BACK GIANT BIOMECHANICS FOR COACHES

Hiley, M. J. Mechanics of the Giant Circle on High Bar. Dissertation, Loughborough University, 1998

Summary and review by James Major, Davis Diamonds Gymnastics

Introduction

This is a summary of Dr. M. J. Hiley's 410 page doctoral dissertation on the mechanics of high bar back giant swings. Dr. Hiley's dissertation is a treasure trove of essential information for gymnastics coaches. His results and insights are basic knowledge of a basic gymnastics skill, won at the cost of great effort. Most research on the back giant circle has focused on the regular giant circle, but Dr. Hiley also investigated the accelerating giant circle, the so-called "Chinese tap", as well as back giants immediately prior to a release skill or dismount. Much of what he discovered is also applicable to giant swings on the uneven bars. Dr. Hiley treated the high bar as bouncy and also attempted to include the shoulders as a spring. A first, Hiley studied the shoulders as a spring and not just the bar. He obtained stiffness and damping coefficients for the shoulder spring as well as the bar. His results were in line with the previous research results of other scientists and expanded them.

Dr. Hiley emphasized creating a model of gymnasts swinging back giants on a high bar. Computer models of gymnasts performing skills can be used to discover how to change the technique of the skill to make it better, or optimization. The aim of optimisations is to obtain techniques which may be used by all gymnasts. Simulation models have been used to investigate new skills and techniques which have not been tried by real gymnasts and at least one skill, the straddled Tkatchev, was invented by scientists and then taught to a coach and gymnast. Theoretical optimizations are evaluated by comparing the predictions with experimental data. The details of this highly sophisticated work is probably of less relevance to coaches so I have not included most of it here. However, suffice to say that a model that closely reproduces the empirical data is a useful tool for coaches creating and testing new skills, as well as evaluating in finer detail the actual performance of a gymnast. Dr. Hiley did find that it is possible that there is an optimal technique that may be used for any gymnast given the appropriate strength.

Obviously, any dissertation contains many sections required by the University. Some of these are of limited interest to a coach and I have left them out. Dr. Hiley also discussed a list of future research questions that arose directly from his work here. I have also chosen to leave this part out. All of the figures are original from Dr. Hiley's dissertation with the original identification numbers and captions so that anyone who wishes to consult the dissertation can find them and more text that explains them. The illustrations of gymnasts are all computer drawn from real data and not influenced by artistic subjectivity. I encourage anyone who wants a deeper dive to read Dr. Hiley's original dissertation. My hope is that this summary will be an inspiration.

The Olympic Teams of the former D.D.R. and Soviet Union had staff gymnastics scientists working together with the gymnasts and coaches to directly improve performance. With these exceptions, many scientists don't investigate subjects that are important for coaches or publish their results in journals that coaches don't, and sometimes can't, or won't, read. Too often, scientific knowledge is expressed in inexcusable jargon that even confuses scientists. Many American coaches are not familiar with scientific units of measure and therefore can't easily visualize distances and forces in meters, radians, or Newtons. But the knowledge gap goes both ways: under constant pressure to qualify and produce champions, coaches and the federations don't make a priority of funding research or development, even if it could give them a competitive edge. With the number of hours professional gymnastics coaches spend in the gym, in a physically demanding profession, there is precious little time or energy left to spend decoding important information. But our national outbreak of science denial mental illness must not infect our wonderful sport of gymnastics.

Methods

Dr. Hiley collected data from international elite gymnasts. For safety reasons, the gymnast was in straps as well as wearing grips. Three-dimensional coordinate data were collected from a gymnast swinging on the high bar. Simultaneously force recordings from the bar were obtained and synchronised with the video data.

Dr. Hiley expended a great deal of time and effort measuring and calculating estimated errors of every data point. Every instrument was calibrated and this data is included for readers to inspect. The error of each measurement was also calculated and listed. The highly sophisticated techniques of how this was done in each case is explained in detail. However, these technical aspects of this work are not directly relevant to the needs of coaches. Rest assured that independent experts evaluated the precision of every measurement in this research and evaluated Dr. Hiley's assumptions and conclusions.

First, we need to understand how he dissected a back giant swing. He used a convention that could be useful for coaches. Circling the bar counter-clockwise, space around the bar was divided into four quadrants:

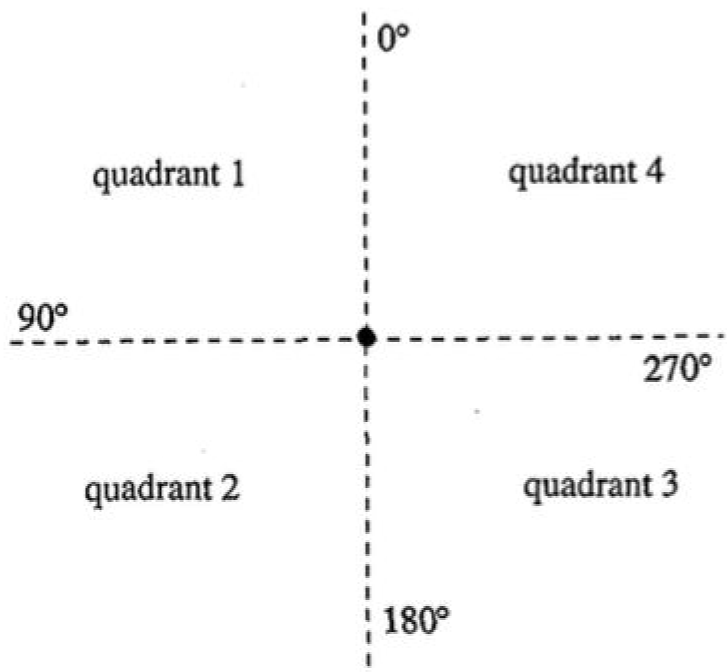

Figure 8.4. The four quadrants of the giant circle.

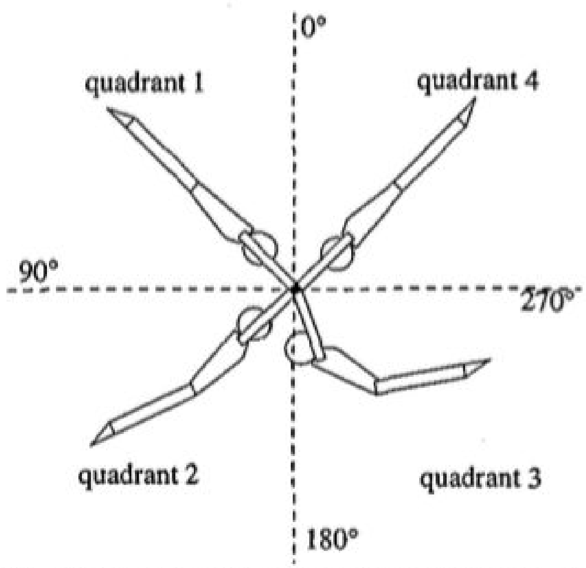

Figure 2.15. The four quadrants of the backward giant circle.

Note that these four quadrants are defined for a gymnast circling the bar in a counter-clockwise direction. This convention was maintained in all other figures. Next, we need to understand the elementary swing, the regular back giant swing, and the accelerating back giant swing:

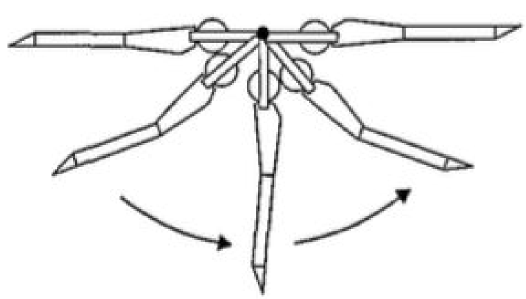
Figure 2.8. The elementary swing.

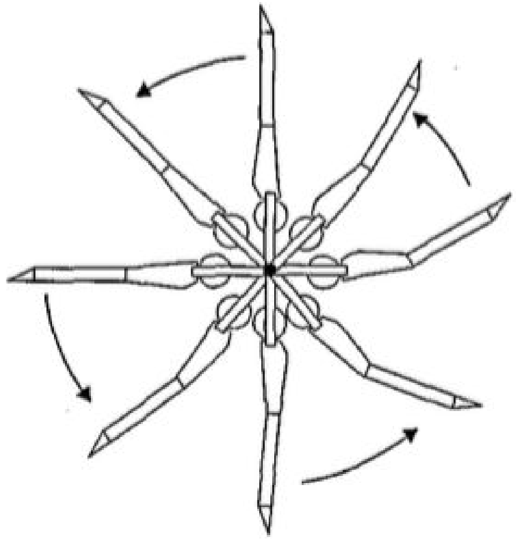

Figure 2.6. The backward giant circle.

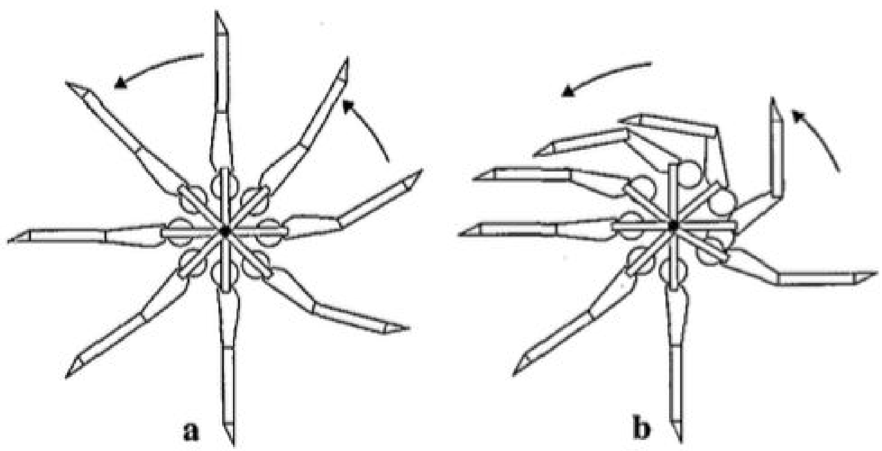

Figure 1.1. Two types of accelerated giant circle.

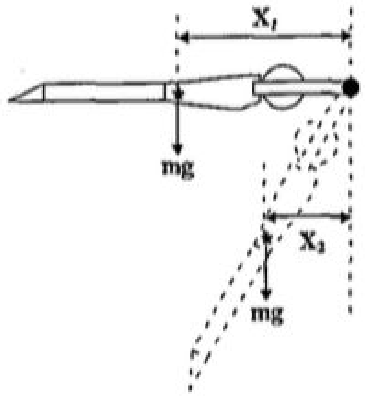

Figure 2.9. Torque created by the gymnast during swinging.

The acceleration acting during a giant circle is created by the force of gravity and the gymnast's mass (mg) (Figure 2.9). There is friction between hands and bar. In fact, the friction between the gymnast's hands and bar while swinging defines how the gymnast grasps the bar. When a gymnast swings, the hands tend to rotate with the rest of the body, This is opposed by frictional forces. During the downswing the torque created by friction acts in the opposite direction to the torque created by the gymnast's weight, reducing the gymnast's angular acceleration. During the upswing, the friction torque acts in the same direction as the torque created by the gymnast's weight, both slowing down the gymnast. Swinging forwards, the frictional forces have the effect of wrapping the gymnast's fingers around the bar, tightening the gymnast's grip. But when swinging backwards, the frictional forces tend to loosen the gymnast's grip. This is why a gymnast will re-grasp the bar at the top of the backswing during elementary swings.

A second way to describe swinging mechanics is to look at transfers of energy. In the handstand position, the gymnast has potential energy due his position above the ground. During the downswing the gymnast remains extended to maximise the effect of the gravitational moment. As the gymnast passes through the lowest point, his rotational energy equals the change in potential energy between the handstand and the hanging position, minus any losses in energy due air resistance and friction between the gymnast's hands and the bar. The “beatswing” in British English, or “tap swing” action (Figure 2.11) which is seen as the gymnast passes through the lowest part of the swing uses muscular energy to replace energy “lost” to friction, enabling the gymnast to return to the handstand position, or in the case of the elementary swing to reach the horizontal. However, if the gymnast puts more energy into the system during the tap swing than has been lost, then when completing the giant circle the gymnast will have more energy than at the start. This extra energy appears in the form of rotational energy. On returning to the handstand position the gymnast will be rotating faster than at the start of the circle. This type of giant circle is called an accelerating giant circle and is used to increase the gymnast's rotation around the bar for dismount or release-and-regrasp skills.

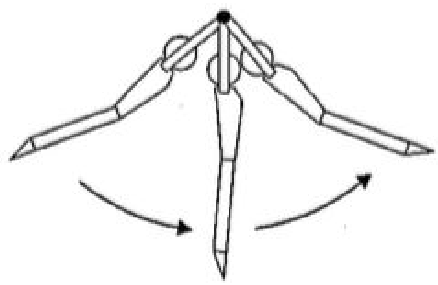

Figure 2.11. The beatswing action.

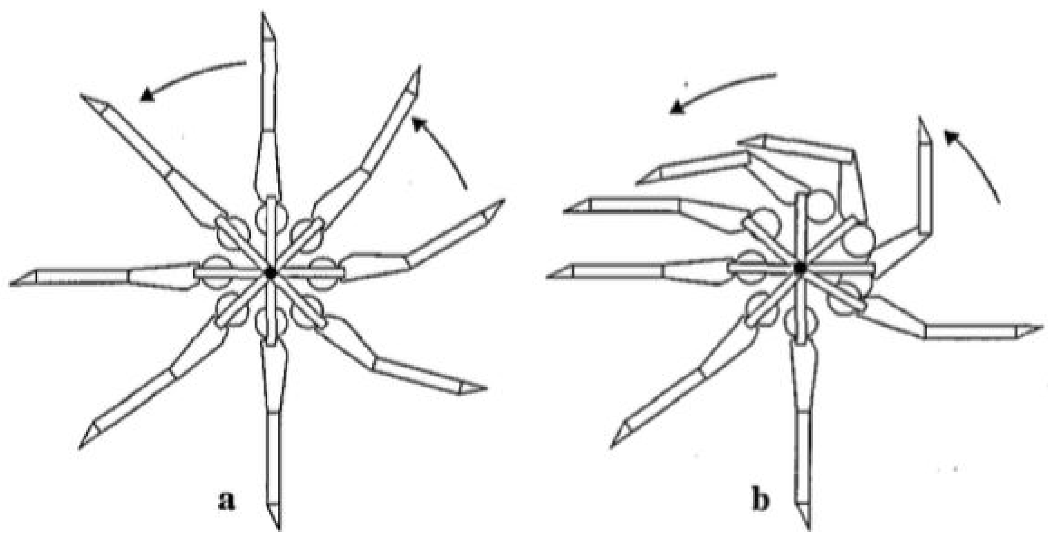

Figure 2.12. The two general techniques used by gymnasts winding up for a dismount.

Reaction force data have been collected from gymnasts performing regular giant circles and also from gymnasts performing accelerating giant circles. However, Dr. Hilley recorded force from the same gymnast performing both regular and accelerating giant circles. To record forces while the gymnast circled the high bar, he glued 16 strain gauges to the surface of the bar. An arrangement of four electronic circuits recorded the force applied to the bar independent of where the force was applied. High bar flexibility was calibrated vertically, pulling down towards the floor, as well as horizontally, pulling towards the far wall. The video analysis program calculated the lengths of the subjects' limbs in each quadrant. The hypothesis was that the gymnast got longer during the lowest part of the giant circle. The majority of this stretch was believed to be in the shoulders and the spine.

What was the goal of the impressive amount of effort to make a model? Dr. Hilley's model aimed to be simple enough to allow the mechanics of the backward giant circle to be determined, yet sophisticated enough to model the important technical elements. Previous research suggested that the simplest model which could accurately model a gymnast swinging on a high bar had to include certain components. The model must be able to move in the shoulders, hips and knees. These movements would require a model with a minimum of four segments, one each for the arms, torso (including the head), thighs, and shins (including feet). As the major movements of the backward giant circle appear to occur in the sagittal plane, with symmetrical left and right sides of the body, a two-dimensional model could be used. The arm, thigh, and shin segments would represent both arms, both thighs and both shins, respectively. In addition, the elastic properties of the high bar and gymnast must be incorporated. Damped linear springs have been shown to be a simple and effective method of describing these phenomena.

The four segment simulation model was driven by changes of joint angle over time, a joint angle history. Joint angle time histories must be mathematically tractable. These time histories can come from either video (kinematic) analysis of gymnastic performances or from mathematical formulae. The problem with a mathematical approach is that these time histories do not consider gymnast strength. Therefore, the simulation model could perform joint actions which are humanly impossible. Consequently, to validate the model, the actual gymnasts performed strength tests in addition to the video recordings.

Results

Dr. Hiley posed seven questions at the beginning of his research that he then attempted to answer.

Question 1. "What are the technique differences between the gymnast's regular and accelerating giant circles?"

Both regular and accelerating giant circles use actions at the shoulders, hips, and knees. In general, the flexion angles used in the accelerating giant circles were larger than those used in the regular giant circles. Other differences included the timing of the flexion at the hips and shoulders. The gymnast recorded for the video analysis of the accelerating giant circles used a "scooping" technique during his accelerating giant circles. The flexion action in his hips was performed through a larger angle of rotation than a gymnast performing a classic accelerating giant circle. Similarly the extension action during the "scooping" accelerating giant circle occurs later (after the gymnast has passed through the highest point) and is performed over a larger angle of rotation. In the regular giant circle the gymnast was fully extended as he passed through the highest point, in other words before passing vertical. Dr. Hiley doesn't discuss this, but extending to handstand before passing through the vertical will slow the velocity of the gymnast around and over the bar.

The deflections of the high bar were also larger for the accelerating giant circles. In the vertical direction, the difference between peak deflections was approximately 1.18 inch (0.03 m). In the horizontal direction the difference in peak bar deflections was 1.57 inch (0.04 m). An interesting feature of the accelerating giant circles was that the peak horizontal and vertical deflections of the bar were approximately equal. In the regular giant circles, the horizontal displacement of the bar was consistently smaller than the peak vertical deflections by approximately 20%, or a fifth. **This indicates that the "scooping" technique adopted in the accelerating giant circles leads to a larger horizontal loading of the high bar.**

Question 2. "What are the reaction forces exerted by the bar on the gymnast as he performs regular or accelerating giant circles?"

During regular giant circles the peak reaction forces in the horizontal and vertical directions were 2.4 and 3.4 times body weight, respectively. The peak resultant reaction force was also 3.4 times body weight. During accelerating giant circles, peak reaction forces in the horizontal and vertical directions were 4.0 and 4.4 times body weight, respectively. The peak resultant reaction force was 5.0 times body weight. A 5.0 times body weight equals approximately 3092.2 N[1] or 695 pounds of force for this gymnast.

Question 3. "Does a high bar behave like a damped linear spring? If it does, can analyzing the forces and movements of regular and accelerating giant circles be used to obtain stiffness and damping coefficients for such a spring?"

---

[1] N is the standard abbreviation for Newton, a measure of the force of one kilogram (2.2 pounds) accelerated at 1 meter per second squared, or a little more than 3 ft. per second squared. One Newton of force is approximately the size of the force of gravity.

The standardized errors for the relationship between the reaction forces and the bar deflections in the horizontal and vertical directions, respectively, were very small, less than 0.1 of a body weight. When the same equation was used to estimate the reaction force for another regular giant circle (whose data had not been included in the first analysis), based purely on the displacement of the bar during the trial, the difference between the recorded and the estimated reaction forces was less than 0.12 body weight. Therefore the high bar appeared to act like a linear spring. When the linear velocity of the bar was entered into the equation, how fast the bar was bending and recoiling, the standard errors were reduced to less than 0.11 body weight. Although there did not appear to be a great difference between the two sets of equations, the standard errors always improved by adding bar velocity. The coefficients in the equations represent the stiffness and damping coefficients of the bar. These could be used to estimate the reaction forces at the bar or could be used as the stiffness and damping coefficients of a damped linear spring in a simulation model. Adding a damped linear spring to a single segment simulation model improved the accuracy of the model.

Question 4. “Do the gymnast’s joints behave as elastic structures as he circles the high bar? If so, which joints behave this way?”

The video analysis program was used to find the segment lengths in each video field. During backward giant circles the gymnast increased in length as he passed through the lower part of the circle where the increase in length was greatest. Looking at the time histories of the length of each segment, most of the increase in length occurred between the gymnast's wrists and hips. Dr. Hiley guessed that this could be from shoulder stretch and to stretch between the vertebrae of the spine. During the giant circles analysed in this study, the extension between the wrist and hips was between 3.9 and 5.5 inches (0.10 and 0.14 m). This agreed with the findings of N. Suchilin (personal communication to Dr. Hiley). To see if this extension could be represented by a linear spring, the extension in the gymnast was mathematically related to the reaction force at the bar. When the calculations were done with the data from both regular and accelerating giant circles, the stiffness coefficient ranged from 12816 to 16467 N.m^-I. The standard error approached one bodyweight, with the correlation coefficient approaching 0.5. However, there was a trend in the raw data looking that as the reaction force increased so did the stretching of the gymnast. Had the internal joint forces been available a better correlation may have been obtained.

Question 5. “What are the mechanics of the flexion and extension actions performed by gymnasts during regular and accelerating giant circles?”

The gymnast's body parts have mass and moments of inertia which need to be considered. A three segment simulation model was used to optimise a backward giant circle. Initially there were no constraints placed on the size of the joint torques the model could produce. The optimum solution had the model performing the flexion action at the hip and shoulder joint before the lowest point of the circle, a technique not used by gymnasts. Looking at the joint torques when performing an early flexion action, it appeared that this produced a greater increase in energy. A similar result explained the model extending before reaching the highest point.

The simulation was repeated using a joint torque limit at the shoulders. The flexion action was then performed as the model passed through the lowest point. This was because the model was no longer strong enough to perform the action before the lowest point. Similarly the model performed the extension action as it passed through the highest point. This technique more closely represented the techniques used by actual gymnasts.

A similar result was obtained when the muscle models that limit the joint torques at the hip and shoulder joints were used in a four segment simulation model. The model performed the flexion action passing through the lowest point and the extension action passing through the highest point. Since the four segment model was used to optimise angular momentum around the model's center of mass after performing 1 3/4 giant circles, had the more simple three segment model not been used to optimise the backward giant circle, the underlying mechanics might have been missed.

Question 6. “How does the strength of the gymnast affect optimum technique?”

Adding a joint torque limit changed the optimum technique found by the three segment model from a theoretical solution to one that resembled the technique used by real gymnasts. With a joint torque limit, the model was not strong enough to perform the theoretical solution and adjusted the technique accordingly. Therefore, one could conclude that gymnasts do not perform the flexion action before the lowest point, either because they are not strong enough, or because they choose to conserve energy. A third reason may be due to the skill performed after the giant circle. Flexing before the lowest point may produce an undesired loading of the bar. This is a question for further research.

In another simulation, a kind of computer experiment, the strength of the muscle models was increased and decreased by 10% to see the effect this would have on the optimum solution. When the strength of the muscle models was changed by 10%, the change in rotation was less than 3%. Change in muscle strength caused just small changes in the joint angle time histories. When the strength of the muscle models was decreased by 25%, the final angular momentum was reduced by 11%. This is still more rotation than is required to perform a double layout backward salto dismount, and is therefore not a large drop in performance, particularly now that the theoretical gymnast is only 25% as strong. However, when the joint angle time histories were compared, the model was now performing a "scooping" technique through the upper part of the accelerating giant circle. When the strength of the model was returned to 100%, this technique was found to be a local optimum. But the difference in angular momentum from the original optimization was less than 3%. For the majority of both the local and global optimum techniques the model used 30% of the maximum joint torques given by the muscle models. Only for the first flexion action and in the last quadrant of the optimum simulations did the joint torques approach the maximum values used by the simulation model.

At the end of a gymnastic routine it may not be in the gymnast's interest to rely on a technique that will require maximum effort. Alternatively, since both techniques appear to produce similar amounts of rotation, gymnasts have a choice of which technique to use. However, an intermediate technique which connects the two optima was not found. That is, **the two techniques are distinct and separate. A technique half way between these two techniques results in less angular momentum than either.**

Question 7. “Does the optimum technique of the backward giant circle differ between gymnasts or does a common technique exist that could be used by all gymnasts?”

Only small differences between joint angle time histories were found when the backward giant circle was optimised using the inertia data of gymnasts jbO1 and tvO1[2]. Even when the joint torque limit at the shoulder was added, the two optimum giant circles were very similar (Figures 8.14 and 8.15). Therefore, it seems that, although small changes in the joint angle time histories will occur, the underlying technique and mechanics remain the same.

---

[2] Jb01 and tv01 are codes used to keep the identities of the two gymnasts private.

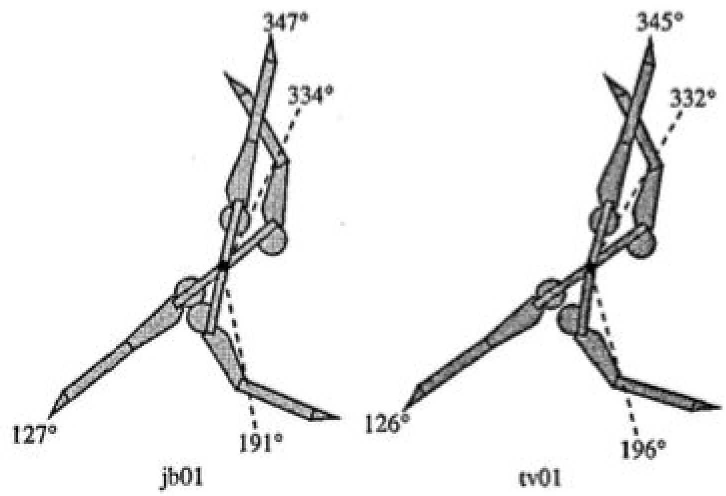

Figure 8.14. The effect of using different inertia data on the optimal solution obtained using no joint torque limit.

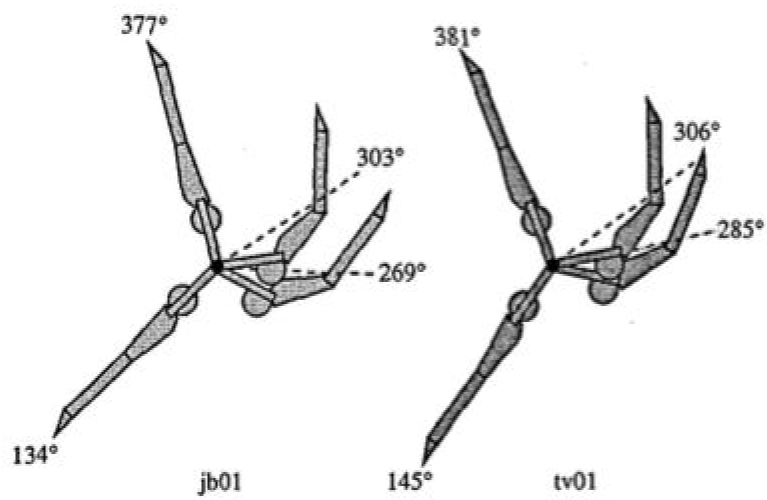

Figure 8.15. The effect of using different inertia data on the optimal solution obtained using a 250 Nm joint torque limit at the shoulders.

When the optimum joint angle time histories from the four segment model were used with gymnast tvO1's inertia data and gymnast jbOI's maximum torque data, the model was not strong enough to complete the 1 ¾ giant circles. However, after optimising the backward giant circle using tvO1's inertia set, an optimum solution was obtained. Using tvO1's inertia set resulted in an increase in angular momentum about the model's center of mass of 28%. When this was normalised so that the two gymnasts could be compared, the difference dropped to 3%. When the sets of joint angle time histories were compared they were very similar; again any small differences could be explained.

Gymnasts are a select group of individuals whose inertia parameters differ from the general population. Given these characteristics, and that the laws of mechanics apply to everyone, it is likely that given a set of inertia data from a gymnast, the optimum solution will lie close to the one found in the present study. Small differences in the joint angle time histories will arise due to different strength abilities; however, the general technique can be explained by the mechanics.

Regular Back Giant Swings

Figure 6.10 shows the angular velocity of the rotation angle for one giant circle. Angular velocity is graphed against rotation angle. Peak angular velocity occurred at a rotation angle of 167°; 0° is a handstand, 180° is hanging directly under the bar, and 360° is back to handstand again. Cheetham (1984) found a double peak in the angular velocity of the regular giant circles he studied. The first peak occurred before the gymnast had reached the lowest point of the giant circle and the second peak followed shortly afterwards. The second peak was associated with the closing of the hip and shoulder angles. The second peak was always greater than the first. Figure 6.10, the history of the angular velocity, also shows a double peak. However, the first peak is greater than the second. Perhaps the gymnasts in Cheetham's study performed more vigorous "pike-ing" actions than the gymnast in the current study.

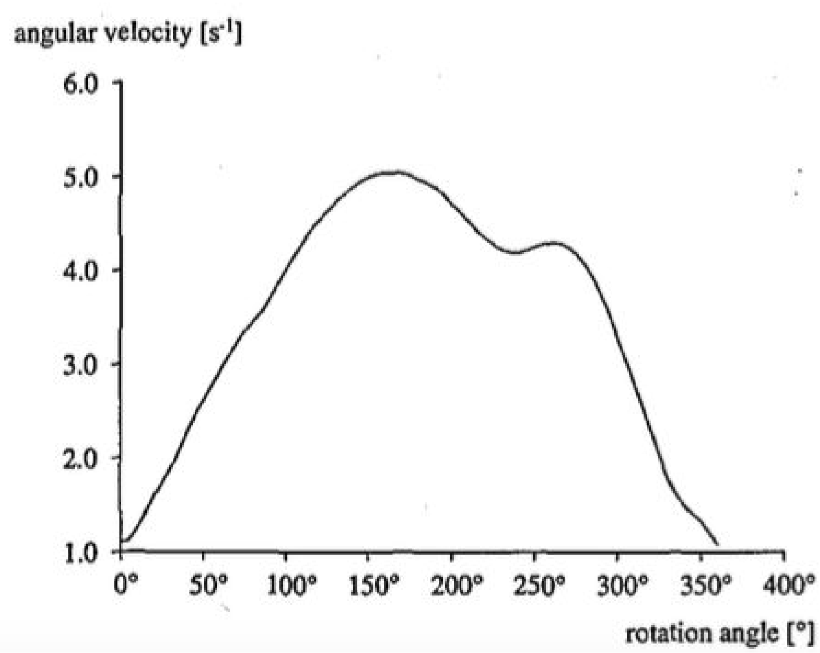

Figure 6.10. History of the angular velocity of the rotation angle during one regular giant

Bar Deflections

Figure 6.11 shows the history of the up and down movements of the bar away from its neutral position during a regular giant. This giant used about two seconds to complete. When the graph line is above the dashed line showing the neutral bar position in meters above the floor, this means that the bar is being pulled upwards.

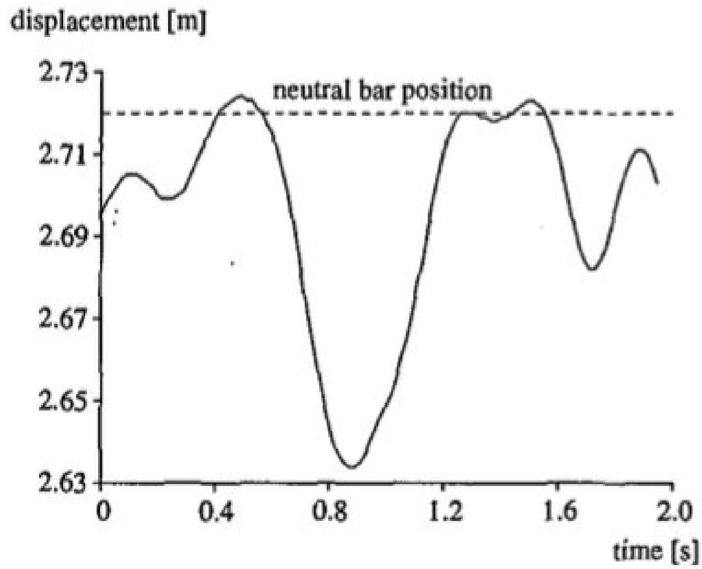

Figure 6.11. Time history of the vertical displacement the center of the bar for the first regular giant circle of trial 10.

Figure 6.13 shows the horizontal and vertical deflections of the bar against rotation angle. The height of the bar has been subtracted from the vertical bar displacement so that it would fit on the same axes as the horizontal displacement. The peak vertical displacement occurred at a rotation angle of 175° when the gymnast is almost at the lowest point of the circle (180°). The peak horizontal deflections occurred at rotation angles of 121° (quadrant 2) and 227° (quadrant 3).

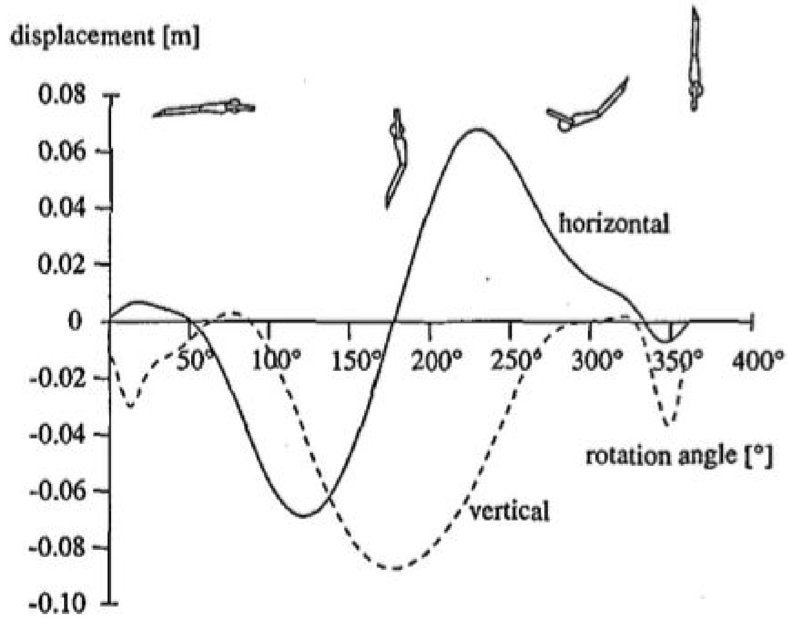

Figure 6.13. History of the horizontal and vertical displacement of the center of the bar plotted against rotation angle for the second regular giant circle from trial 10.

Accelerating Back Giant Swings

An accelerating giant circle should be optimised for the skill that follows. For example, the release conditions for the Tkatchev are considerably different to those of the double layout backward salto dismount (Brüggemann et al., 1994). Therefore, the optimum technique will be different for an accelerating backward giant circle prior to these two skills. Of all the dismounts analysed in the scientific literature, the double layout backward salto dismount needs the greatest angular momentum in flight (Brüggemann et al., 1994; Kerwin et al., 1990). Since angular momentum during flight is determined at release, the only way angular momentum can be increased is during the accelerating giant circles prior to the release. Brüggemann et al. (1994) reported a mean angle at release of 8° below the horizontal for four double layout somersault dismounts (at about 262° of rotation from handstand).

The range of displacements of accelerating giant circles are larger than the range of displacements of regular giant circles. Unlike regular giant circles, the peak absolute deflections about the bar's neutral resting position are equal in both the vertical and horizontal directions. Since the displacement of the bar was larger during the accelerating giant circles, the load on the bar must also have been greater than during regular giant circles.

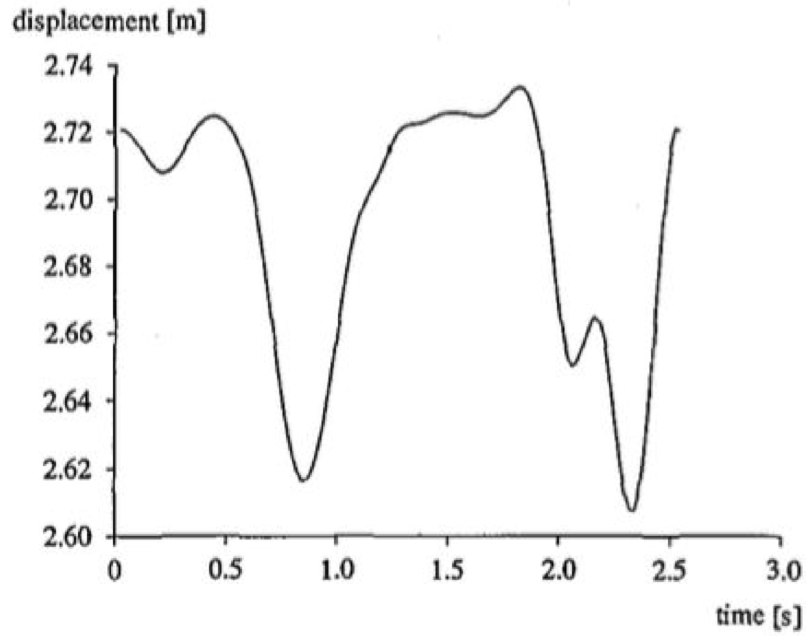

Figure 6.18. Time history of the vertical displacement of the center of the bar during trial 4. Please compare with Figure 6.11.

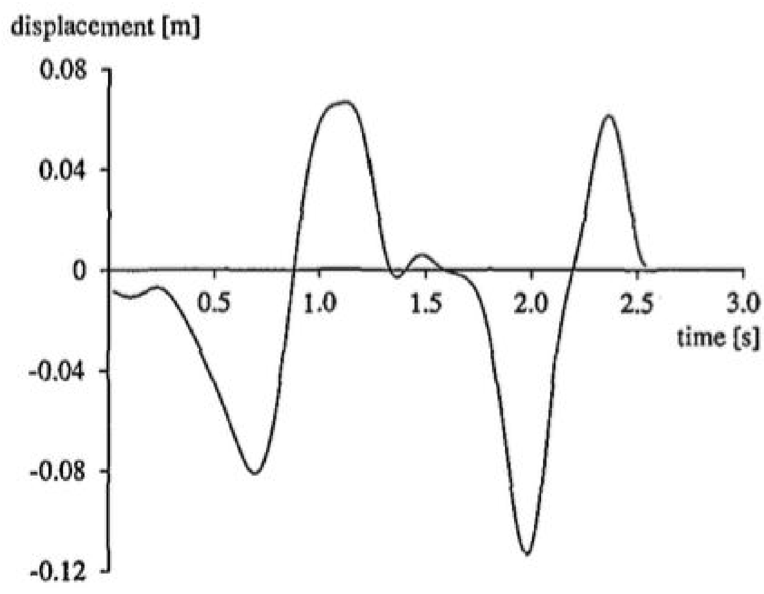

Figure 6.19. Time history of the horizontal displacement of the center of the bar during trial 4.

The first vertical displacement peak occurs at a rotation angle 173°, when the gymnast is almost at the lowest point of the circle (180°). The second peak in vertical displacement was at a rotation angle 569°. This corresponds to 30° past the lowest point of the second giant circle. The small peak prior to this, as described earlier, occurred at a rotation angle of approximately 500°. The first two peaks in horizontal deflections occurred at rotation angles of 126° and 250°. Both of these angles correspond to the gymnast being in the lower half of the giant circle. The second two peaks occurred at 467° and 578°. The first of these two peaks occurs some 20° earlier than the same peak for the first giant circle. Similarly, the second peak of the second giant occurred 30° **earlier** than in the previous giant circle. Apparently, the technique the gymnast uses as he passes through the highest point alters the way that the bar is deflected during the release giant circle. The deflections are different both in terms of size and timing.

Comparing the deflections of the bar at 262° and 622° for the two accelerating trials, the most striking thing is that at the release angle of 622° the vertical bar displacement was zero, compared with 0.79 inches (0.02 m) at the rotation angle of 262°. Similarly for the horizontal deflections, at 622° the bar had a positive horizontal displacement of less than 0.79 inches (0.02 m) compared with 3.15 inches (0.08 m) at a rotation angle of 262°. Figure 6.21 shows the horizontal and vertical velocities of the bar leading up to the point of release in trial 4. **At release, the vertical bar velocity was very close to zero. That is, in the vertical direction, at or very close to release, the bar was stationary.** This may have implications for the angular momentum the subject possessed at release. Clearly, if the hands were stationary at release the angular momentum about the subject's mass center would be greater than if the bar were displaced vertically downwards with a positive vertical velocity.

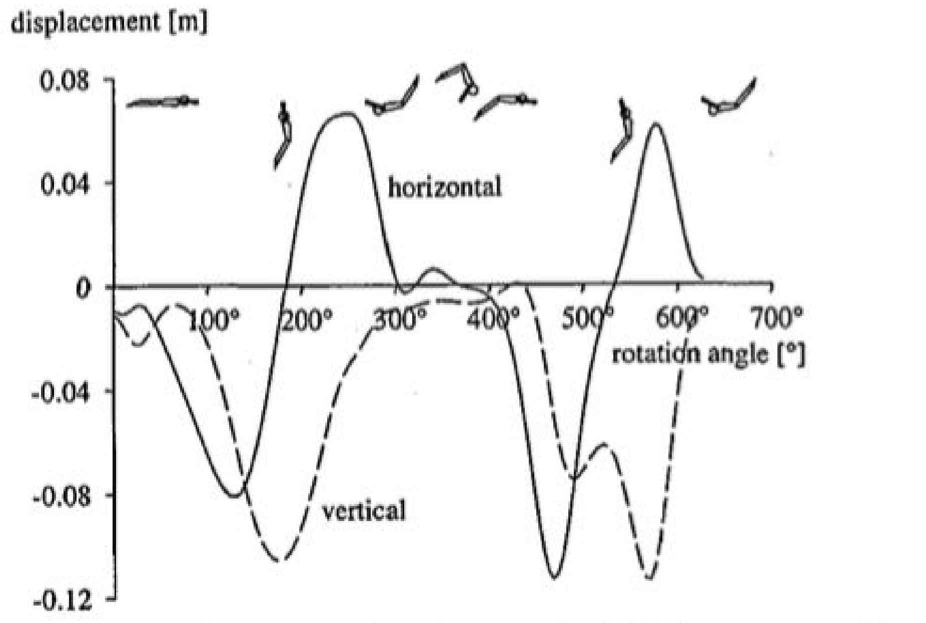

Figure 6.20. Histories of the horizontal and the vertical deflections of the bar (trial 4).

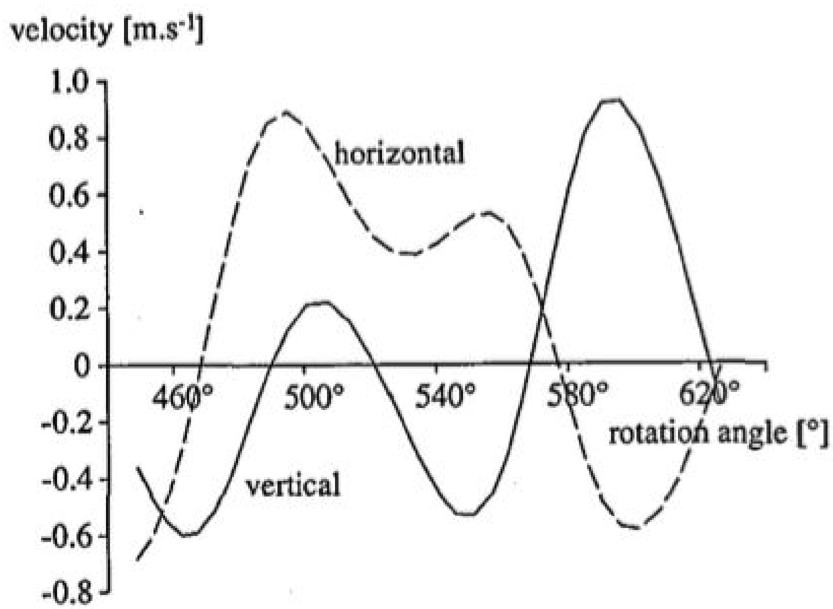

Figure 6.21. Histories of the horizontal and the vertical velocity of the bar (trial 4).

In general, the gymnast keeps his center of mass away from the axis of rotation during the downswing. During the upswing the gymnast reduces this distance, by changing body shape, so as to reduce the effect of the torque created by his weight.

The peak angular velocity for the accelerating giant circles was greater than the peak value for the regular giant circles..

The deflections of the bar for the regular giant circles were in the region of ± 3.9 inches (0.10 m) in both the horizontal and vertical directions. The bar deflections for the accelerating giant circles were greater than those for the regular giant circles. When the bar deflections were compared between trials/circles they were found to be very similar. That is, when the bar deflections for two regular giant or two accelerating circles were compared the differences between them were small.

The major joint actions performed during the regular giant circle occurred at the hips and the shoulders, with a small contribution from the knees. The size of the flexion angles at the hips and shoulders were larger for the accelerating giant circles compared with the regular giant circles. The timing of the flexion and extension actions were slightly different in the accelerating giant circles. The flexion at the hips started later and lasted longer. Similarly, the extension at the hips started later and finished later. This altered action is probably used to load the bar, resulting in increased angular momentum at release.

With no joint torque limits, the optimum instants to perform the flexion and extension actions were before the lowest point and before the highest point, respectively. This optimum solution for accelerating giant circles differed from the technique used by elite gymnasts who generally perform the flexion after the lowest point and the extension while passing through the highest point. Performing the flexion before the lowest point and the extension before the highest point would result in more work being done by the gymnast and therefore a greater increase in energy.

The Gymnast’s Body Acting as a Spring

The majority of the lengthening and shortening of the gymnast appears to occur in the region from the wrists to the hips. The lengthening possibly occurs due to the elastic properties/structures of the joints within that region. Since the increases in length occur with increasing reaction force at the bar (Kopp & Reid, 1980), the joints at the elbow, shoulder and spine seem to act as springs which are able to stretch and recoil under the fluctuating load. During giant circles the gymnast gets longer by between 2.0 and 5.5 inches (0.05 and 0.14 m). The majority of this increase occurred between the wrists and the hips. This increase seems to be a result of extensions in the shoulders and spine of the gymnast. Since the increase in gymnast length occurred through the lower part of the giant circle, part of this extension is probably a result of the elastic properties of the shoulders and spine. In addition, the length of the gymnast's torso was greater when the arms were elevated than when they were by his sides. This is due to the elevation of the shoulder girdle.

Analysis of Forces

The force recorded at the bar is closely related to the displacement in the bar. During an accelerating giant circle followed by a dismount the bar is likely to be loaded to over 3,000 N and then unloaded.

Regular giant circles

Peak force in the vertical and horizontal directions were recorded during the three giant circles performed in trial 10. Table 6.16 contains these peak forces expressed both in Newtons and in multiples of body weight. The third column of Table 6. 6. contains the peak resultant force for trial 10.

Table 6.16. Peak forces expressed in Newtons and bodyweights for trial 10

circle (trial 10)	vertical peak force (N, (BW))	horizontal peak force (N, (BW))	resultant peak force (N, (BW))
first	2036.42 (3.31)	1440.84 (2.34)	2037.60 (3.31)
second	2036.42 (3.31)	1501.63 (2.44)	2047.58 (3.33)
third	2110.43 (3.43)	1484.03 (2.41)	2110.99 (3.43)
mean	2061.09 (3.35)	1475.50 (2.40)	2065.39 (3.36)

Accelerating giant circles (including the release giant)

The accelerating giant circles were one complete circle and a second three- quarter circle after which the gymnast would normally release the bar. All peak forces were found to occur in the final three-quarter circle leading up to the release. The peak forces for the accelerating giant circles in trials 4 and 11 are given in Table 6.18. **The mean peak resultant force was found to be 50% larger than the mean peak resultant force of the regular giant circles**. Note that the peak horizontal force during accelerating giant circles exceeds the peak vertical force during regular giant circles.

Table 6.18. Peak forces expressed in Newtons and bodyweights for trials 4 and 11

circle (trial)	vertical peak force (N, (BW))	horizontal peak force (N, (BW))	resultant peak force (N, (BW))
4	2656.07 (4.31)	2498.35 (4.06)	3050.01 (4.95)
11	2792.05 (4.53)	2431.12 (3.95)	3134.46 (5.09)
mean	2724.06 (4.42)	2464.74 (4.01)	3092.24 (5.02)

Comparing the graphs of the regular and accelerating giant circles (especially the portion containing the release circle), there are obvious differences. The vertical reaction force for the accelerating giant circle has two peaks (Figure 6.42) compared with the single peak for the regular giant circle (Figure 6.40). As in the vertical bar deflections of the accelerating giant circles, the first of the double peaks correspond to the gymnast's maximum hip hyper-extension and maximum knee flexion angle. This first peak in force may be used as a timing mechanism by the gymnast. Once the gymnast feels the force increase the hyper- extension of the hips is reduced in order to initiate the flexion of the hip joint.

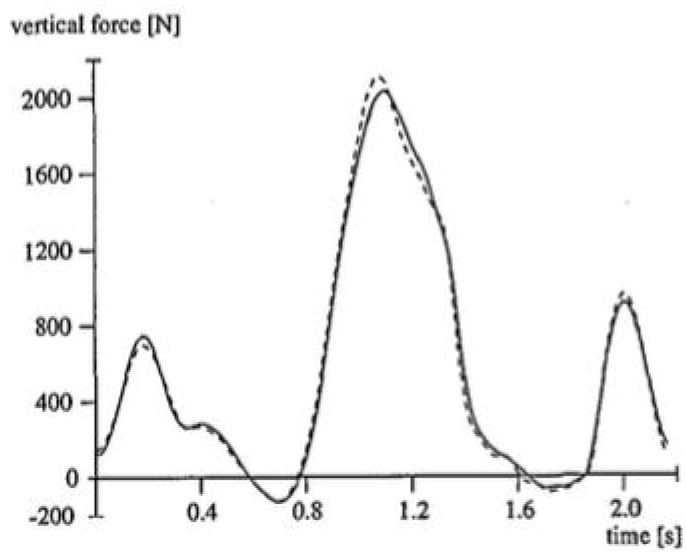

Figure 6.40. Vertical force trace for two regular giant circles.

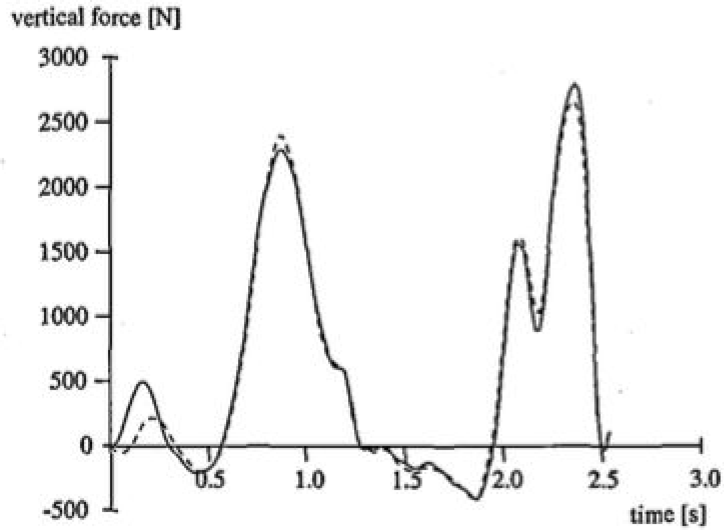

Figure 6.42. Vertical force trace for two accelerated giant circles.

The force trace in Figure 6.42 shows the vertical force up until the point where the gymnast would release the bar for a double layout back salto dismount. This would occur at a rotation angle of approximately 622°. At this point the force in the vertical and horizontal directions (Figures 6.42 and 6.43, respectively) drops near to zero. Had this been a wind up giant circle, the vertical reaction force would be closer to one bodyweight in the vertical direction and 2.5 body weight in the horizontal direction. Is the vertical and horizontal force dropping to zero at release a coincidence or is there some mechanical benefit to this when performing a double layout backward somersault dismount? Again, this cannot be answered using the force trace alone.

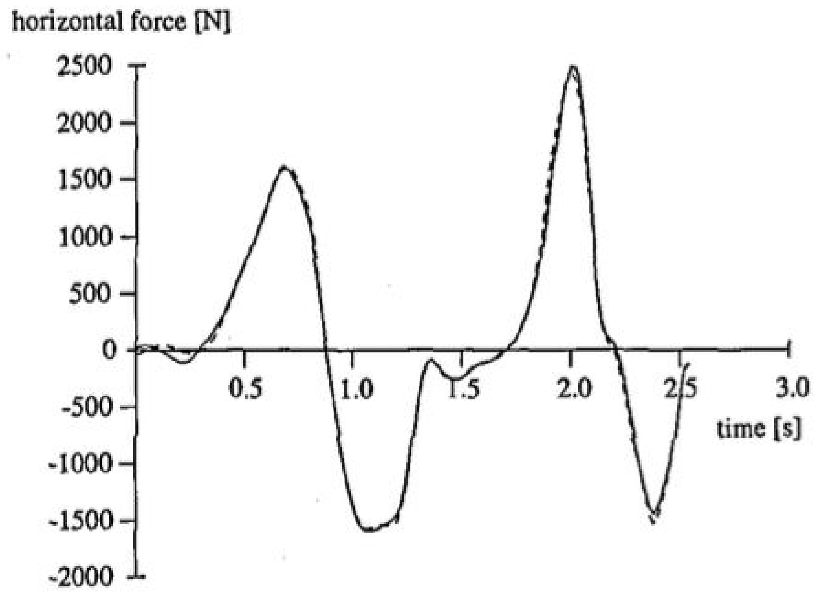

Figure 6.43. Horizontal force trace for two accelerated giant circles.

The peak resultant reaction force for the regular giant circles was approximately 2065.4 N or 3.4 times body weight. The reaction forces for the accelerating giant circles were found to be larger than those obtained from the regular giant circles. The peak resultant reaction force was 3092.2 N (5.0 body weight). The peak horizontal and vertical components of force were 2464.7 and 2724.1 N respectively.

Apparently, there are two back giant techniques for double layout dismounts. In the first technique the gymnast extends shortly after passing through the highest point of the giant circle. This is a more "classic" style of backward giant circle. The second technique involves the gymnast "scooping" through the highest point and extending close to the horizontal. This is a modern technique which is now used by many elite gymnasts. The fact that both optima are so close in the angular momentum values they generate would explain why some gymnasts use the classic style of backward giant circle and others use the modern "scooping" technique. Since both techniques may be used to increase the gymnast's rotation by similar amounts it would seem that the choice of technique used lies with the gymnast's preference. However, under certain circumstances the "scooping" local optimum becomes the global optimum and the classical global optimum becomes a local optimum. When the strength of the muscle models was decreased by 25% the "scooping" technique became the optimum technique. This presents a number of questions for the researcher and choices for the gymnast. A less well-conditioned gymnast may opt for the "scooping" technique since he can achieve more rotation given his state of physical preparation. Similarly a well-conditioned gymnast may choose the "scooping" technique because he feels that he can achieve similar amounts of rotation for slightly less effort than the classic technique. The gymnast is therefore using a technique where he knows he will not have to make a maximal effort. This would be an obvious advantage since the gymnast is likely to be most fatigued at the end of his high bar routine which is when the dismount is performed.

The effect of bar elasticity on angular velocity and reaction force

Gymnasts often train on one high bar but compete on another, which may or may not be of equal stiffness. Therefore Dr. Hiley investigated the effect of varying the stiffness of the bar. The high bar is required to have certain elastic properties which are described by the Code of Points (FIG, 1979). The bar is required to produce a sag of 3.9 inches ± 0.4 (100 mm ± 10 mm) when loaded at its center with a weight of 2200 N. This would produce a range of stiffness coefficients of between 20000 $N.m^{-1}$ and 24444 N.m-I. However, due to different manufacturers, different materials used in the construction and the tension in the supporting cables of the uprights, it is possible for the high bar to have a greater range of possible stiffness values. The high bar was reported to have a stiffness of between 22000 $N.m^{-1}$ and 27500 $N.m^{-1}$ (Norm-testing, Continental, 1994).

Model Performance

Comparing the simulation model with the video analysis, the model over-estimated the peak angular velocity by 6%, indicating that a single segment model which models the elasticity of the bar is close to representing a gymnast during the downswing phase of the giant circle. Adding bar elasticity reduced the peak angular velocity by 11% and the reaction force by 7%. The reduction in peak angular velocity and reaction force could be explained in terms of the strain energy stored in the bar and the increase in moment of inertia of the model about the neutral bar position. Reducing the difference in peak angular velocity and reaction force between the model and the video data even more will require a more sophisticated model. The distance from the gymnast's wrist to hips varied during the backward giant circle, with the largest increase occurring as the gymnast passed through the lower part of the circle. This may lead to a further increase in the moment of inertia of the gymnast and to a possible storage of energy, similar to that seen in the bar. Also, the bar was less stiff in the horizontal direction than in the vertical direction. When modelling a gymnast swinging on the high bar, probably both the elastic properties of the bar and of the gymnast should be considered.

Using the model in simulations of giant swings to double layout dismount, the optimum solution performance does not appear to be sensitive to the stiffness coefficients of the bar. The stiffness of the bar was increased and decreased to cover the range of stiffnesses that would be expected from the manufacture of the bar. This range was larger than the acceptable range quoted by the FIG. To confirm the insensitivity of the optimum solution, the backward giant circle was optimised using increased and decreased high bar stiffness coefficients. After the optimisations were completed, the values for the angular momentum about the model's center of mass were very close to the original optimised values (less than 1/2% different).

Uneven bars

This dissertation was about "The mechanics of swinging on the high bar". However, many of the ideas and techniques could be applied to swinging on the uneven bars. Obvious differences are the construction of the bar, inertia, and strength characteristics of the female gymnast, and the second bar which the gymnast must avoid during the downswing. The bar would require different spring coefficients and would therefore need to be calibrated like the high bar. Due to the uneven bar's larger surface area, frictional forces between the gymnast's hand and bar would also need to be considered and quantified.

The four segment simulation model assumed that the hand was an extension of the arm. The hand was forced, by this assumption, to slide around the bar. For the high bar this is a close representation of the bar/hand interface. However, the diameter of the asymmetric bar is larger than that of the high bar and the female hand smaller. This makes female gymnasts perform a distinct "wrist shift" in the fourth quadrant of the giant circle. Although men also perform a wrist shift, it is not as large or as obvious as the one women make. For this reason, a hand segment may need to be incorporated into the simulation model. Even if the hand were not used, the present simulation model could still be used to investigate the strategies used to pass the lower bar.

Discussion

Unfortunately, Dr. Hiley defined flexion and extension in the joints differently than the definition used in anatomy, physiology, physical therapy, and by most coaches. The confusion probably resulted from the colloquial expressions commonly used in the gym of “extending to handstand”, “flexing to a pike”, “closing the shoulder”, or “opening the hips”. Stretching out to a straight handstand shaped is (hyper-) flexion of the shoulder with extension of the hips. Pike-ing involves flexion of the hips and extension of the shoulder if the gymnast reaches for the legs. Although the action has been termed "closing" the shoulder angle, due to the definition of the simulation model the angle at the shoulder will increase from 180° (fully extended) to 200°, a change of 20°. We can see from Dr. Hiley's Fig. 8.1 that "closing" the shoulder or hip angle is labeled as an increase in angle, contrary to common practice. From the "extended" shape on the left, the shoulders are extending while the hips are flexing in common terminology.

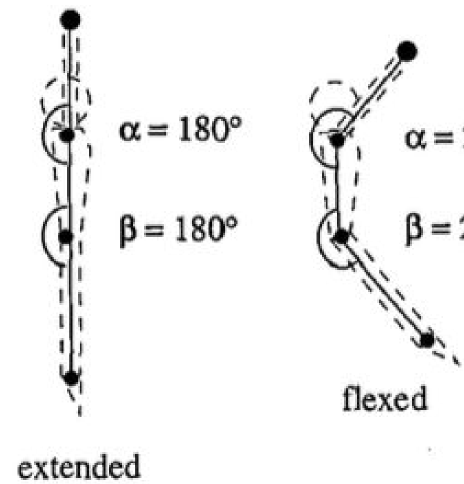

Figure 8.1. Angles at the hips and shoulders.

Dr. Hiley also found that the bar was less stiff in the horizontal direction than in the vertical direction. This is potentially an important finding. This could be because in the vertical direction, any downward movement of the bar is resisted by the full set of cables anchoring the high bar, on both ends of the bar. In the horizontal direction however, only the cables on the opposite side of the bar from the direction the bar is pulled are resisting this deflection. The cables cannot push against the uprights, only pull. In the horizontal direction, only half of the full set of cables can resist pull on the bar. This characteristic of the bar could be used to accelerate a scoop over the bar greater than is currently the practice.

Conclusion

In the Men's High Bar event, the accelerating backward giant circle is used to generate more rotation for the next skill. When used prior to the dismount that ends a high bar routine, the gymnast performs a number of backward giant circles in order to generate sufficient rotation to perform the dismount. The most common dismounts from the high bar require the gymnast to perform two backward saltos in the layout position.

The double layout salto dismount requires a great deal of rotation. Elite gymnasts show two different techniques to make the accelerating giant circle before releasing. Gymnasts are able to perform the dismount from both types, so the question arises: "What is the best technique for increasing rotation using accelerating backward giant circles?"

A four segment simulation model was developed with arms, torso, thigh, and shins. The high bar and the gymnast's shoulder structure were modelled as damped linear springs. The inertia data for the model were obtained from anthropometric measurements of an elite gymnast using the inertia model of Yeadon (1990). Joint angle changes over time were used as input to the model. Joint torques predicted by the simulation model were limited using subject specific muscle data collected using an isokinetic dynamometer (King, 1998).

The simulation model was compared to movement and force data recorded from elite gymnasts performing accelerating giant circles. Two video cameras were used to record the gymnast performing accelerating giant circles on a high bar instrumented with strain gauges. The simulation model was evaluated by driving the simulation model joint angle time histories from the video analysis and comparing the whole body angles of rotation and reaction forces with the measured values.

To study the double layout dismount, the simulation model was created to maximise angular momentum about the model's center of mass after performing 1 3/4 giant circles. The optimisation algorithm manipulated the parameters which defined the joint angle time histories in order to obtain the optimum technique. During the optimization two optima were found. The first had a slightly higher value for the angular momentum about the model's center of mass, and was called the "global" optimum. The two optima closely resembled the two different techniques used by gymnasts. However, these optima were so close that for different muscle strength the local optimum would become the global optimum. This explains why gymnasts use two distinct techniques.

References

Brüggemann, G-P., Cheetham, P.J., Alp, Y. & Arampatzis, D. (1994). Approach to a biomechanical profile of dismounts and release-regrasp skills of the high bar. *Journal of Applied Biomechanics,* 10, 291-312.

Cheetham, P.J. (1984). Horizontal bar giant swing centre of gravity motion comparisons. In J. Terauds, K. Bartheis, R. Mann & J. Crakes (Eds.), *Proceedings: International Symposium ofBiomechanics in Sports* (pp. 99-108). California, USA.

Hiley, M. J. (1998). Mechanics of the Giant Circle on High Bar. Dissertation, Loughborough University

Kerwin, D.G., Yeadon, M.R, & Lee, S. (1990). Body configuration in multiple high bar dismounts. *International Journal of Sports Biomechanics,* **6,** 149-159.

King, M.A. (1998). Contribution to performance in dynamic jumps. *Unpublished Doctoral Dissertation.* Loughborough University.

Kopp, P.M. & Reid, J.G. (1980). A force torque analysis of giant swings on the horizontal bar. *Canadian Journal of Applied Sports Science,* 5, 98-102.

Yeadon, M.R. (I990). The simulation of aerial movement-I. The determination of orientation angles from film data. *Journal of Biomechanics,* **23** (1), 59-66.