incline(1,1),Incline(1,2),Incline(1,3)
1660        READ #1;Angvel(1,1),Angvel(1,2),Angvel(1,3)
1670        FOR F=1 TO N
1680            DISP "Angacc";F;
1690            FOR S=1 TO 3
1700                READ #1;Angacc(F,S)
1710            NEXT S
1720            DISP Angacc(F,1);Angacc(F,2);Angacc(F,3)
1730        NEXT F
1740        FOR F=1 TO N
1750            READ #1;Xpt(F,1)
1760            DISP "Xpt";F;Xpt(F,1)
1770        NEXT F
1780        FOR F=1 TO N
1790            READ #1;Ypt(F,1)
1800            DISP "Ypt";F;Ypt(F,1)
1810        NEXT F
1820        DISP "Input data read from file ";Save$
1830        FOR F=1 TO N
1840            FOR S=1 TO 5
1850                T(F,S)=Initime+(F-1)*Time
1860            NEXT S
1870        NEXT F
1880        ASSIGN * TO #1
1890        RETURN
1900 Saveinput:INPUT "Do you want to save this input [Y/N]",Save$
1910        IF Save$<>"Y" THEN RETURN
1920        LINPUT "Please enter a file name",Save$
1930        Numrecs=INT(N*5*8/256)+1
1940        DISP "Number of records=";Numrecs;"  Press CONTINUE to begin saving"
1950        PAUSE
1960        CREATE Save$,Numrecs
1970        ASSIGN #1 TO Save$
1980        DISP "Saving input data in file ";Save$;""
1990        PRINT #1;"Format$,Descrfile$,Numfrms,Time,Initime,Incline(1,1:3),Angvel(1,1:3),Angacc(1:Numfrms,1:3
),Xpt(1:Numfrms,1),Ypt(1:Numfrms,1)"
```

```
2000        PRINT #1;"Model "&Model$&" -- Input data only"
2010        PRINT #1;N,Time,Initime
2020        PRINT #1;Incline(1,1),Incline(1,2),Incline(1,3)
2030        PRINT #1;Angvel(1,1),Angvel(1,2),Angvel(1,3)
2040        FOR F=1 TO N
2050            FOR S=1 TO 3
2060                PRINT #1;Angacc(F,S)
2070            NEXT S
2080        NEXT F
2090        FOR F=1 TO N
2100            PRINT #1;Xpt(F,1)
2110        NEXT F
2120        FOR F=1 TO N
2130            PRINT #1;Ypt(F,1)
2140        NEXT F
2150        DISP "Input data saved in file ";Save$
2160        WAIT 1000
2170        ASSIGN * TO #1
2180        RETURN
2190 Scale:DISP "Please digitize the lower left corner of the digiziter area to be defined"
2200        CALL Digdisplay(Dig,"DIG ORIGIN",0)
2210        CALL Getpoint(Dig,Locxmin,Locymin,P,A,Keyint)
2220        CALL Digdisplay(Dig,"ORIGIN SCALE",0)
2230        Xmin=FNGetannot(Dig,1)
2240        Ymin=FNGetannot(Dig,1)
2250        CALL Digdisplay(Dig,"DIG UP LEFT PT",0)
2260        CALL Getpoint(Dig,X,Locymax,P,A,Keyint)
2270        CALL Digdisplay(Dig,"UP LEFT PT",0)
2280        Ymax=FNGetannot(Dig,1)
2290        CALL Digdisplay(Dig,"DIG LO RIGHT PT",0)
2300        CALL Getpoint(Dig,Locxmax,Y,P,A,Keyint)
2310        CALL Digdisplay(Dig,"LO RIGHT PT",0)
2320        Xmax=FNGetannot(Dig,1)
2330        Xslope=(Xmax-Xmin)/(Locxmax-Locxmin)
2340        Yslope=(Ymax-Ymin)/(Locymax-Locymin)
2350        Xb=Xmin-Xslope*Locxmin
2360        Yb=Ymin-Yslope*Locymin
2370        RETURN
2380 Digitize:DISP "Begin digitizing points, press key fa to signal completion"
2390        CALL Digdisplay(Dig,"DIG. POINTS",0)
2400        F=0
2410        FOR B=1 TO 3
2420            OUTPUT Dig;"BP"
2430            WAIT 200
2440        NEXT B
2450 Top:   OUTPUT Dig;"OA"
2460        ENTER Dig;X,Y,P,A
2470        X=X*Xslope+Xb
2480        Y=Y*Yslope+Yb
2490        IF X<Initime THEN OUTPUT Dig USING "AA,MD";"LB",-1
```

```
2500        IF NOT (X<Initime) AND NOT (X>Initime+(N-1)*Time) THEN OUTPUT Dig USING "AA,MD";"LB",0
2510        IF X>Initime+(N-1)*Time THEN OUTPUT Dig USING "AA,MD";"LB",1
2520        OUTPUT Dig;"OS"
2530        ENTER Dig;Stat
2540        IF NOT BIT(Stat,2) AND NOT BIT(Stat,7) THEN GOTO Top
2550        IF BIT(Stat,7) THEN GOTO Finished
2560        CALL Getpoint(Dig,X,Y,Pen,A,K)
2570        F=F+1
2580        X(F,S)=X*Xslope+Xb
2590        Y(F,S)=Y*Yslope+Yb
2600        OUTPUT Dig USING "AA,D.3D,X,4D.3D";"LB",X(F,S),Y(F,S)
2610        GOTO Top
2620 Finished:Key=FNGetdigkey(Dig,0)
2630        IF Key<>1 THEN GOTO Top
2640        OUTPUT Dig;"SK0"
2650        OUTPUT Dig;"BP"
2660        WAIT 500
2670        OUTPUT Dig;"BP"
2680        N(S)=F
2690        RETURN
2700 Interpolate:!
2710        CALL Digdisplay(Dig,"INTERPOLATING",0)
2720        DISP "Interpolating data set ";S;""
2730 !      Old_t(1)=T(1,1)
2740        FOR I=1 TO N(S)
2750            Old_t(I)=X(I,S)    ! Save digitized times
2760        NEXT I
2770        Dmin=Initime
2780        Dmax=Initime+(N-1)*Time
2790        I=0
2800        FOR D=Dmin TO Dmax STEP Time
2810            I=I+1
2820            New_t(I)=D          ! Calculate new times
2830        NEXT D
2840        N=I
2850        CALL Interp(Y(*),Old_t(*),New_t(*),N(S),N,S,Errtol,Error,1)
2860        PRINT CHR$(27)&"E"
2870        FOR I=1 TO N
2880            T(I,S)=New_t(I)
2890        NEXT I
2900        RETURN
2910 Plotcurves:DISP "Please get the plotter ready -- then press CONTINUE"
2920        PAUSE
2930        DISP
2940        PLOTTER IS "9872A"
2950        LOCATE 20,110,20,90
2960        SCALE Xmin,Xmax,Ymin,Ymax
2970        FRAME
2980        RESTORE Linetypes
2990        FOR S=1 TO Ns
```

```
3000           PRINT PAGE;
3010           READ Lt,L1
3020           LINE TYPE Lt,L1
3030           FOR F=1 TO N
3040               PLOT T(F,S),Y(F,S)
3050               PRINT T(F,S),Y(F,S)
3060           NEXT F
3070           PENUP
3080       NEXT S
3090       LINE TYPE 1,4
3100       RETURN
3110 Labelcurve:PLOTTER IS 7,5,"9872A"
3120       CSIZE 2.5
3130       MOVE 1,1
3140       LABEL Model$;" (";Date$;") ";L$;", Iter=";Iter
3150       RETURN
3160 Linetypes:DATA 1,4,4,1,3,.5
3170 Integrate:FOR S=1 TO 3
3180           FOR F=2 TO N
3190               DISP "Integrating the angular data:";F
3200               Angvel(F,S)=Angvel(F-1,S)+Angacc(F-1,S)*Time
3210               Incline(F,S)=Incline(F-1,S)+Angvel(F-1,S)*Time+Angacc(F-1,S)*Time^2
3220           NEXT F
3230       NEXT S
3240       RETURN
3250 Getpos:FOR F=1 TO N
3260           STANDARD
3270           DISP "Frame:";F;"   Time:";T(F,1)
3280           FIXED 5
3290           Xpt(F,2)=Xpt(F,1)+COS(Incline(F,1)-PI)*Length(1)    ! Shoulders
3300           Ypt(F,2)=Ypt(F,1)+SIN(Incline(F,1)-PI)*Length(1)
3310           Xpt(F,3)=Xpt(F,2)+COS(Incline(F,2)+PI)*Length(2) ! Head
3320           Ypt(F,3)=Ypt(F,2)+SIN(Incline(F,2)+PI)*Length(2)
3330           Xpt(F,4)=Xpt(F,2)+COS(Incline(F,2))*Length(3)    ! Hips
3340           Ypt(F,4)=Ypt(F,2)+SIN(Incline(F,2))*Length(3)
3350           Xpt(F,5)=Xpt(F,4)+COS(Incline(F,3))*Length(4)    ! Toes
3360           Ypt(F,5)=Ypt(F,4)+SIN(Incline(F,3))*Length(4)
3370       NEXT F
3380       STANDARD
3390       RETURN
3400 Plotmodel:BEEP
3410       INPUT "Do you want to plot out the model positions [Y/N]",Pm$
3420       IF Pm$<>"Y" THEN RETURN
3430       Xpmin=Ypmin=9E99
3440       Xpmax=Ypmax=-9E99
3450       DISP "Calculating scaling factors for plotting...."
3460       FOR F=1 TO N
3470           FOR S=1 TO 5
3480               Xpmax=MAX(Xpt(F,S),Xpmax)
3490               Ypmax=MAX(Ypt(F,S),Ypmax)
```

```
3500              Xpmin=MIN(Xpt(F,S),Xpmin)
3510              Ypmin=MIN(Ypt(F,S),Ypmin)
3520          NEXT S
3530      NEXT F
3540      PLOTTER IS "9872A"
3550      LOCATE 20,110,10,100
3560      SCALE Xpmin-.1,Xpmax+.1,Ypmin-.1,Ypmax+.1
3570      BEEP
3580      DISP "Ready to plot -- press CONTINUE"
3590      PAUSE
3600      FOR F=1 TO N
3610          DISP "Plotting frame ";F;""
3620          RESTORE Ptorder
3630          FOR P=1 TO 8
3640             READ Pt
3650             IF Pt<0 THEN GOTO 3680
3660                 PLOT Xpt(F,Pt),Ypt(F,Pt)
3670             GOTO 3690
3680                 PENUP
3690          NEXT P
3700      NEXT F
3710      L$="POSITIONS"
3720      GOSUB Labelcurve
3730 Xp:   RETURN
3740 Ptorder:DATA 1,2,3,-1,2,4,5,-1
3750 Calc_new_barpos:! Calculate the new bar position using spring constant K
3760      IF K=0 THEN INPUT "Enter the spring constant of the bar",K
3770      Iter=Iter+1
3800      FOR F=1 TO N
3810          Xpt(F,1)=(Mass*Xacc(F,1)-Xforce(F,1))/K
3820          Ypt(F,1)=(Mass*Yacc(F,1)-Yforce(F,1))/K
3840      NEXT F
3850      RETURN
3860 Getsubs:INPUT "Have the subprograms been linked [Y/N]",Link$
3870      IF Link$="Y" THEN RETURN
3880      RESTORE Linkfiles
3890      FOR S=1 TO 2
3900          READ Link$
3910          GOSUB Linksub
3920      NEXT S
3930      RETURN
3940 Linkfiles:DATA Digsb2,Interp
3950 Graphdata:Link$="Autgrf"
3960      GOSUB Linksub
3970      FOR S=1 TO 5
3980          Var(S)=S
3990      NEXT S
4000 Regraph:ON ERROR GOTO Getline
4010          F=-1
4020          GOSUB Xaxis
```

```
4030            Xline$=VAL$(ERRL)
4040            GOSUB Yaxis
4050            Yline$=VAL$(ERRL)
4060        OFF ERROR
4070        PRINT PAGE;" DATA GRAPHING PROCEDURE ";LIN(1)
4080        PRINT "-2) EXIT GRAPHING ROUTINE"
4090        PRINT "-1) Plot coordinates";TAB(40);"0) Plot tracings"
4100        RESTORE Grfdata
4110        FOR Opt=1 TO 25
4120            READ Opt$
4130            PRINT " ";VAL$(Opt);") ";Opt$;
4140            IF NOT (Opt MOD 2) THEN PRINT
4150            IF Opt MOD 2 THEN PRINT TAB(39);
4160        NEXT Opt
4170        PRINT LIN(1)
4180        Ax$="X"
4190        Nt=0
4200        FOR I=1 TO 2
4210            DISP "Please enter the number of the data set for the ";Ax$;"-AXIS";
4220            INPUT "",Set
4230            IF Set=-2 THEN RETURN
4250            IF Set=0 THEN GOTO Tracings
4255            IF (Set<>1) AND (I=1) THEN Nt=1
4260            IF Set<>-1 THEN GOTO 4290
4270                GOSUB Plotmodel
4280                GOTO Regraph
4290            RESTORE Axlabel
4300            FOR J=1 TO Set
4310                IF Ax$="X" THEN READ Xaxis$
4320                IF Ax$="Y" THEN READ Yaxis$
4330            NEXT J
4340            PRINT Ax$;"-axis units: ";
4350            IF Ax$="X" THEN PRINT Xaxis$;
4360            IF Ax$="Y" THEN PRINT Yaxis$;
4370            IF (Set=1) OR (Set>18) THEN RESTORE Seg1
4380            IF (Set>1) AND (Set<8) THEN RESTORE Seg2
4390            IF (Set>7) AND (Set<17) THEN RESTORE Seg3
4400            IF (Set>16) AND (Set<20) THEN RESTORE Seg4
4410            IF Set>19 THEN RESTORE Seg5
4420            READ Nv
4430            IF Nv>1 THEN GOTO 4460
4440                Leg$(1)=""
4450            GOTO 4560
4460                DISP "Variables=";Nv;"  Enter a new value or press CONTINUE";
4470                INPUT "",Nv
4480                FOR S=1 TO Nv
4490                    READ Leg$(S)
4500                NEXT S
4510 Seg1:      DATA 1,""
4520 Seg2:      DATA 5,HANDS,SHLDRS,HEAD,HIPS,TOES
```

```
4530 Seg3:      DATA 3,ARMS,TRUNK,LEGS
4540 Seg4:      DATA 3,HANDS,SHLDRS,HIPS
4550 Seg5:      DATA 1,COFG
4560            PRINT ",";Nv;"Data sets:";
4570            FOR S=1 TO Nv
4580                PRINT Leg$(S);" ";
4590            NEXT S
4600            PRINT LIN(1);
4610            RESTORE Grfdata
4620            FOR Opt=1 TO Set
4630               READ Opt$
4640            NEXT Opt
4650            IF I=1 THEN Opt$=Xline$&" Xaxis:       X(F,S)="&Opt$&"(F,S)"
4660            IF I=2 THEN Opt$=Yline$&" Yaxis:       Y(F,S)="&Opt$&"(F,S)"
4670            EDIT "Please press  STORE  then  CONTINUE  ....",Opt$
4680            Ax$="Y"
4690        NEXT I
4700        EDIT "Please enter a title for the graph",Title$
4710        EDIT "Please enter a footnote for the graph",Foot$
4720        INPUT "Enter the pen change option [1=YES,0=NO]",Penchange
4730        GOSUB Dropends
4740        FOR F=1 TO N
4750            FOR S=1 TO Nv
4760 Xaxis:         X(F,S)=T(F,S)
4770 Yaxis:         Y(F,S)=Xforce(F,S)
4780            NEXT S
4790        NEXT F
4800 Callgrf:CALL Autograph(N,Nv,X(*),Y(*),Var(*),Scale(*),Loc(*),Xaxis$,Yaxis$,Leg$(*),Title$,Foot$,Penchange
)
4810        GOSUB Pickupends
4820 Labsub:PLOTTER IS "9872A"
4830        MOVE 116,95
4840        LORG 3
4850        LABEL "MODEL:"
4860        CSIZE 3,.45
4870        LABEL "SUB ";VAL$(Subject);", TRIAL";Trial
4880        LOCATE 114,139,88,97
4890        FRAME
4900 Tracings:Nf=10
4910        IF Nt THEN GOTO 4000  ! Skip tracings
4920 Callgt:CALL Graphtrace(Xpt(*),Ypt(*),T(*),Scale(*),Loc(*),Numfrms,5,Nf,F(*))
4930        GOTO 4000
4940        RETURN
4950 Link_trace:IF (ERRN()7) AND (ERRN()8) THEN GOTO 5030
4960            OFF ERROR
4970            Link$="HBGtrc"
4980            GOSUB Linksub2
4990        GOTO 4920
5000            BEEP
5010            DISP ERRM$
```

```
5020           PAUSE
5030       GOTO 5000
5040 Getline:RETURN
5050 Linksub:ON ERROR GOTO File_missing
5060           ASSIGN #1 TO Link$
5070       OFF ERROR
5080       DISP "Linking ";Link$;""
5090       IF Link$="Interp" THEN LINK Link$,7050
5100       IF Link$<>"Interp" THEN LINK Link$,End
5110       DISP
5120       RETURN
5130 File_missing:BEEP
5140       DISP "Please insert the cartridge holding file ";Link$;""
5150       GOTO Linksub
5160 ! -------------------- D A T A   S T A T E M E N T S -----------------
5170 !              1    2    3   ! Segments (Arms, Head & trunk, Legs)
5180 Ordpts: DATA  2,3,4,5,7      ! Endpts from data file
5190 Endpts: DATA  2,1, 2,4, 4,5  ! Segment endpoint (Prox,Dist)
5200 Cgdist: DATA .512,.280,.434  ! Distance of seg CG from prox. end
5210 Segperc:DATA .117,.554,.329  ! Segment % weightings
5220 Radgyr: DATA .183,.188,.257  ! Radius of gyration
5230 Pjt:    DATA P.J.THIESSEN,74.84,1.772        ! Name,mass,height
5240         DATA .19,.27,.28,.3,.56,.39,.42,.28  ! Segment lengths
5250 Grfdata:DATA T,Xpt,Ypt,Xvel,Yvel,Xacc,Yacc,Xg,Yg,Xgvel,Ygvel,Xgacc,Ygacc
5260         DATA Incline,Angvel,Angacc,Xforce,Yforce,Moment
5270         DATA Xtg,Ytg,Xtgvel,Ytgvel,Xtgacc,Ytgacc
5280 Axlabel:DATA TIME (seconds),X-POINT (meters),Y-POINT (meters)
5290         DATA X-VELOCITY (meters/sec),Y-VELOCITY (meters/sec)
5300         DATA X-ACCELERATION (m/s/s),Y-ACCELERATION (m/s/s)
5310         DATA SEG CG X-POINT (meters),SEG CG Y-POINT (meters)
5320         DATA SEG CG X-VEL (meters/sec),SEG CG Y-VEL (meters/sec)
5330         DATA SEG CG X-ACCEL (m/s/s),SEG CG Y-ACCEL (m/s/s)
5340         DATA INCLINATION (radians),ANGULAR VELOCITY (rad/sec),ANGULAR ACCEL (rad/s/s)
5350         DATA X-FORCE (Newtons),Y-FORCE (Newtons),MOMENT (Newtons x meters)
5360         DATA TOT CG X-POINT (meters),TOT CG Y-POINT (meters)
5370         DATA TOT CG X-VEL (meters/sec),TOT CG Y-VEL (meters/sec)
5380         DATA TOT CG X-ACCEL (m/s/s),TOT CG Y-ACCEL (m/s/s)
5390 ! ------------------------------------------------------------------
5400 K_analysis:!
5410 Km:    GOSUB Sub_data
5420        GOSUB Calc_seg_cg
5430        GOSUB Calc_tot_cg
5440        GOSUB Kinematics
5450 Kn:    GOSUB Getinertias
5460        GOSUB Calc_kinetics
5470        RETURN
5480 Pr:    GOSUB Printkinematics
5490        GOSUB Printkinetics
5500        RETURN
5510 ! ------------------------------------------------------------------
```

```
5520 Sub_data:RESTORE Pjt
5530        RESTORE Pjt
5540        READ Name$,Mass,Height,Seglen(*)
5550        RETURN
5560 Calc_seg_cg:!
5570        DISP "Calculating segmental Center of Gravity positions...."
5580        RESTORE Cgdist
5590        READ Cgdist(1),Cgdist(2),Cgdist(3)  ! Distance of CofG from prox. end
5600        RESTORE Endpts
5610        FOR S=1 TO 3
5620            READ Prox,Distal                ! Segment endpoints
5630            FOR F=1 TO N
5640                Xg(F,S)=(Xpt(F,Distal)-Xpt(F,Prox))*Cgdist(S)+Xpt(F,Prox)
5650                Yg(F,S)=(Ypt(F,Distal)-Ypt(F,Prox))*Cgdist(S)+Ypt(F,Prox)
5660            NEXT F
5670        NEXT S
5680        RETURN
5690 Calc_tot_cg:RESTORE Segperc
5700        READ Segpercent(*)
5710        FOR F=1 TO N
5720            Xtg(F,1)=Ytg(F,1)=0
5730            FOR S=1 TO 3
5740                Xtg(F,1)=Xtg(F,1)+Xg(F,S)*Segpercent(S)
5750                Ytg(F,1)=Ytg(F,1)+Yg(F,S)*Segpercent(S)
5760            NEXT S
5770        NEXT F
5780        RETURN
5790 Kinematics:!
5800        Link$="Velac1"
5810        IF (Iter=0) AND (Auto$="Y") THEN GOSUB Linksub
5820        FOR I=1 TO 5
5830            DISP "Differentiating data (I=";I;")"
5840            CALL Velacc(Xpt(*),Xvel(*),Xacc(*),N,I,Time)
5850            CALL Velacc(Ypt(*),Yvel(*),Yacc(*),N,I,Time)
5860            IF I>3 THEN GOTO 5900
5870                CALL Velacc(Xg(*),Xgvel(*),Xgacc(*),N,I,Time)
5880                CALL Velacc(Yg(*),Ygvel(*),Ygacc(*),N,I,Time)
5890                IF Op$="R" THEN CALL Velacc(Incline(*),Angvel(*),Angacc(*),N,I,Time)
5900        NEXT I
5910        DISP "Differentiating the total body C of G data"
5920        CALL Velacc(Xtg(*),Xtgvel(*),Xtgacc(*),N,1,Time)
5930        CALL Velacc(Ytg(*),Ytgvel(*),Ytgacc(*),N,1,Time)
5940        RETURN
5950 Printkinematics:IF Pr$="N" THEN RETURN
5960        BEEP
5970        PRINTER IS 7,0,WIDTH(132)
5980        OUTPUT 700;CHR$(27)&"n"
5990        Status=PPOLL(7)
6000        IF BIT(Status,7) THEN GOTO 6040
6010            BEEP
```

```
6020         DISP "Please turn printer ON-LINE"
6030         GOTO 5990
6040     DISP
6050     PRINT "KINEMATIC DATA"
6060     PRINT "**************";LIN(2)
6070     OUTPUT 9;"R"
6080     ENTER 9;Time$
6090     PRINT Time$;LIN(2)
6100     PRINT "Model:   SUBJECT";Subject;"   TRIAL";Trial
6110     PRINT "Iteration:";Iter
6120     PRINT "Time: ";Time
6130     PRINT LIN(2)
6140     FOR P=2 TO 5
6150         PRINT "POINT ";P;LIN(1);"F   Time","Point (X,Y)","Velocity (X,Y)","Accel (X,Y)"
6160         FOR F=1 TO N
6170             PRINT F;
6180             FIXED 5
6190             PRINT T(F,1),Xpt(F,P);Ypt(F,P),Xvel(F,P);Yvel(F,P),Xacc(F,P);Yacc(F,P)
6200             STANDARD
6210         NEXT F
6220         PRINT LIN(1)
6230     NEXT P
6240     PRINT LIN(2)
6250     FOR S=1 TO 3
6260         PRINT "SEG CG";S;LIN(1);"F   Time","Point (X,Y)","Velocity (X,Y)","Accel (X,Y)"
6270         FOR F=1 TO N
6280             PRINT F;
6290             FIXED 5
6300             PRINT T(F,S),Xg(F,S);Yg(F,S),Xgvel(F,S);Ygvel(F,S),Xgacc(F,S);Ygacc(F,S)
6310             STANDARD
6320         NEXT F
6330         PRINT LIN(1)
6340     NEXT S
6350     PRINT LIN(2)
6360     FOR S=1 TO 3
6370         PRINT "SEG INCLINE";S;LIN(1);"F   Time","Incline","Ang Velocity","Ang Acceleration"
6380         FOR F=1 TO N
6390             PRINT F;
6400             FIXED 5
6410             PRINT T(F,S),Incline(F,S),Angvel(F,S),Angacc(F,S)
6420             STANDARD
6430         NEXT F
6440         PRINT LIN(1)
6450     NEXT S
6460     PRINT LIN(2)
6470     PRINT "TOTAL BODY CG";LIN(1);"F    Time","Point (X,Y)","Velocity (X,Y)","Accel (X,Y)"
6480     FOR F=1 TO N
6490         PRINT F;
6500         FIXED 5
6510         PRINT T(F,1),Xtg(F,1);Ytg(F,1),Xtgvel(F,1);Ytgvel(F,1),Xtgacc(F,1);Ytgacc(F,1)
```

```
6520            STANDARD
6530        NEXT F
6540        PRINT LIN(5)
6550        STANDARD
6560        PRINTER IS 16
6570        RETURN
6580 Getinertias:DISP "Calculating inertia values ...."
6590        Gravity=9.81
6600        RESTORE Radgyr
6610        REDIM Radgyration(1:3)
6620        READ Radgyration(*)
6630        FOR S=1 TO 3
6640            Segmass(S)=Mass*Segpercent(S)
6650            Segwt(S)=Segmass(S)*Gravity
6660            I(S)=Radgyration(S)^2*Segmass(S)   ! I=k^2m
6670        NEXT S
6680        RETURN
6690 Calc_kinetics:!
6700        FOR F=1 TO N
6710            DISP "Calculating segment kinetics for frame";F
6720            !  SEGMENT 3 -- Legs
6730            Xforce(F,3)=Segmass(3)*Xgacc(F,3)+Xforce(F,4)
6740            Yforce(F,3)=Segmass(3)*Ygacc(F,3)+Segwt(3)+Yforce(F,4)
6750            Moment(F,3)=I(3)*Angacc(F,3)-SIN(Incline(F,3))*Xgacc(F,3)*Segmass(3)*Cgdist(3)
6760            Moment(F,3)=Moment(F,3)+COS(Incline(F,3))*Ygacc(F,3)*Segmass(3)*Cgdist(3)
6770            Moment(F,3)=Moment(F,3)+COS(Incline(F,3))*Segwt(3)*Cgdist(3)
6780            !  SEGMENT 2 -- Body
6790            Xforce(F,2)=Segmass(2)*Xgacc(F,2)+Xforce(F,3)
6800            Yforce(F,2)=Segmass(2)*Ygacc(F,2)+Segwt(2)+Yforce(F,3)
6810            Moment(F,2)=I(2)*Angacc(F,2)-SIN(Incline(F,2))*Xgacc(F,2)*Segmass(2)*Cgdist(2)
6820            Moment(F,2)=Moment(F,2)+COS(Incline(F,2))*Ygacc(F,2)*Segmass(2)*Cgdist(2)
6830            Moment(F,2)=Moment(F,2)+COS(Incline(F,2))*Segwt(2)*Cgdist(2)
6840            Moment(F,2)=Moment(F,2)+COS(Incline(F,2))*Yforce(F,3)*Seglen(2)
6850            Moment(F,2)=Moment(F,2)-SIN(Incline(F,2))*Xforce(F,3)*Seglen(2)
6860            Moment(F,2)=Moment(F,2)+Moment(F,3)
6870            !  SEGMENT 1 -- Arms
6880            Xforce(F,1)=Segmass(1)*Xgacc(F,1)+Xforce(F,2)
6890            Yforce(F,1)=Segmass(1)*Ygacc(F,1)+Segwt(1)+Yforce(F,2)
6900            Moment(F,1)=I(1)*Angacc(F,1)-SIN(Incline(F,1))*Xgacc(F,1)*Segmass(1)*Cgdist(1)
6910            Moment(F,1)=Moment(F,1)+COS(Incline(F,1))*Ygacc(F,1)*Segmass(1)*Cgdist(1)
6920            Moment(F,1)=Moment(F,1)+COS(Incline(F,1))*Segwt(1)*Cgdist(1)
6930            Moment(F,1)=Moment(F,1)+COS(Incline(F,1))*Yforce(F,2)*Seglen(1)
6940            Moment(F,1)=Moment(F,1)-SIN(Incline(F,1))*Xforce(F,2)*Seglen(1)
6950            Moment(F,1)=Moment(F,1)+Moment(F,2)
6960        NEXT F
6970        RETURN
6980 Printkinetics:IF Pr$="N" THEN RETURN
6990        BEEP
7000        PRINTER IS 7,0,WIDTH(132)
7010        PRINT "KINETIC DATA"
```

```
7020       PRINT "************";LIN(2)
7030       FOR S=1 TO 3
7040          PRINT "SEGMENT";S;LIN(1);"Frame","Xforce","Yforce","Moment"
7050          FOR F=1 TO N
7060             PRINT F;T(F,1),Xforce(F,S),Yforce(F,S),Moment(F,S)
7070          NEXT F
7080          PRINT LIN(1)
7090       NEXT S
7100       PRINT LIN(10)
7110       PRINTER IS 16
7120       RETURN
7130 End:!
```

```
1000 End: !
1010 ! File: Digsb2                  Cartridge: BIOMECH PROG (3)
1020 ! Date: Dec 6, 1982 (update)    Author: P.J.Thiessen
1030 ! Desc: These subprograms allow easy access to digitizer features such as
1040 ! displaying characters, digitizing a single point, checking for a key
1050 ! press, getting the annotation number (data input from the key board), as
1060 ! well as procedures for scaling a film and calculating film speed.  This
1070 ! set of subprograms allows the digitizer to interrupt while digitizing a
1080 ! single point.  See also "Digsub" for similar programs.
1090 ! Keys: DIG,SUB,GET,DIGKEY,ANNOT,POINT,ALIGN,SCALE,FILM SPEED,DIGDISPLAY
1100 ! ------------------------------------------------------------------------
1110 Getdigkey:DEF FNGetdigkey(Select,Wait)  ! To determine which key is pressed
1120 IF Wait THEN OUTPUT Select;"SK0"        ! If Wait=0 then the function just
1130 OUTPUT Select;"OK"                      ! gets the key press, and then
1140 ENTER Select;Key                        ! returns.  Otherwise it clears the
1150 IF Wait AND (Key=0) THEN GOTO 1130      ! keys and waits for a key press.
1160 IF Key=4 THEN Key=3
1170 IF Key=8 THEN Key=4
1180 IF Key=16 THEN Key=5
1190 RETURN Key
1200 !
1210 Getannot:DEF FNGetannot(Select,Wait)       ! For entering annotation number.
1220 OUTPUT Select;"OS"                         ! If Wait=0 then function will
1230 ENTER Select;Status                        ! check annot. and then return.
1240 IF Wait AND NOT BIT(Status,0) THEN 1220    ! Otherwise, annot. is cleared
1250 OUTPUT Select;"ON"                         ! and function waits for a
1260 ENTER Select;Annot                         ! value to be entered.
1270 RETURN Annot
1280 !
1290 Getpoint:SUB Getpoint(Select,X,Y,Pen,Annot,Keyint)! For digitizing a single
1300 OUTPUT Select;"OS"                         ! point.  Also returns the pen
1310     ENTER Select;Status                    ! and annotation parameters.
1320     IF BIT(Status,7) THEN Keyint
1330     IF BIT(Status,2)=0 THEN Getpoint
1340 OUTPUT Select;"OD"
1350 ENTER Select;X,Y,Pen,Annot
1360 OUTPUT Select;"BP75,200"
1370 Keypress=0
1380 SUBEND
1390 Keyint:! KEY PRESS INTERRUPT
1400     Keyint=FNGetdigkey(Select,0)
1410     IF Keyint THEN SUBEXIT
1420     GOTO 1330
1430 !
1440 Pointalign:SUB Pointalign(Select,Xalign,Yalign)    ! To point align, add
1450 DIM C$[180]
1460 CALL Digdisplay(Select,"SCREEN ALIGN PT",0)        ! Xalign to X-coord. and
1470 CALL Getpoint(Select,Ox,Oy,P,A,Keyint)             ! Yalign to Y-coord,
1480 CALL Digdisplay(Select,"ACTUAL ALIGN PT",0)        ! before converting to
1490 CALL Getpoint(Select,Tx,Ty,P,A,Keyint)             ! real distances.
```

```
1500 Xalign=Ox-Tx
1510 Yalign=Oy-Ty
1520 SUBEND
1530 !
1540 Scale:SUB Scale(Select,Cfact)         ! To scale the data points (Cfact)
1550 DIM C$[180]
1560 DIM Sx(2),Sy(2)                       ! To convert digitizer coord. to
1570 OUTPUT Select;"IN;SG;AT"              ! real coord. simply multiply by
1580 FOR C=1 TO 2                          ! Cfact.
1590     OUTPUT Select;"BP;LB"
1600     CALL Digdisplay(Select,"DIG. SCALE PT "&VAL$(C),0) ! Dig. 2 points
1610     CALL Getpoint(Select,Sx(C),Sy(C),Pen,Annot,Keyint)
1620 NEXT C
1630 OUTPUT Select;"BP"
1640 WAIT 200
1650 OUTPUT Select;"BP;LB"
1660 CALL Digdisplay(Select,"ENTER ACTUAL",0)       ! Enter the actual distance
1670 Actual=FNGetannot(Select,1)                    ! between the two points.
1680 IF Actual=0 THEN GOTO 1650
1690 Digdist=SQR((Sx(2)-Sx(1))^2+(Sy(2)-Sy(1))^2)
1700 Cfact=Actual/Digdist                           ! Calculate convers. factor.
1710 FIXED 7
1720 CALL Digdisplay(Select,VAL$(Cfact)&" [A-R]",0)
1730 STANDARD
1740 Accept=FNGetdigkey(Select,1)
1750 IF Accept<>1 THEN GOTO 1570
1760 SUBEND
1770 !
1780 Fspeed:SUB Fspeed(Select,Cfact,Time,Fincr)  ! To calculate film speed
1790 DIM X(3),Y(3)
1800 CALL Scale(Select,Cfact)
1810 CALL Digdisplay(Select,"ENTER T",0)
1820 Assumed_t=FNGetannot(Select,1)
1830 STANDARD
1840 FOR I=1 TO 3
1850     CALL Pointalign(Select,Xalign,Yalign)
1860     OUTPUT Select USING "K,13X,K";"LB",(I-1)*Fincr ! Digitize ball at frame
1870     CALL Digdisplay(Select,"DIG BALL FR ",0)      ! in three frames
1880     CALL Getpoint(Select,X,Y,P,A,Keyint)          !
1890     X(I)=X-Xalign
1900     Y(I)=Y-Yalign
1910 NEXT I
1920 Vel1=SQR((X(2)-X(1))^2+(Y(2)-Y(1))^2)*Cfact/(Assumed_t*Fincr) ! Calculate
1930 Vel2=SQR((X(3)-X(2))^2+(Y(3)-Y(2))^2)*Cfact/(Assumed_t*Fincr) ! velocities
1940 Accel=(Vel2-Vel1)/(Assumed_t*Fincr)  !  Acceleration calculated here .
1950 Ratio=Accel/9.81                     ! Ratio to convert to real time.
1960 Time=Assumed_t*Ratio                 ! Calculate real time.
1970 FIXED 7
1980 OUTPUT Select USING "K";"LB",Time
1990 CALL Digdisplay(Select," [A-R]",10)
```

```
2000 STANDARD
2010 Accept=FNGetdigkey(Select,1)
2020 IF Accept=1 THEN GOTO 2070
2030      CALL Digdisplay(Select,"RE-SCALE [A-R]",0)
2040      Rescale=FNGetdigkey(Select,1)
2050      IF Rescale=1 THEN GOTO 1800
2060      GOTO 1810
2070 SUBEND
2080 !
2090 DEF FNDigflip(X)                      ! To flip X-coord. if projecting
2100 X=17400-X                             ! through the screen.
2110 RETURN X
2120 !
2130 Digdisplay: SUB Digdisplay(Select,D$,Offset) ! For displaying
2140 DIM C$[40],N(40),Code$[180]           ! characters on the digitizer display
2150 CALL Dispcode(Select,D$,Offset,Code$)
2160 OUTPUT Select;"LB"
2170 OUTPUT Select;Code$
2180 SUBEND
2190 !
2200 Dispcode:SUB Dispcode(Select,D$,Offset,Code$) ! For creating codes for
2210 DIM C$[40],N(40)                      ! displaying characters of the dig.
2220 STANDARD
2230 C$="ABCDEFGHIJLNOPQRSTUYZ1234567890-.dnou []"    ! (-- VALID CHARACTERS  !
2240 IF Offset)14 THEN SUBEXIT
2250 IF LEN(D$)+Offset(=15 THEN GOTO 2270
2260      D$=D$[1;15-Offset]               ! Offset leaves first positions empty
2270 RESTORE Convert
2280 MAT READ N
2290 Code$=""
2300 FOR D=1 TO LEN(D$)
2310      Code$=Code$&"DD"&VAL$(D+Offset)&","&VAL$(N(POS(C$,D$[D;1])))
2320      IF D(LEN(D$) THEN Code$=Code$&";"
2330 NEXT D
2340 SUBEND
2350 !  NUMERIC CONVERSIONS FOR THE VALID CHARACTERS  !
2360 Convert:DATA 0,238,254,156,252,158,142,246,110,12,120,28,236,252,206,230,204,182,30
2370 DATA 124,118,218,12,218,242,102,182,190,224,254,230,252,2,1,122,42,58,56,0,156,240
```

```
5000 End:!
5010 ! File: Interp                    Cartridge: DATA SMOOTHING
5020 ! Date: 1983 Update               Author: PJT adapted from HP software
5030 ! Desc: This subprogram interpolates data points within a specific domain
5040 ! defined by the user.  An old domain (X) is passed as well as the new
5050 ! domain and the original data (Y).  The subprog returns the new Y.  The
5060 ! user must also pass the error tolerance, while the subprog returns an
5070 ! error code if an error is encountered.
5080 !  SUB Interp(Data(*),Old_x(*),New_x(*),N,New_n,Numv,Errtol,Error,Prnt)
5090 ! Keys: INTERPOLATE,SMOOTH,FIT,NUMANL,SUB
5100 ! ------------------------------------------------------------------------
5110 Interp:SUB Interp(Data(*),Old_x(*),New_x(*),N,New_n,Numv,Errtol,Error,Prnt)
5120 DIM Y(New_n),X(New_n),Func(New_n)
5130 GOSUB Printparameters
5140 GOSUB Gety
5150 CALL Interpolator(N,New_n,Old_x(*),Y(*),New_x(*),Func(*),Errtol,Error)
5160 GOSUB Printinterp
5170 GOSUB Accept_reject
5180 IF Rejected THEN GOTO 5150
5190 SUBEND
5200 ! ------------------------------------------------------------------------
5210 Printparameters:IF NOT Prnt THEN RETURN
5220       PRINT PAGE;"Original Data (passed from main program):  N=";N;LIN(1);
5230       PRINT " ##","Old Domain","Data";LIN(1);CHR$(27)&"l";
5240       FOR F=1 TO N
5250           PRINT F,Old_x(F),Data(F,Numv)
5260       NEXT F
5270       WAIT 1000
5280       PRINT "";PAGE;"New Domain to be used for interpolation:  N=";New_n;LIN(1)
5290       PRINT " ##","New Domain";LIN(1);CHR$(27)&"l"
5300       FOR F=1 TO New_n
5310           PRINT F,New_x(F)
5320       NEXT F
5321       IF Errtol)0 THEN GOTO 5330
5322           BEEP
5323           INPUT "Error tolerance is undefined (0).  Please enter an error tolerance",Errtol
5324           GOTO 5321
5330       DISP "Error tolerance:";Errtol
5340       RETURN
5350 Gety: FOR F=1 TO N
5360           Y(F)=Data(F,Numv)
5370       NEXT F
5380       RETURN
5390 Printinterp:IF NOT Prnt OR Error THEN RETURN
5400       PRINT CHR$(27)&"m";PAGE;"Interpolated Data:";LIN(1);
5410       PRINT " ##","New Domain","New Data";LIN(1);CHR$(27)&"l"
5420       FOR I=1 TO New_n
5430          PRINT I,New_x(I),Func(I)
5440       NEXT I
5450       RETURN
```

```
5460 Accept_reject:!
5470       Reject=0
5480       IF Error THEN GOTO Errortrap
5490       IF NOT Prnt THEN GOTO 5630
5500       INPUT "Is the above acceptable [Y/N]",Accept$
5510       IF Accept$="Y" THEN GOTO 5610
5520           INPUT "Do you want to reinterpolate with a new error tolerance [Y/N]",Redo$
5530           IF Redo$<>"Y" THEN GOTO 5580
5540               DISP "Please enter the new Error Tolerance (currently set at ";VAL$(Errtol);")";
5550               INPUT "",Errtol
5560               Rejected=1
5570           RETURN
5580               DISP "Interpolation rejected -- data will be returned unaltered!!"
5590               WAIT 2000
5600               GOTO 5660
5610       DISP "Interpolation accepted -- New number of arguments:";New_n
5620       WAIT 2000
5630       FOR I=1 TO New_n
5640           Data(I,Numv)=Func(I)
5650       NEXT I
5660       RETURN
5670 Errortrap:BEEP
5680       IF NOT Prnt THEN GOTO 5730
5690           DISP " ERROR";Error;" ";
5700           IF Error=-1 THEN DISP "  N=";N;"    Errtol=";Errtol
5710           IF Error=-2 THEN DISP "A new domain value (New_x) is outside of the old domain (Old_x)"
5720       WAIT 2000
5730       SUBEXIT
5740 ! ----------------------------------------------------------------------
5750 !         ***  SUBPROGRAM Interpolate -- Does the interpolation  ***
5760 ! ----------------------------------------------------------------------
5770 SUB Interpolator(N,Narg,X(*),Y(*),Domain(*),Func(*),Eps,Error)
5780 ! BAD DATA CHECK.
5790 Baddta=(N<=0) OR (Eps<=0)
5800 IF Baddta=0 THEN 5850
5810    BEEP
5820    Error=-1
5830    GOTO Out
5840 ! BEGIN SUBPROGRAM.
5850 OPTION BASE 1
5860 DIM S(N),G(N-1),Work(N-1)
5870 DEFAULT ON
5880 FOR I=2 TO N-1
5890    Xi=X(I)
5900    Ximi=X(I-1)
5910    Xipi=X(I+1)
5920    Yi=Y(I)
5930    Yimi=Y(I-1)
5940    Yipi=Y(I+1)
5950    X=Xi-Ximi
```

```
5960    H=Xip1-Xim1
5970    Work(I)=.5*X/H
5980    T=((Yip1-Yi)/(Xip1-Xi)-(Yi-Yim1)/X)/H
5990    S(I)=2*T
6000    G(I)=3*T
6010 NEXT I
6020 S(1)=S(N)=0
6030 ! W IS THE RELAXATION FACTOR FOR SUCCESSIVE OVER-RELAXATION.
6040 W=8-4*SQR(3)
6050 U=0
6060 FOR I=2 TO N-1
6070    T=W*(-S(I)-Work(I)*S(I-1)-(.5-Work(I))*S(I+1)+G(I))
6080    H=ABS(T)
6090    IF H>U THEN U=H
6100    S(I)=S(I)+T
6110 NEXT I
6120 IF U>=Eps THEN 6050
6130 FOR I=1 TO N-1
6140    G(I)=(S(I+1)-S(I))/(X(I+1)-X(I))
6150 NEXT I
6160 IF Narg=0 THEN 6440
6170 ! CALCULATE FUNCTION VALUES AND DERIVATIVES.
6180 FOR J=1 TO Narg
6190 Corrector:    I=1
6200    T=Domain(J)
6210    IF T>=X(1) THEN 6250
6220       BEEP
6230       Error=-2
6240       GOTO Out
6250    I=I+1
6260    IF I>N THEN 6220
6270    IF T>X(I) THEN 6250
6280    I=I-1
6290    H=Domain(J)-X(I)
6300    T=Domain(J)-X(I+1)
6310    X=H*T
6320    S=S(I)+H*G(I)
6330    Z=1/6
6340    U=Z*(S(I)+S(I+1)+S)
6350    W=(Y(I+1)-Y(I))/(X(I+1)-X(I))
6360    Func(J)=W*H+Y(I)+X*U
6370  ! Deriv(J)=W+(H+T)*U+Z*X*G(I)  ! For calculating the derivative (NOT DONE)
6380 NEXT J
6390 Out:SUBEND
6400 Errtrap:Error=ERRN
6410 SUBEND
6420 ! ----------------------------------------------------------------------
6430 ! ROUTINE FOR CALCULATING THE INTEGRAL FROM X(1) TO X(N).
6440 Int=0
6450 FOR I=1 TO N-1
```

```
6460    H=X(I+1)-X(I)
6470    Int=Int+.5*H*(Y(I)+Y(I+1))-1/24*H^3*(S(I)+S(I+1))
6480 NEXT I
6490 ! ------------------------------------------------------------------------
```

```
10   ! File: HBDIG                  Cartridge: PJT THESIS PROGRAMS (2)
20   ! Date: June 1983              Author: P.J.Thiessen
30   ! Desc: This program is specifically designed for digitizing ten points
40   ! of a subject swinging on a horizontal bar, as required by PJT in his
50   ! thesis work.  The C of G's are not calculated.  All coordinates are rel-
60   ! ative to the top of the near support post of the high bar.
70   ! Keys: HIGH BAR,DIG,PJT THESIS
80   ! ----------------------------------------------------------------
90   OPTION BASE 0
100  INTEGER Coord(500,9,1)
110  DIM Code$(9)[40],Disp$(9)[30],Code$[80],Descr$[180]
120  DIM Sub$(4)[25],Skill$(4)[25]
130  Select=706
140  GOSUB Setup
150  GOSUB Getdigcodes
160  GOSUB Digitize
170  GOSUB Storedata
180  DISP "Program HBDIG ended."
190  END
200 Setup:RESTORE 220
210       MAT READ Sub$,Skill$
220       DATA "",P.THIESSEN,M.GIFFORD,R.HEIDERICH,""
230       DATA "",FULL TWIST,NO TWIST,FRONT GIANT,INWARD
240       PRINT CHR$(27)&"m";PAGE;TAB(23);"  PJT H.BAR DIGITIZING PROGRAM  ";LIN(2);CHR$(27)&"l"
250       PRINT "File name format:";TAB(36);CHR$(34);"HBabcd";CHR$(34)
260       PRINT
270       PRINT "                        where   a = subject number"
280       PRINT "                                b = film number"
290       PRINT "                                c = skill number"
300       PRINT "                                d = trial number";LIN(1)
310       PRINT RPT$("-",80);LIN(1)
320       PRINT "Subjects";TAB(40);"Skills";LIN(1)
330       FOR I=1 TO 4
340          IF I<3 THEN PRINT VAL$(I);") ";Sub$(I);
350          PRINT TAB(40);VAL$(I);") ";Skill$(I)
360       NEXT I
370       INPUT "Setup: Please enter the file name for this digitizing session",File$
380       PRINT PAGE;
390       PRINT "File: ";File$;LIN(1)
400       Subject=VAL(File$[3;1])
410       Film=VAL(File$[4;1])
420       Skill=VAL(File$[5;1])
430       Trial=VAL(File$[6;1])
440       Descr$="PJT THESIS: Subject: "&Sub$(Subject)&", Film: "&VAL$(Film)&", Skill: "&Skill$(Skill)&", Trial
: "&VAL$(Trial)
450       PRINT "Desc: ";Descr$;LIN(1)
460       PRINT "Subject:";Subject
470       PRINT "Film:   ";Film
480       PRINT "Skill:  ";Skil
490       PRINT "Trial:  ";Trial;LIN(1)
```

```
500     Descr$="PJT THESIS: Subject: "&Sub$(Subject)&", Film: "&VAL$(Film)&", Skill: "&Skill$(Skill)&", Trial
: "&VAL$(Trial)
510     Numpts=9
520     Start=0
530     LINPUT "Setup: Are you continuing on an already existing file [Y/N]",Cont$
540     IF Cont$<>"Y" THEN GOTO 720
550       DISP "Setup:  Please insert the cartridge holding the file -- then CONTINUE"
560       PAUSE
570       ASSIGN #1 TO File$,Rerr
580       IF NOT Rerr THEN GOTO 630
590         BEEP
600         DISP "Setup: File ";File$;" not found or wrong protect code"
610         WAIT 3000
620       GOTO Setup
630         READ #1;Descr$,Nf,Np,Cfact,Time
640         PRINT "File ";File$;" thus far;";LIN(1)
650         PRINT "Frames:";Nf
660         PRINT "Points:";Np
670         PRINT "C.factor:";Cfact
680         PRINT "Time/fr:";Time
690         Start=Nf+1
700         DISP "Setup: Digitizing will begin with frame";Start;"-- press CONTINUE"
710         PAUSE
720     INPUT "Setup: Do you want to check each frame (plot & then accept) [Y/N]",Check$
730     IF Check$="Y" THEN PLOTTER IS 7,5,"9872A"
740     IF Cont$="Y" THEN GOTO 850
750     INPUT "Setup: Do you want to calculate film speed [Y/N]",Fs$
760     IF UPC$(Fs$)="Y" THEN GOTO 840
770       INPUT "Setup: Please enter the time between frames",Time
780       INPUT "Setup: Are you digitizing every frame, every 2nd, 3rd, etc. [Enter 1,2,3]",Ev
790       Time=Time*Ev
800       INPUT "Setup: Do you want to scale the film",Sc$
810       IF UPC$(Sc$)="Y" THEN CALL Scale(Select,Cfact)
820       IF UPC$(Sc$)<>"Y" THEN INPUT "Setup: Please enter the scale factor",Cfact
830     GOTO 850
840       CALL Fspeed(Select,Time,Cfact,10)
850     RETURN
860 Getdigcodes:PRINT PAGE;"Joint point digitizer code names:";LIN(1)
870     DISP "Generating joint codes -- please wait"
880     RESTORE Digcodes
890     FOR I=0 TO 9
900       READ Disp$(I)
910       CALL Dispcode(Select,Disp$(I),12,Code$(I))
920       READ C$
930       Disp$(I)=Disp$(I)&" = "&C$
940     NEXT I
950     GOSUB Hpbeep
960     FOR I=0 TO 9 STEP 2
970       PRINT VAL$(I);") ";
980       IF I<10 THEN PRINT " ";
```

```
990          PRINT CHR$(133);Disp$(I)[1;3];CHR$(128);
1000         PRINT Disp$(I)[4];TAB(40);
1010         IF I=21 THEN GOTO 1060
1020         PRINT VAL$(I+1);") ";
1030         IF I+1(10 THEN PRINT " ";
1040         PRINT CHR$(133);Disp$(I+1)[1;3];CHR$(128);
1050         PRINT Disp$(I+1)[4]
1060      NEXT I
1070      PRINT LIN(2);"Digitizer key codes:";LIN(1)
1080      PRINT "fa = Accept","fb = Reject","fc = Back 1 pt"
1090      PRINT "fd = Ahead 1 pt","fe = start a new frame"
1100      RETURN
1110 Digcodes:DATA BAR,H.Bar,RST,Wrist,ELB,Elbow,SHO,Shoulder,TOH,Top of head
1120 DATA HIP,Hips,NEE,Knees,ANL,Ankles,HEL,Heels,TOE,Toes
1130 Digitize:OUTPUT Select;"IN;SG;AT"
1140      F=Start
1150      DISP "Digitize:  Ready to begin digitizing frame";F;"-- please press CONTINUE"
1160      PAUSE
1170      DISP
1180      F=Start
1190 Nextframe:! GOSUB Digbeep
1200          Newf=0
1210          DISP "Digitize: Top of support post";F
1220          GOSUB Support_pt
1230          IF NOT Keyint THEN GOTO 1250
1240          ON Keyint GOTO 1220,Exit,1220,1220,1220
1250          Maxpt=1
1260          FOR P=0 TO Numpts
1270              DISP "Digitize:   Frame:";F;"   Point:";P
1280              IF (P=11) AND (Chip$="C") THEN GOTO 1410
1290              OUTPUT Select USING "K,DDD,2X,DD";"LB";F,P
1300              IF P(22 THEN OUTPUT Select;Code$(P)
1310              Keyint=0
1320              CALL Getpoint(Select,X,Y,Pen,A,Keyint)
1330              IF NOT Keyint THEN GOTO 1380
1340                  GOSUB Keypress
1350                  IF Finished THEN GOTO Exit
1360                  IF NOT Newf THEN GOTO 1270
1370                  GOTO 1190
1380              Coord(F,P,0)=X-Sx      ! Save coord as point relative to the
1390              Coord(F,P,1)=Y-Sy      ! support post (Post =0,0)
1400              Maxpt=MAX(P,Maxpt)
1410          NEXT P
1420          IF Check$="Y" THEN GOSUB Plotframe
1430          IF Ar$="R" THEN GOTO 1190
1440          F=F+1
1450      GOTO Nextframe
1460 Exit:CALL Digdisplay(Select,"DIG FINISHED",0)
1470      GOSUB Digbeep
1480      CALL Digdisplay(Select,"SEE HP....",0)
```

```
1490      Numfrms=F-1
1500      DISP "Number of frames digitized: ";VAL$(Numfrms);", is that all ? [Y/N]";
1510      INPUT "",Fin$
1520      IF UPC$(Fin$)="Y" THEN GOTO 1590
1530          BEEP
1540          Finished=0
1550          DISP "Digitizing will be continued at frame";Numfrms+1
1560          F=Numfrms+1
1570          WAIT 2000
1580          GOTO 1190
1590      RETURN
1600 Support_pt:CALL Digdisplay(Select,"SUPPORT ["&VAL$(F)&"]",0)
1610      CALL Getpoint(Select,Sx,Sy,P,A,Keyint)
1620      OUTPUT Select;"SK0"
1630      IF Keyint AND ((Keyint<>3) AND (Keyint<>4)) THEN GOSUB Keypress
1640      IF Keyint=5 THEN GOTO Support_pt
1650      RETURN
1660 Keypress:OUTPUT Select;"SK0"
1670      IF Keyint=1 THEN RETURN
1680      IF Keyint=2 THEN Finished=1
1690      IF Keyint=2 THEN RETURN
1700      IF Keyint=3 THEN Decpoint
1710      IF Keyint=4 THEN Incpoint
1720      IF Keyint=5 THEN Newframe
1730      GOTO 1310
1740 Decpoint:IF P>0 THEN P=P-1
1750      OUTPUT Select;"BP100,100"
1760      RETURN
1770 Incpoint:IF (P=21) OR (P>Maxpt) THEN RETURN
1780      OUTPUT Select;"BP100,100"
1790      P=P+1
1800      RETURN
1810 Newframe:OUTPUT Select;"BP100,100"
1820      WAIT 50
1830      OUTPUT Select;"BP100,100"
1840      CALL Digdisplay(Select,"ENTER FR",0)
1850      F=FNGetannot(Select,1)
1860      P=Maxpt=1
1870      Newf=1
1880      RETURN
1890 Plotframe:CALL Digdisplay(Select,"PLOTTING",0)
1900      OUTPUT Select;"SK0"
1910      OVERLAP
1920      GOSUB Digbeep
1930      PLOTTER IS "9872A"
1940      SCALE -17400/2,17400/2,-13500/2,13500/2
1950      RESTORE Plotorder
1960      FOR I=1 TO 13
1970          READ Pt
1980          IF Pt=-1 THEN GOTO 2010
```

```
1990             PLOT Coord(F,Pt,0),Coord(F,Pt,1)
2000         GOTO 2020
2010             PENUP
2020     NEXT I
2030     PENUP
2040     K=FNGetdigkey(Select,0)    ! Check keys in case of rejection
2050     Ar$="A"
2060     IF K=2 THEN Ar$="R"
2070     RETURN
2080 Ploterder:DATA 0,1,2,3,4,-1,3,5,6,7,8,9,-1
2090 Digbeep:FOR B=1 TO 5
2100         OUTPUT Select;"BP150,50"
2110         WAIT 50
2120     NEXT B
2130     RETURN
2140 Hpbeep:FOR B=1 TO 5
2150         BEEP
2160         WAIT 50
2170     NEXT B
2180     RETURN
2190 Storedata:PRINT PAGE
2200     Numrecs=Numfrms+3
2210     IF Cont$="Y" THEN GOTO 2240
2220     DISP "Data Storage:  Records needed:";Numrecs;"  Please insert cartridge, then CONTINUE"
2230     PAUSE
2240     ASSIGN #1 TO File$,Rerr
2250     IF Rerr THEN GOTO 2340
2260         IF Cont$<>"Y" THEN GOTO 2300
2270             DISP "Data Storage:  File ";File$;" has been found"
2280             WAIT 1000
2290         GOTO 2420
2300             BEEP
2310             DISP "Data Storage:  File ";File$;" already exists, please begin again"
2320             WAIT 3000
2330         GOTO Storedata
2340     IF Cont$<>"Y" THEN GOTO 2390
2350         BEEP
2360         DISP "Data Storage:  File ";File$;" cannot be located, please try again"
2370         WAIT 3000
2380         GOTO Storedata
2390     ON ERROR GOTO Storerror
2400     DISP "Data Storage:  Creating file ";File$;""
2410     CREATE File$,Numrecs,80
2420     DISP "Data Storage:  Storing data in file ";File$;""
2430     ASSIGN #1 TO File$
2440     PRINT #1;Descr$,Numfrms,Numpts,Cfact,Time
2450     FOR F=Start TO Numfrms
2460         PRINT #1,F+3
2470         DISP "Data Storage:  Storing data in file ";File$;"  Frame:";F;"Record:";F+3
2480         FOR P=0 TO Numpts
```

```
2490          PRINT #1;Coord(F,P,0),Coord(F,P,1)
2500       NEXT P
2510    NEXT F
2520    ASSIGN * TO #1
2530    DISP "Data Storage: Completed"
2540    OFF ERROR
2550    WAIT 1000
2560    RETURN
2570 Storerror:BEEP
2580    IF (ERRN<>53) AND (ERRN<>54) THEN GOTO 2610
2590       EDIT " ERROR  -- Improper or Duplicate file name (Please enter a new file name)",File$
2600    GOTO 2340
2610    IF (ERRN<>64) AND (ERRN<>55) THEN GOTO 2650
2620       DISP " ERROR  -- Cartridge is full, please insert another and press CONTINUE'
2630       PAUSE
2640    GOTO 2340
2650    DISP " ERROR  encountered while trying to store (";ERRM$;")"
2660    PAUSE
2670    GOTO 2650
2680 End: !
2690 ! -----------------------------------------------------------------------
2700 !                     DIGITIZER SUBPROGRAMS & FUNCTIONS
2710 ! -----------------------------------------------------------------------
2720 Getdigkey:DEF FNGetdigkey(Select,Wait)
2730 IF Wait THEN OUTPUT Select;"SK0"
2740 OUTPUT Select;"OK"
2750 ENTER Select;Key
2760 IF Wait AND (Key=0) THEN GOTO 2740
2770 IF Key=4 THEN Key=3
2780 IF Key=8 THEN Key=4
2790 IF Key=16 THEN Key=5
2800 RETURN Key
2810 Getannot:DEF FNGetannot(Select,Wait)
2820 OUTPUT Select;"OS"
2830 ENTER Select;Status
2840 IF Wait AND (Status<>17) THEN GOTO 2820
2850 OUTPUT Select;"ON"
2860 ENTER Select;Annot
2870 RETURN Annot
2880 Getpoint:SUB Getpoint(Select,X,Y,Pen,Annot,Keyint)
2890 Keyint=0
2900 OUTPUT Select;"OS"
2910    ENTER Select;Status
2920    IF BIT(Status,7) THEN Keyint
2930    IF BIT(Status,2)=0 THEN Getpoint
2940 OUTPUT Select;"OD"
2950 ENTER Select;X,Y,Pen,Annot
2960 OUTPUT Select;"BP75,200"
2970 Keypress=0
2980 SUBEND
```

```
2990 Keyint:! KEY PRESS INTERRUPT
3000     Keyint=FNGetdigkey(Select,0)
3010     IF Keyint THEN SUBEXIT
3020     GOTO 2930
3030 Pointalign:SUB Pointalign(Select,Xalign,Yalign,F)
3040 DIM C$[180]
3050 CALL Digdisplay(Select,"SCREEN PT ["&VAL$(F)&"]",0)
3060 CALL Getpoint(Select,Ox,Oy,P,A,Keyint)
3070 CALL Digdisplay(Select,"ACTUAL PT ["&VAL$(F)&"]",0)
3080 CALL Getpoint(Select,Tx,Ty,P,A,Keyint)
3090 Xalign=Ox-Tx
3100 Yalign=Oy-Ty
3110 SUBEND
3120 Scale:SUB Scale(Select,Cfact)
3130 DIM C$[180]
3140 DIM Sx(2),Sy(2)
3150 OUTPUT Select;"IN;SG;AT"
3160 FOR C=1 TO 2
3170     OUTPUT Select;"BP;LB"
3180     CALL Digdisplay(Select,"DIG. SCALE PT "&VAL$(C),0)
3190     CALL Getpoint(Select,Sx(C),Sy(C),Pen,Annot,Keyint)
3200 NEXT C
3210 OUTPUT Select;"BP"
3220 WAIT 200
3230 OUTPUT Select;"BP;LB"
3240 CALL Digdisplay(Select,"ENTER ACTUAL",0)
3250 Actual=FNGetannot(Select,1)
3260 IF Actual=0 THEN GOTO 3230
3270 Digdist=SQR((Sx(2)-Sx(1))^2+(Sy(2)-Sy(1))^2)
3280 Cfact=Actual/Digdist
3290 FIXED 7
3300 CALL Digdisplay(Select,VAL$(Cfact)&" [A-R]",0)
3310 STANDARD
3320 Accept=FNGetdigkey(Select,1)
3330 IF Accept<>1 THEN GOTO 3150
3340 SUBEND
3350 Fspeed:SUB Fspeed(Select,Cfact,Time,Fincr)
3360 DIM X(3),Y(3)
3370 CALL Scale(Select,Cfact)
3380 CALL Digdisplay(Select,"ENTER T",0)
3390 Assumed_t=FNGetannot(Select,1)
3400 STANDARD
3410 FOR I=1 TO 3
3420     CALL Pointalign(Select,Xalign,Yalign)
3430     OUTPUT Select USING "K,13X,K";"LB",(I-1)*Fincr
3440     CALL Digdisplay(Select,"DIG BALL FR ",0)
3450     CALL Getpoint(Select,X,Y,P,A,Keyint)
3460     X(I)=X-Xalign
3470     Y(I)=Y-Yalign
3480 NEXT I
```

```
3490 Vel1=SQR((X(2)-X(1))^2+(Y(2)-Y(1))^2)*Cfact/(Assumed_t*Fincr)
3500 Vel2=SQR((X(3)-X(2))^2+(Y(3)-Y(2))^2)*Cfact/(Assumed_t*Fincr)
3510 Accel=(Vel2-Vel1)/(Assumed_t*Fincr)  !  Acceleration calculated here .
3520 Ratio=Accel/9.81                     ! Ratio to convert to real time.
3530 Time=Assumed_t*Ratio                 ! Calculate real time.
3540 FIXED 7
3550 OUTPUT Select USING "K";"LB",Time
3560 CALL Digdisplay(Select," [A-R]",10)
3570 STANDARD
3580 Accept=FNGetdigkey(Select,1)
3590 IF Accept=1 THEN GOTO 3640
3600      CALL Digdisplay(Select,"RE-SCALE [A-R]",0)
3610      Rescale=FNGetdigkey(Select,1)
3620      IF Rescale=1 THEN GOTO 3370
3630      GOTO 3380
3640 SUBEND
3650 DEF FNDigflip(X)
3660 X=17400-X
3670 RETURN X
3680 Digdisplay: SUB Digdisplay(Select,D$,Offset)
3690 DIM C$[40],N(40),Code$[180]
3700 CALL Dispcode(Select,D$,Offset,Code$)
3710 OUTPUT Select;"LB"
3720 OUTPUT Select;Code$
3730 SUBEND
3740 Dispcode:SUB Dispcode(Select,D$,Offset,Code$)
3750 DIM C$[40],N(40)
3760 STANDARD
3770 C$="ABCDEFGHIJLNOPQRSTUYZ1234567890-.dnou []"    ! (-- VALID CHARACTERS  !
3780 IF Offset)14 THEN SUBEXIT
3790 IF LEN(D$)+Offset(=15 THEN GOTO 3810
3800      D$=D$[1;15-Offset]
3810 RESTORE Convert
3820 MAT READ N
3830 Code$=""
3840 FOR D=1 TO LEN(D$)
3850     Code$=Code$&"DD"&VAL$(D+Offset)&","&VAL$(N(POS(C$,D$[D;1])))
3860     IF D(LEN(D$) THEN Code$=Code$&";"
3870 NEXT D
3880 SUBEND
3890 !  NUMERIC CONVERSIONS FOR THE VALID CHARACTERS  !
3900 Convert:DATA 0,238,254,156,252,158,142,246,110,12,120,28,236,252,206,230,204,182,30
3910 DATA 124,118,218,12,218,242,102,182,190,224,254,230,252,2,1,122,42,58,56,0,156,240
```

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