BIOMECHANICAL ANALYSIS OF THE STALDER ON THE UNEVEN PARALLEL BARS

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The current trend in competitive uneven parallel bars work, as in all gymnastics, is toward high level difficulty skills in intricate, flowing routines. Many of the skills being performed are considered risk elements in that improper execution can lead to falls or other deductions or even injury to the gymnast who incorrectly executes an element. It is, however, not enough to simply perform difficult skills or even to perform those skills well, but also to perform skills with sufficient execution and amplitude to insure swing for connections in a complete bar routine. Due to the nature of the sport of gymnastics and its apparatus demands, failure to utilize sound mechanics in the performance of skills usually results in incompleted movements or unaesthetic execution.

This study was conducted to determine those factors which most greatly affect the performance of the handstand to handstand stalder on the uneven parallel bars. While it is necessary for coaches to have a thorough understanding of a particular skill pattern, without the knowledge of the factors which significantly contribute to successful execution, the coach is still faced with having to use trial and error methods to develop progressions of skill learning and training procedures through which the athlete can benefit. In this study investigation of both of these areas was undertaken - skill analysis as well as a statistical analysis to investigate the relationships between and among all the variables to isolate the factors most critical to stalder performance.

Methods and Procedures

Fourteen Class I and Elite level gymnasts from the United States and Canada were selected as subjects. Criterion for selection was the gymnasts' ability to perform a stalder without spotting

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assistance. Each subject was filmed performing two stalders. A Photo-Sonics 1PL 16mm camera set at 100 frames per second placed perpendicular to the action was used to film the trials in the sagittal plane. A Bendix Platen (model 9864A) interfaced to a Hewlett-Packard HP9825A Desk Top Computer through a Hewlett-Packard Digitizer was utilized in obtaining all the data from the filmed stalders.

Each stalder was analyzed from the initial highest straight body cast position to the final position of maximum shoulder flexion and hip extension at the end of the circle. The stalder was divided into seven phases of skill execution so that analysis of specific actions could be carried out. The seven phases were identified as:

1. initial straddle-in
2. passing the high bar on the down swing
3. rock back
4. bottom swing
5. initial up swing
6. passing the high bar on the up swing
7. final straddle-out.

In order to carry out a statistical analysis of the data, a panel of gymnastics judges was formed for the purpose of evaluating the filmed stalders and rank ordering the trials. The rank order, from best to poorest, was a subjective evaluation comparing the trials to one another so that the lowest ranked performances were considered poor compared only to the highest ranked trials. All trials were successfully completed stalders. From the final rank ordering, the trials were divided into four groups each containing seven trials. This division was undertaken for the purpose of carrying out a one-way analysis of variance between the groups.

Following the mechanical analysis of each stalder, an initial analysis of variance was run to determine if any differences in subject-specific variables existed which would affect the comparison of the mechanical data between the groups. Although individual differences between subjects existed, for the variables: total years in competition, years as a Class I or higher gymnast, age, mass, height, mean grip strength, upper extremity length, trunk length, lower extremity length, active shoulder flexibility, and active hip flexibility the analysis of variance indicated that there were no significant differences between any of the groups on these variables. Significant differences occurring between the groups in kinematic and kinetic variables could not be attributed to differences in mass or segment lengths. Differences in actual performance styles were responsible for differences between the groups.

Due to the similarity of performances within each group, the reporting of results will be concerned with the differences in performance between the highest ranking group and the lowest ranking group.

Results

The stalder involves a 360 degree rotation about a bar beginning and ending with the body in a handstand position. Within the course of the circle, the gymnast must straddle-in to a piked hang and straddle-out again into the final handstand. Because of the changes in body position in the stalder the effects on the mechanics of circling motions become prime criteria for the performance style chosen by the gymnast. Figures 1 and 2 are typical performances of Group I and Group IV trials respectively. Differences in starting positions and body positions throughout the stalder were similar for all performances within each group. Osborne (1979) defined two types of stalders: early- and late-straddle-in styles. All subjects in this study performed early-straddle-in types of stalders in which flexion at the hips occurred prior to any extension at the shoulders.

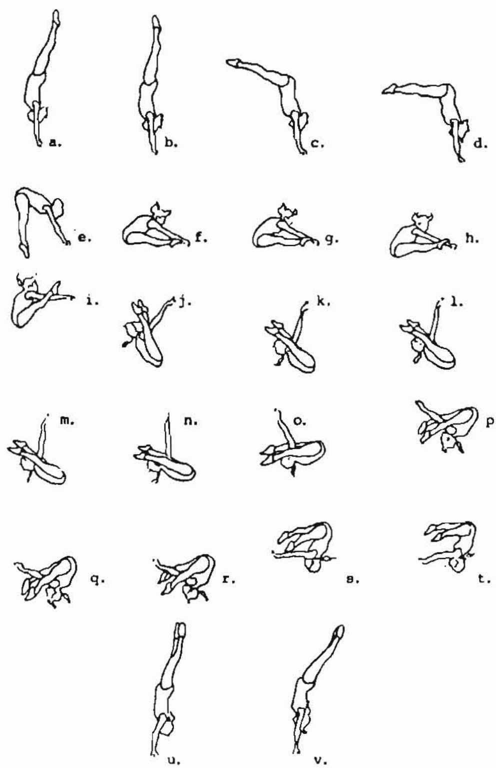


Figure 1. Tracings of Selected Frames for Total Stalder Performance for Group I Trial

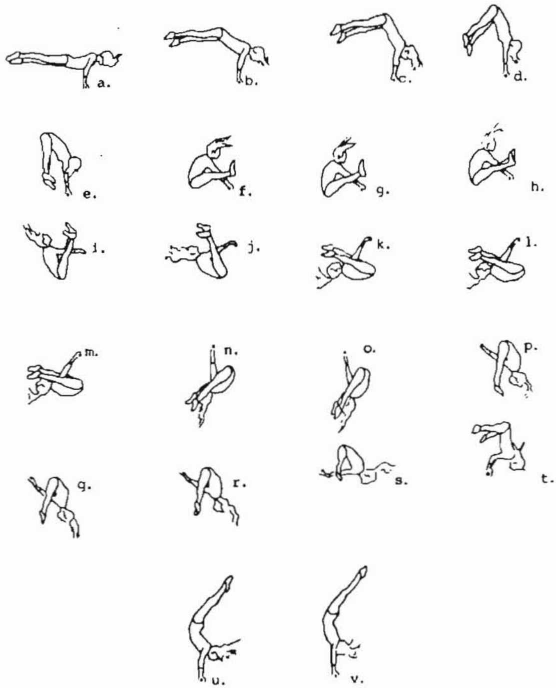


Figure 2. Tracings of Selected Frames for Total Stalder Performance for Group IV Trial

Temporal Data

The performance times of the stalders ranged from 2.09 to 3.14 seconds with a mean time of 2.48 seconds. Temporal data for the total skill, the down swing and the up swing are presented in Table 1. There were no significant differences between the groups on any of the phases of the stalder except for the straddle-out action. Group I trials performed the straddle-out action in a mean time of .74 seconds which was significantly faster (3 F 26 = 3.37) than Group IV trials which averaged .96 seconds. There was also a significant correlation (r=+.383) obtained between the time of the up swing and the overall ranking of the trials. This correlation indicated that a faster up swing was considered to be a desirable action by the judging panel.

Table 1. Temporal Data for Total Skill, Down Swing, and Up Swing in Seconds

	ALL TRIALS	GROUP I	GROUP IV
TOTAL SKILL			
RANGE	2.09 - 3.14	2.09 - 2.78	2.24 - 3.14
MEAN	2.48	2.40	2.58
ST.DEV.	.07	.05	.09
DOWN SWING			
RANGE	1.03 - 1.69	1.10 - 1.69	1.03 - 1.65
MEAN	1.36	1.34	1.37
ST.DEV.	.04	.05	.05
UP SWING			
RANGE	.82 - 1.65	.82 - 1.23	1.11 - 1.65
MEAN	1.12	1.01	1.25
ST.DEV.	.03	.02	.04

Displacements and Moments of Inertia

Gravity acting on the gymnast provides the force which causes sufficient angular momentum to allow the gymnast to circle the rail (Osborne, 1978). Therefore, the gymnast must attempt to cast to a full handstand position above the rail prior to beginning the down swing of the stalder to maximize the effects of gravity on the action. The gymnast must also attempt to swing downward with as great a radius of rotation as possible to maximize the descent phase amplitude. This will aid in establishing the greatest potential for swing amplitude in the ascent phase (George, 1980).

Although all 28 trials completed were successful stalders, only one trial from Group IV, compared to all Group I trials, began the action from a handstand above the rail. All trials ended the stalder in an extended position but not necessarily above the bar. Differences in the path of the centers of mass about the rail for the total skill are shown in Figure 3. Group I trials (Fig. 3a) characteristically showed a smooth, ovoid path while Group IV trials (Fig. 3b) were all somewhat dissimilar in pattern, but all showed uneven paths indicating changes in body positions sufficient to alter the position of the center of mass within the body and about the rail. It is apparent that these body position changes are contra-indicated to good stalder execution.

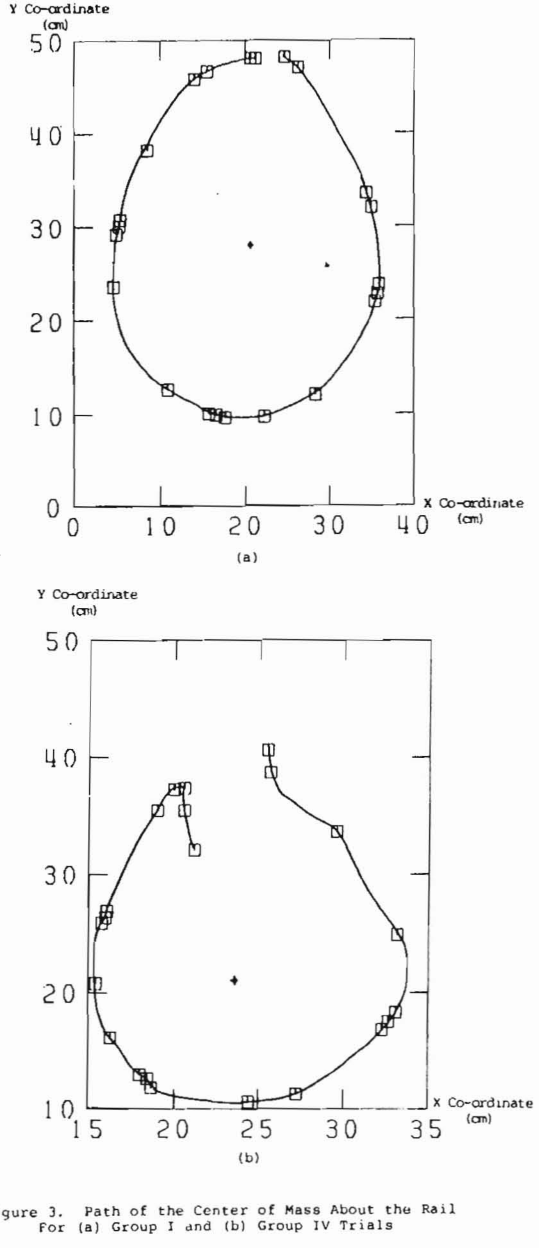


Figure 3. Path of the Center of Mass About the Rail For (a) Group I and (b) Group IV Trials

Internal amplitude differences caused by varying amounts of shoulder extension and hip flexion had a direct effect on kinetic variables. The amplitude of the initial highest cast placed the gymnast in a position which would directly affect the radius of rotation, moments of inertia, and measures of angular momentum about the rail and the gymnasts' center of mass. Initial measures of gravitational potential energy were determined at this point. The initial highest cast position also had an effect on the amount of kinetic energy potentially available. The beginning of the stalder, the straddle-in action, therefore, became a critical part of the skill, directly affecting the performance of the total stalder.

Group I trials averaged 72.19 degrees of center of mass displacement during the straddle-in action compared to 52.71 degrees of center of mass displacement in the lower ranked Group IV. The analysis of variance indicated that this was a significant difference (3 F 26 = 6.31) between the groups. The difference in displacement coupled with the differences in body position throughout this phase contributed to differences in other variables. Figure 4 is an overlay of tracings from selected frames in the straddle-in action. Two important differences are illustrated in this figure. The body positions in Figure 4a show a considerable difference in height above the bar and shoulder flexion at the start of the skill. Throughout the straddle-in, differences in shoulder extension are also apparent (Fig. 4b-f).

The analysis of variance revealed significant differences in certain shoulder and hip angle displacements and in most measures of moments of inertia for phases of skill execution caused by these body positions. The overall range of shoulder extension was different (3 F 26 = 5.58) between Group I ($\bar{X}$ = 80.00 degrees) and Group IV ($\bar{X}$ = 116.80 degrees) for the total stalder. The lower ranked trials, therefore, demonstrated, on the average, 20% more shoulder extension than the highest ranked trials (Fig. 5). It is interesting to note that the variable of judges ranking had a higher correlation (r= +.664) to overall change in shoulder angle than to any other variable measured. Table 2 displays the mean measures of shoulder angles for both groups in all phases. Group IV had greater amounts of shoulder extension, therefore, the shoulder angles are smaller.

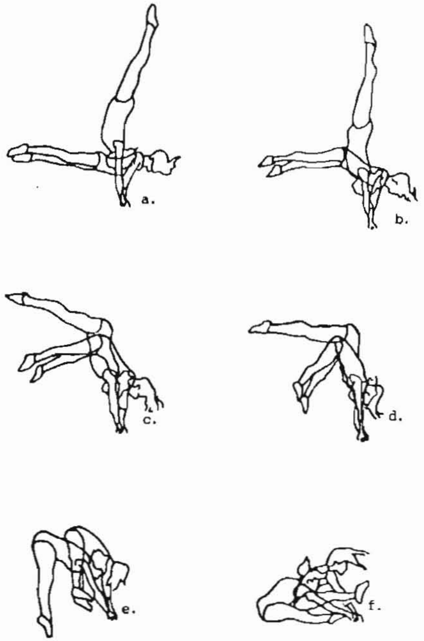


Figure 4. Comparison of Selected Body Positions During the Initial Straddle-In for a Group I and a Group IV Trial

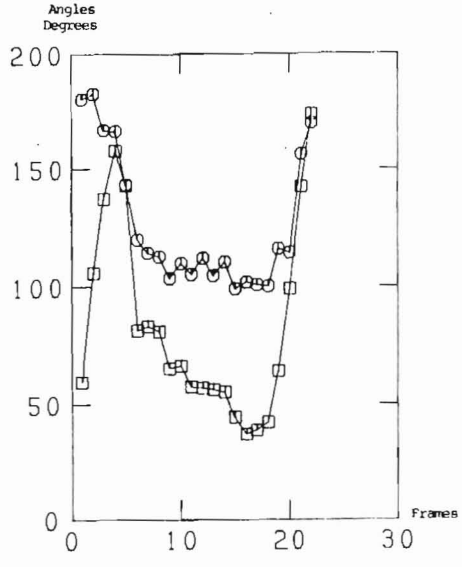


Figure 5. Grame By Frame Comparison of Shoulder Angles for a Group I (○) and a Group IV (□) Trial

Table 2. Mean Shoulder Angles in Degrees for Group I And Group IV For All Phases of Skill Execution

PHASE	GROUP I	GROUP IV	F*
1	169.21	140.49	4.91
2	122.43	85.67	22.31
3	119.38	79.01	20.93
4	111.26	62.39	16.68
5	109.82	60.56	16.51
6	101.38	54.86	14.58
7	127.10	96.88	9.37

* 1 F 12 = 4.75 at .05

Although the pattern of hip flexion was similar between the groups (Fig. 6), the total range of hip flexion occurring throughout the skill also represented a difference between the highest and lowest ranked groups (3 F 26 = 3.74). The trials in Group I showed greater overall hip flexion than did Group IV trials. On the average, Group I trials actually utilized more than 180 degrees of hip flexion ($\bar{X}$ = 182 degrees) while Group IV trials averaged just under full flexion with a mean change of 172 degrees.

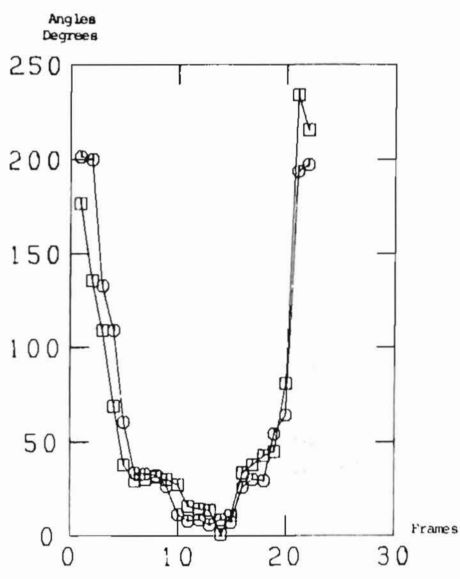


Figure 6. Frame By Frame Comparison of Hip Angles for a Group I (○) and a Group IV (□) Trial

The timing of shoulder extension and hip flexion throughout the stalder was another difference in performance technique demonstrated by the highest and lowest ranked groups. Figure 7 is composed of angle/angle diagrams of shoulder extension and hip flexion characteristic of Group I (a) and Group IV (b) performance styles. These changes in shoulder and hip angles directly affected the radius of rotation of the gymnast about the rail, and therefore, affected the moments of inertia about the rail as well as about the gymnasts' center of mass. As previously stated, there were no differences between the groups for the variables of mass, upper extremity length, trunk length or lower extremity length. The actual position of the body not the mass or individual segment lengths was responsible for differences in the moments of inertia. Figure 8 presents a frame by frame comparison of the moments of inertia for a Group I trial and a Group IV trial. In most cases, the difference in these measures are three times as great for Group I as for Group IV. These differences were significant in all phases of execution except the straddle-out action in which most gymnasts completed the skill in an extended body position. Table 3 shows the differences between Group I and Group IV for the measures of moments of inertia about the rail for Phases 1-6.

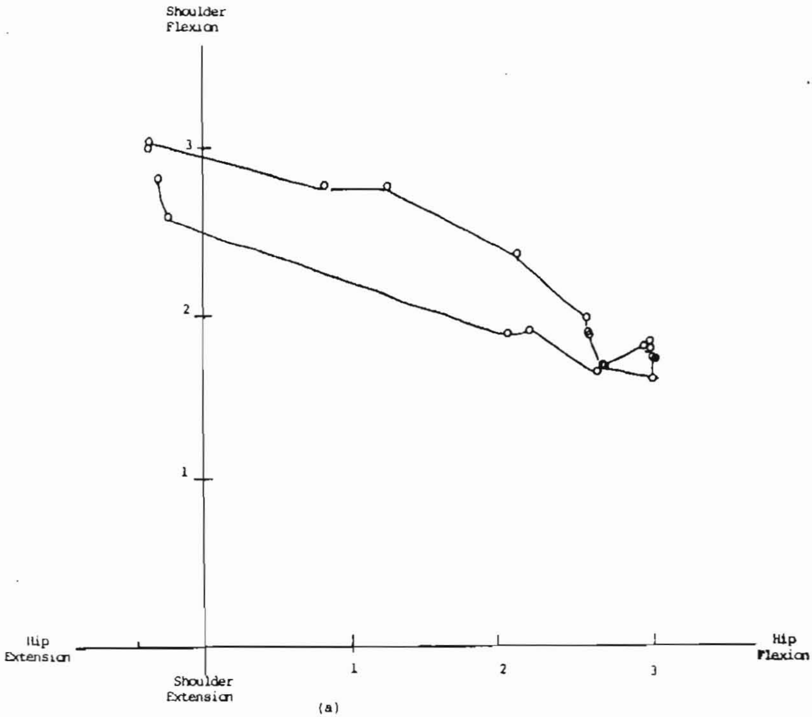
Table 3. Mean Measures of Moments of Inertia in Kg.m2 for Group I and Group IV in Phases 1 - 6

PHASE	GROUP I	GROUP IV	F*
1	23.25	10.64	12.30
2	14.27	5.94	17.63
3	13.95	6.18	16.59
4	15.10	8.25	7.21
5	14.36	7.77	8.86
6	14.21	7.76	8.41

* 1 F 12 = 4.75 at .05

Angular Velocity and Momentum

The performance differences among the trials for the measures of average angular velocity for the total skill ($\bar{x}$ = 2.51 rads/sec), the down swing ($\bar{x}$ = 2.01 rads/sec), and the up swing ($\bar{x}$ = 3.18 rads/sec) were not sufficient to produce significant differences between the groups. Angular velocity data for all the trials is presented in Table 4.



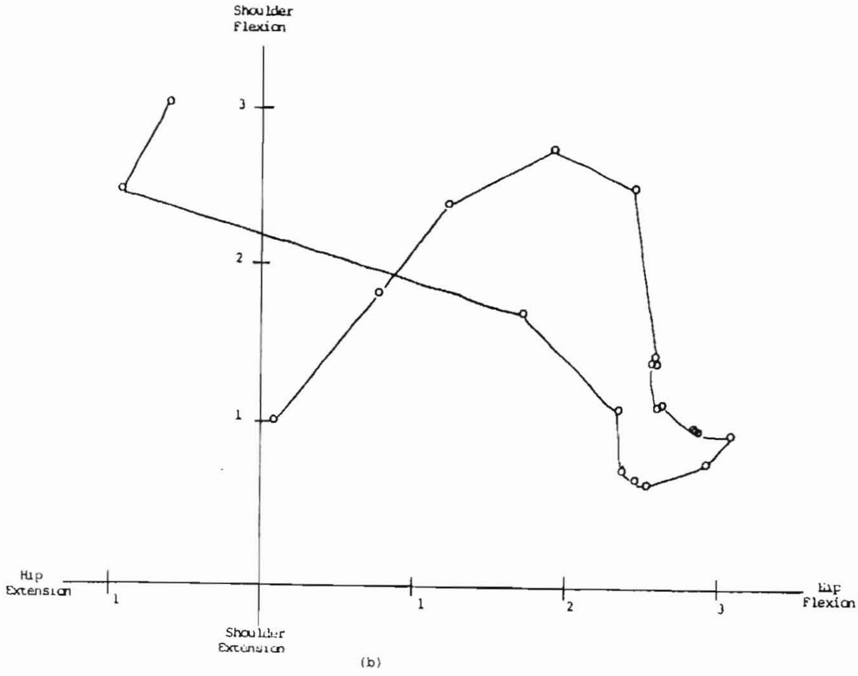


Figure 7. Angle/Angle Diagram of Should Extension and Hip Flexion in Radians of (a) Group I and (b) Group IV Trials

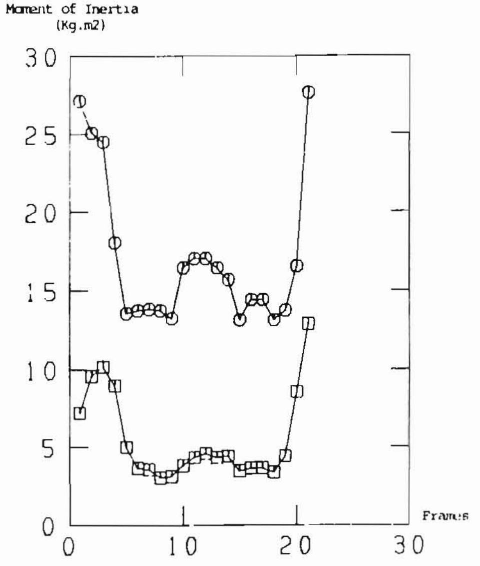


Figure 8. Frame By Frame Comparison of Moments of Inertia for a Group I (O) and a Group IV (□) Trial

Table 4. Angular Velocity Data for the Total Skill, Down Swing, and Up Swing in Radians/Second

	ALL TRIALS	GROUP I	GROUP IV
TOTAL SKILL			
RANGE	1.92 - 2.91	2.43 - 2.91	1.92 - 2.68
MEAN	2.51	2.64	2.39
ST.DEV.	.06	.02	.08
DOWN SWING			
RANGE	1.51 - 2.54	1.73 - 2.54	1.64 - 2.23
MEAN	2.01	2.16	1.95
ST.DEV.	.07	.08	.06
UP SWING			
RANGE	2.19 - 3.90	3.01 - 3.90	2.19 - 3.55
MEAN	3.18	3.33	2.93
ST.DEV.	.16	.12	.15

The similarities in angular velocity patterns for the phases of execution are shown in Figure 9. The rapid increase in angular velocity at the start of the upswing for the Group IV trial can be attributed to the sudden decrease in the moment of inertia occurring at that point to conserve angular momentum.

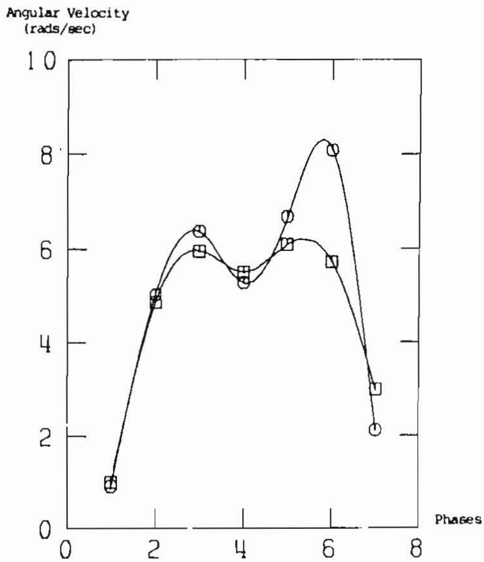


Figure 9. Phase By Phase Comparison of Angular Velocity for a Group I (□) and a Group IV (O) Trial

Although there were no differences between the groups for the variable angular velocity about the rail, the differences existing in moments of inertia were sufficient to cause significant differences in the variable of angular momentum. Group I trials had measures of angular momentum averaging twice those of Group IV trials. These differences were significant in all phases of execution. Table 5 presents the values for measures of angular momentum for all phases. Because only the measures of moments of inertia were significantly greater in Group I than in Group IV, it is possible to assume that this variable caused the differences in angular momentum to exist. The differences in shoulder extension between the groups was most likely responsible for the differences in moments of inertia, and therefore, were also a significant contributor to the differences occurring in angular momentum. Figure 10 shows a frame bv frame comparison and similarity of pattern between a Group I trial and a Group IV trial in angular momentum.

Table 5. Mean Measures of Angular Momentum in Kg.m2/s for Groups I and IV for Phases 1 7

PHASE	GROUP I	GROUP IV	F*
1	31.32	6.45	52.26
2	77.78	42.36	20.34
3	85.62	49.05	18.82
4	106.27	63.90	11.44
5	90.08	60.98	10.35
6	87.28	53.11	10.73
7	55.09	28.78	25.36

* 1 F 12 = 4.75 at .05

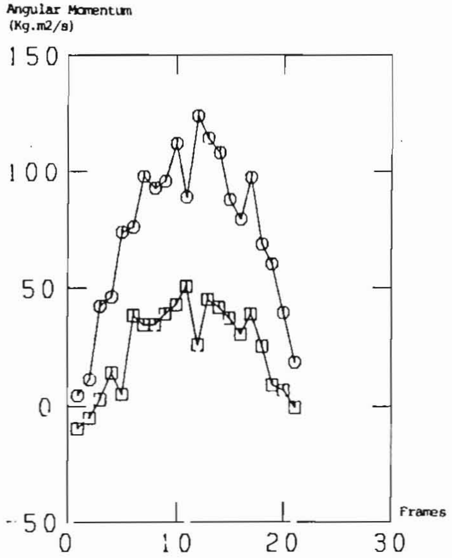


Figure 10. Frame By Frame Comparison of Angular Momentum for a Group I (O) and a Group IV (□) Trial

As gravity was the force which caused the gymnast to circle downward in the beginning of the stalder, it was also the force which retarded the upward swing for the completion of the skill. The gymnast had to attempt to generate more momentum on the down swing than was lost in the up swing so that the stalder could swing to completion rather than be muscled into the final position. The better gymnast will use body position changes to enhance the trade off between moments of inertia and angular velocity to conserve angular momentum. Group I trials were successful in generating more momentum in the down swing by maximizing the moment of inertia about the rail through minimal shoulder extension. A narrow straddle position of the legs in the straddle-in and rock back phases also contributed to the increased radius of rotation by forcing the hips farther from the rail. Group IV trials characteristically used a wide straddle-in position of the legs thus bringing the hips closer to the rail and reducing the moment of inertia. The continual shoulder extension displayed in Group IV trials throughout the down swing also contributed to reduce the moment of inertia which directly affected the amount of angular momentum which could be generated. Figure 11 shows the relationships among the variables of angular momentum, moment of inertia, and angular velocity about the rail for a Group I trial (a) and a Group IV trial (b).

One effect of the differences in angular momentum between the groups was a difference in the amount of force generated against the rail in the bottom swing. The forces the gymnast must withstand are greatest at this point in the skill. Differences between Group I and Group IV for force against the rail when considered in multiples of body weight were significant (3 F 26 = 3.64). Group I trials were subjected to forces averaging 2.51 times their body weight (Kg) as they passed below the rail. Group IV trials average forces equaling 1.69 times their body weight (Kg) during the bottom swing. Table 6 lists the forces against the rail during Phase 4 - the bottom swing.

Table 6. Force Against the Rail in Multiples of Body Weight During Phase 4

	ALL TRIALS	GROUP I	GROUP IV
RANGE	1.07 - 3.30	1.99 - 3.30	1.07 - 2.05
MEAN	2.18	2.51	1.69
ST.DEV.	.22	.17	.13

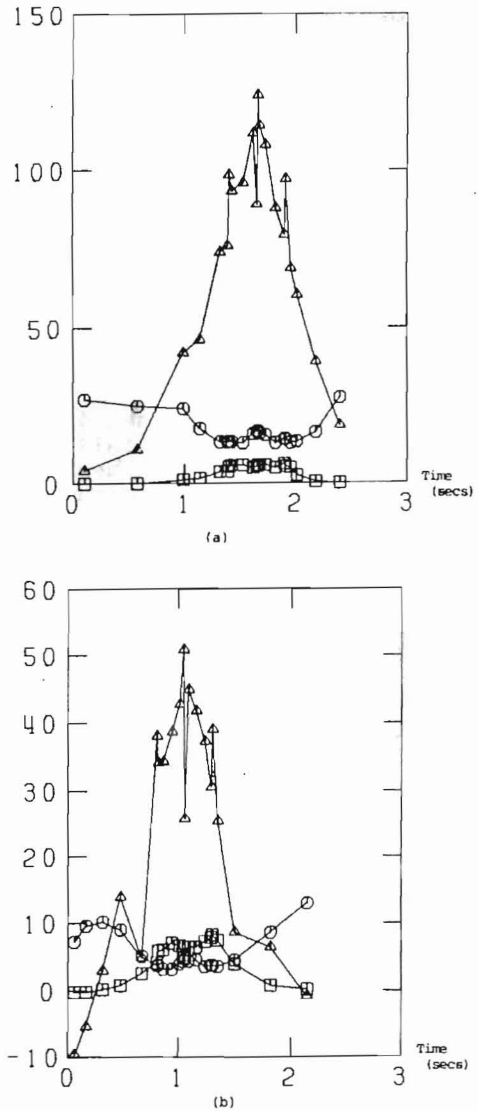


Figure 11. Relationships Among Angular Momentum (△), Moments of Inertia (○), and Angular Velocity (□) for a (a) Group I and a (b) Group IV Trial

Deflections of the Rail

Due to the elastic nature required of uneven parallel bars rails, the forces generated against the rail caused deflections when loads were applied. Overall deflections of the rail caused by various forces in the stalder were generally greater in X, Y, and linear measures for Group I than Group IV trials. The analysis of variance indicated a significant difference (3 F 26 = 10.34) in rail deflection in the X direction during Phase 2 of the down swing. Group I trials produced a horizontal rail deflection to a mean of 6.42 cm. Group IV trials averaged 1.70 cm of deflection during Phase 2. During the bottom swing the load against the rail produced a difference in the Y direction with the better performances averaging 10.37 cm downward deflection. This was significantly greater (3 F 26 = 3.79) than the average 4.73 cm deflection caused by the poorer performances. Figure 12 is a comparison of rail deflection patterns between a Group I trial and a Group IV trial.

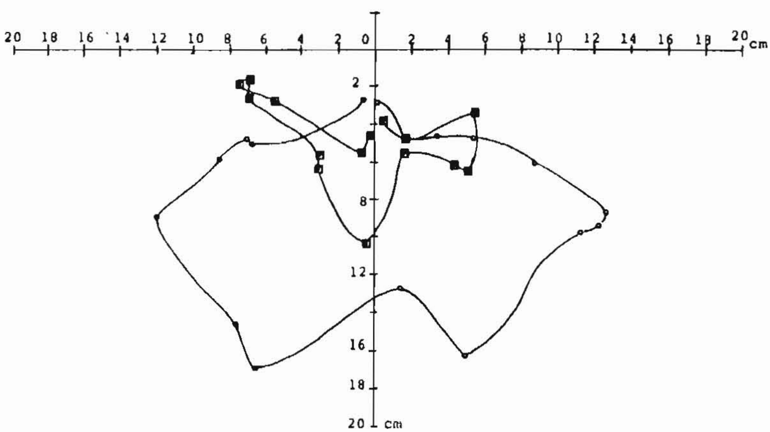


Figure 12. Comparison of Rail Deflection Patterns of a Group I (O) and a Group IV (□) Trial

Energy

Analysis of the stalder performances in terms of potential and kinetic energy variables showed similar differences between the groups as the angular momentum variables. The differences between the groups in the height of the initial cast position produced significant differences between the best and poorest performances for the variable potential energy (1 F 12 = 5.08). Potential energy during the straddle-in phase for Group I averaged 499.08J as compared to 357.08J for Group IV trials. Figure 13 shows a comparison of potential energy values throughout the stalder for the two groups.

The differences in potential energy naturally led to differences in total kinetic energy. In all seven phases of skill execution Group I had significantly greater measures of kinetic energy than Group IV trials. Table 7 presents the specific data for all phases.

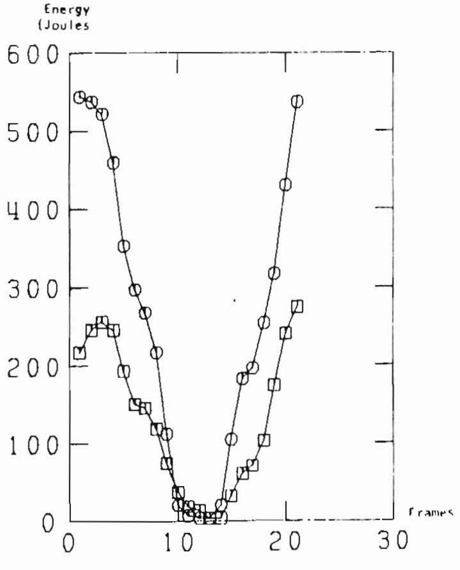


Figure 13. Frame by Frame Comparison of Potential Energy for a Group I (O) and a Group IV (□) Trial

Table 7. Mean Measures of Total Kinetic Energy in Joules for All Phases of Skill Execution

PHASES	GROUP I	GROUP IV	F*
1	63.90	23.47	37.66
2	255.32	155.19	23.26
3	278.33	179.24	22.29
4	448.73	242.01	37.27
5	365.94	222.29	19.77
6	336.68	180.64	21.41
7	175.30	102.36	23.66

1 F 12 = 4.75 at .05

Total kinetic energy was calculated as a summation of translational and rotational kinetic energy. Figure 14 shows a comparison between a Group I trial and a Group IV trial for total kinetic energy, translational kinetic energy, and rotational kinetic energy. The total kinetic energy for Group I trials was significantly greater than Group IV trials. This difference was likely due to the greater amounts of translational kinetic energy produced. Group IV trials, through continuous shoulder extension through the down swing and bottom swing, caused large amounts of rotational kinetic energy to be generated at the cost of translational kinetic energy. This performance difference (Group I trials showed very little change in body position between the straddle-in and the straddle-out phases) likely contributed to the poor performance in the second half of the stalder for Group IV trials.

The slight increase in kinetic energy occurring in the up swing (Fig. 14) illustrates the point at which unloading of the rail occurred. The recoil of the rail was of sufficient magnitude to produce a force acting to accelerate the gymnast upward at that point in the swing. Group I trials successfully timed the beginning of the straddle-out action with the recoil of the rail. Coupled with a body position characteristically showing straight arms and large shoulder angles, the gymnast was able to utilize the additional force to ease the swing to handstand. Group IV trials, on the average, began a very rapid straddle-out action before the recoil of the rail. In order to maintain balance and swing at the point of the additional force application, Group IV gymnasts had to adjust their body positions by flexing at the elbows to bring the body closer to the rail, and therefore, were in a poor position to utilize the force to aid in the completion of the skill.

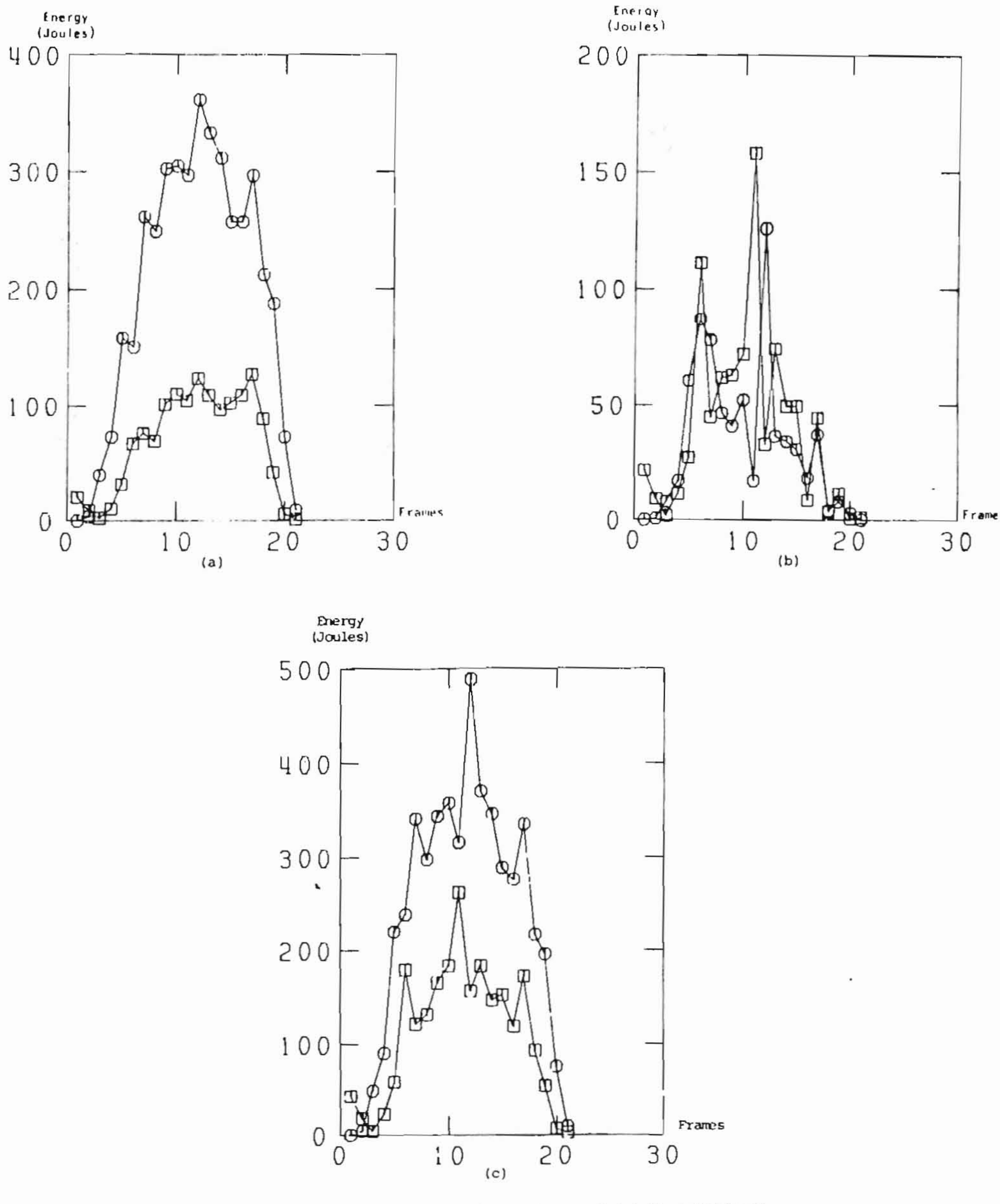


Figure 14. Frame By Frame Comparisons of (a) Translational Kinetic Energy, (b) Rotational Kinetic Energy, and (c) Total Kinetic Energy for a Group I (O) and a Group IV (□) Trial

The combination of large amounts of angular momentum and kinetic energy generated by the better performances in the down swing was sufficient to produce enough momentum for the maintenance of swing in the ascent phase so that the gymnasts could swing to the final handstand in the stalder. Shoulder flexion followed by hip extension into the final handstand was a characteristic action of the better trials. Group IV trials lacking in sufficient momentum to allow the gymnasts to swing to a final position, were characterized by rapid hip extension at the beginning of the up swing followed by elbow flexion to bring the gymnasts into a position where they could muscle into the final handstand.

Successful stalder performance can be accomplished with a variety of techniques thus accommodating differences in strength, size and flexibility of different gymnasts. Certain performance styles, however, are more effective in optimizing critical kinetic variables and influencing judges evaluation of the skill. Evaluation of a specific element within an uneven parallel bars routine will include assessment of the technical execution of the skill, the degree of internal and external amplitude displayed, and the amount of swing within the skill and between its connecting elements. Difficulty credit awarded to the stalder in a competitive routine is dependent upon the final position attained by the gymnast. A stalder which ends in a handstand above the rail is awarded the highest difficulty credit: 'C'. The emphasis on the final position of the stalder as opposed to the initial position indicates the importance of the up swing amplitude. Initial body positions in the stalder may only cause amplitude deductions to be taken, but insufficient amplitude in the beginning position and straddle-in phases will affect the performance of the entire skill by determining the amounts of angular momentum the gymnast can generate in the down swing.

The following conclusions seem supported by the study:

1. Stalder performance is initially enhanced by a starting position in or very near a handstand demonstrating good body position and control to maximize the distance between the center of mass of the gymnast and the axis of rotation.

2. The straddle-in action of the legs should be delayed as long as possible in the down swing and performed slowly with a narrow straddle to maintain an optimum radius of rotation to maximize the moment of inertia.

3. Minimal extension at the shoulders from the initial handstand position should occur to maximize the radius of rotation of the gymnast about the rail. Body positions throughout the entire stalder should be such that the hips are always further from the rail than are the shoulders.

4. Straddle-out actions should be timed to begin with the recoil of the rail on the up swing. A wide straddling of the legs in the frontal plane will have the least effect on the radius of rotation and thus will will cause minimal changes in the moment of inertia or angular momentum.

5. Extension of the legs at the hips should occur throughout the straddle-out action. Slower extension of the legs will have less effect on the path of the center of mass with respect to the rail and will not inhibit shoulder flexion, which for purposes of swing and connections should reach a final position with or just prior to full hip extension.

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