SHOULDER JOINT TORQUES AND THE STRAIGHT ARM/ FLEXED HIPS PRESS HANDSTAND ON THE PARALLEL BARS

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The recent rapid growth of the sport of gymnastics may be based, among other factors, on its versatility. Gymnasts attempt to win points in each of the various events by combining certain skills into spectacular eye pleasing routines. However, while the sport's governing body gives the athlete considerable freedom to choose or develop the appropriate skills for a particular routine, it also imposes certain restrictions. One of those restrictions is that routines on the floor, rings, and parallel bars should include a press handstand, i.e. a gymnastic skill requiring the slow elevation of an individual's body from an initial (usually an "L") stationary position to a handstand position. Several variations of press handstands exist depending on body configuration between initial and final positions. One of them, the straight arms/flexed hips press (SAFHP), is the variation most commonly used by gymnasts, and is depicted in Figure 3 (see results).

Obviously, accomplishment of the skill requires a continual change in body configuration brought about by muscular torques acting at the wrist, shoulder, and hip joints. From a practical standpoint, however, the shoulder joint torque is the most important. The hip joint extensors are quite powerful and capable of developing the necessary force during movement, regardless of limb positioning, whereas the wrist joint torque can be considered negligible, at least when the body's center of mass (CM) is above the gymnast's hands.

From a mechanical viewpoint, torque can be defined kinematically as the product of moment of inertia and angular acceleration. Since a press handstand is a slow movement, the angular acceleration is, or should be, small throughout the movement. Hence, a gymnast's moment of inertia about the shoulder joint determines, largely, the magnitude of the muscular torques at the respective joint. Since moment of inertia is the product of mass and the square of the distance of a body's CM from the axis of rotation, one should expect that greater hip joint flexion, timed properly during the execution of the SAFHP, would reduce the muscular demands at the shoulder joint by reducing the gymnast's moment of inertia. Furthermore, taking again into account the slow nature of the movement, one should expect the shoulder joint torque to be proportional to the moment arm of the combined trunk/lower extremities segments from the center of rotation.

In spite of its importance to gymnasts, research on handstands is very limited. Several gymnastics books, however, offer practical recommendations suggesting that the key to performing the SAFHP successfully is the ability of the gymnast to raise the hips above the shoulders, as close to a vertical position as possible, before raising the lower extremities, i.e. almost complete shoulder joint flexion before starting hip joint extension (Brown, 1980; Faria, 1972; Fukushima and Russel, 1980).

Coaches and athletes attempt to utilize intuitively these recommendationns and mechanical principles when they teach/practice the skill. However, even after considerable practice some gymnasts still experience difficulties ranging from complete failure to perform the skill to improperly performing it because of premature hip joint extension. Thus, the question is raised as to the degree to which such factors as shoulder joint strength, hip joint flexibility, and timing relate to these difficulties. It was the purpose of this project to investigate how these factors affect the performance of the skill under investigation. Particular emphasis was given to the shoulder joint torque, which in the present investigation is perceived as an indicator of strength, whereas timing and (utilization of) flexibility indicate technique. In turn, it is hoped that the results of the study will be useful to gymnasts.

METHODS

Subjects

Five gymnasts of differing ability served as subjects. Subject one had competed internationally, subjects two and four competed in college, subject three is currently involved in the sport of acrobatics, and subject five is a relatively novice gymnast. Their age, height, and mass at the time of data collection is presented in Table 1.

TABLE 1
(n = 5)

Selected Parameters for the Five Subjects

	Subject				
	1	2	3	4	5
Age (yrs)	35	23	21	25	21
Height (m)	1.63	1.67	1.52	1.82	1.63
Mass (Kg	60	65	48	80	53

Cinematographic Methods

The filming took place at the University of Maryland, College Park Campus. Ten SAFHPs were recorded on Kodak RAR 2498 Estar base, 16mm black/white film loaded in a Photosonics 16mm-1PL camera fitted with a 25mm Kern-Paillard lens. The camera was placed 15.2m from the proximal bar with the optical axis perpendicular to the plane of motion. The transport speed was set at 32f/sec and verified by a 10Hz pulsed signal applied to an internal LED timing light.

For each subject, one trial was chosen for analysis. A Numonics, Inc. 1224 digitizer interfaced with a Univac 1140 computer was utilized to digitize reference points (used to align the frames and as a scaling factor), and the centers of the wrist, shoulder, hip, and ankle joints. The segmental parameters used in this study were those derived by Demster (1955) as presented by Plagenhoef (1971). The raw displacement data were digitally filtered with a frequency of 2Hz before being submitted to further analysis.

Flexibility Measurements

Since hip joint intersegmental angle is a function of both hamstrings musculature flexibility and vertebral column flexion, measurements were made under several conditions (Figure 1). Position 1 (RF) restricts vertebral column movement, thus revealing only the hamstrings musculature's "active" flexibility. In position 2 (UF), by permitting posterior pelvic tilt, total "active" hip joint flexibility can be measured. Position 3 (PF) reveals total combined hip joint "passive" flexibility.

Cybex Measurements

Each subject was tested for maximum shoulder joint flexion torque on a calibrated Cybex II Isokinetic Dynamometer on line to a Dual-Channel Recorder (recording torque and position). The apparatus was set according to the manufacturer's recommendations for maximum torque testing at a speed of 60 degrees/sec, which was reasonably similar to the speed at which a press handstand is performed. Two maximal isokinetic contractions were recorded for each subject. In addition maximal isometric torques at 30, 45, 90, and 135 degrees of shoulder joint flexion were recorded.

RESULTS

Flexibility Measurements

Table 2 presents the subjects' hip joint intersegmental angles obtained during the flexibility test. In addition, the minimum hip joint angle achieved by each gymnast during the analyzed SAFHP is included. Subjects 3 and 4 proved to be the most flexible in all positions tested, and were also the ones that achieved the greatest hip joint flexion during the execution of the SAFHP. During the performance of the SAFHP, as was expected, none of the subjects reached the minimum

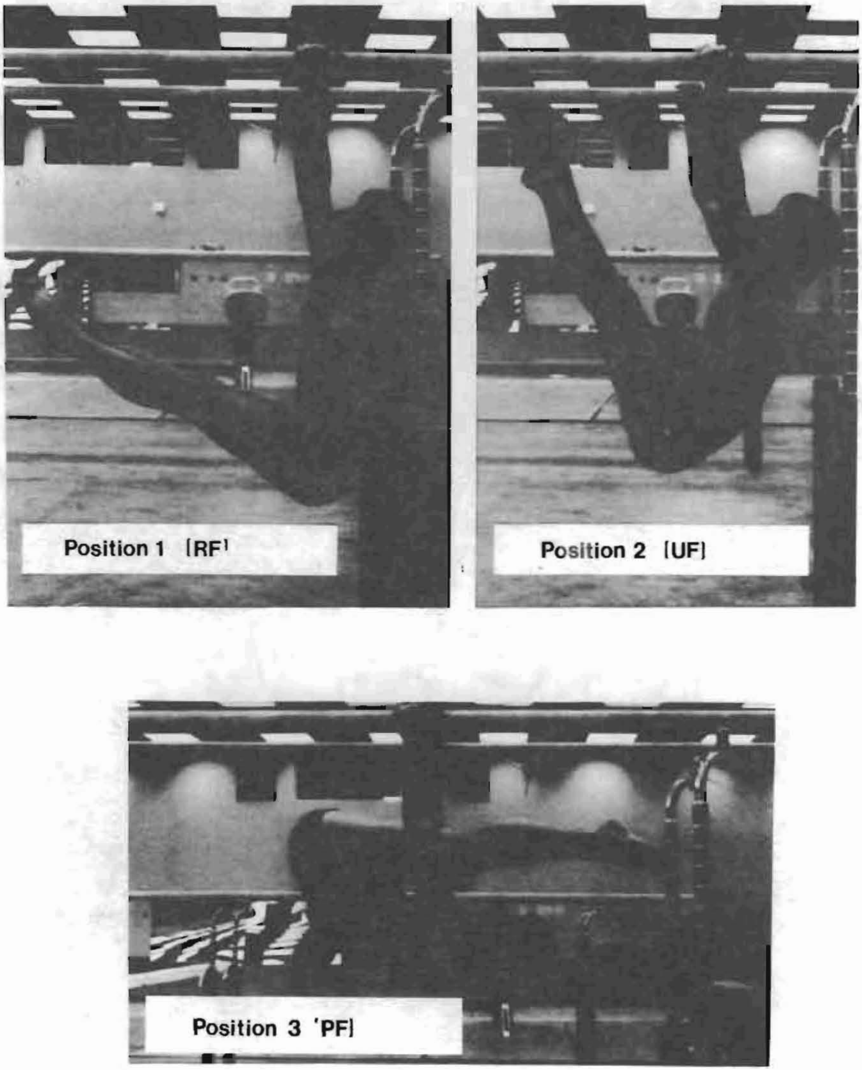

FIGURE 1. Flexibility measurements

angle obtained during the passive flexibility test (PF). The differences between the angles obtained under restricted (RF) and unrestricted (UF) conditions were from zero (subject 3) to sixteen (subject 4) degrees. All subjects showed greater hip joint flexion during the execution of the SAFHP than in RF, which indicates that gymnasts, in general, utilize some lower vertebral column flexibility when performing the SAFHP. In contrast, there is no similarity among the subjects when the angles from the film and UF are compared: subjects 2 and 3 showed greater hip joint flexion when performing the SAFHP, the angles for subject 5 were equal, and subjects 1 and 4 had smaller angles in UF.

TABLE 2
(n = 5)

Hip Joint Intersegmental Angle during the Flexibility Test and during the SAFHP (degrees)

Subject	Flex. Test			SAFHP
	RF	UF	PF	
1	73	59	44	64
2	69	62	50	53
3	46	46	31	36
4	54	38	25	47
5	72	61	44	61

Torque Normalization

To be able to make comparisons between subjects, the shoulder joint torque obtained from each analyzed trial was normalized by expressing it as a percentage of the torque required to hold the planche position, i.e. a skill in which the prone gymnast supports himself/herself over the hands with body held parallel to the floor and elbow joints fully extended. For each subject, the shoulder joint torque required to hold a planche position was given by the equation:

$$\underline{\tau}_{sh} = (\underline{W3} + \underline{W2}) * \underline{r}$$

where, $\underline{W3}$, $\underline{W2}$ = weights of lower extremities and trunk segments, respectively, and

$\underline{r}$ = position vector of the segment's CM from the shoulder joint

The solution to the above equation yielded the following values for subjects 1 through 5, respectively: 288.8, 301.6, 173.0, 361.4, and 224.7, Newton meters (N.m.).

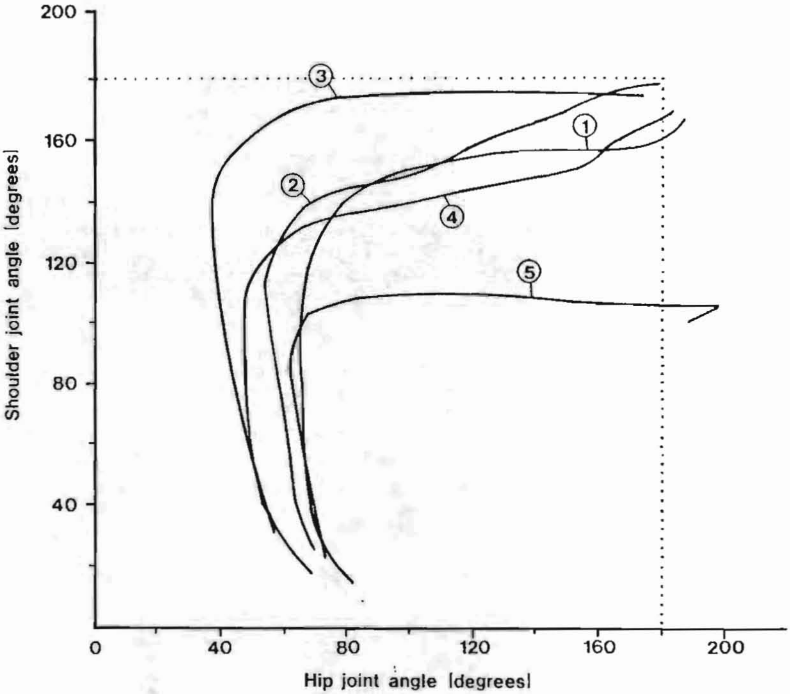

FIGURE 5. Shoulder vs hip joint angle

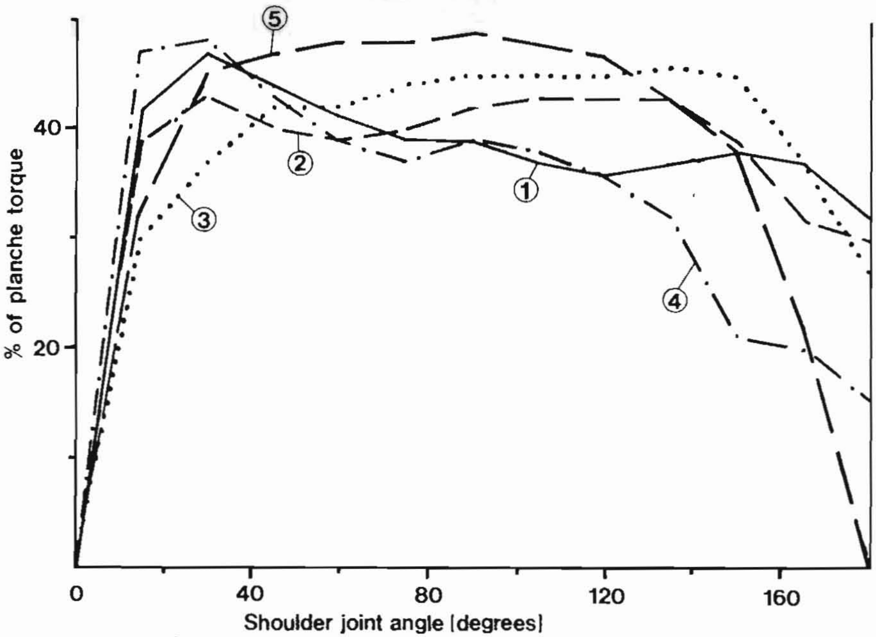

FIGURE 2. Cybex shoulder joint torques

Cybex Measurements

Figure 2 presents the normalized shoulder joint flexion torque curves for the five subjects. In general, all torques showed a steep initial increase followed by plateaus of varying lengths, and a subsequent decrease. The final decrease was sharper in the relatively novice gymnast (subject 5) than in the more experienced gymnasts (subjects 1-3). Subjects 1, 2, and 4 achieved maximum torques during the early phases of shoulder joint flexion (between 30-45 degrees). Subject 5 reached a maximum value at 90 degrees, and surprisingly, subject 3 (who performed the "best" SAFHP) reached peak torque considerably late in the movement at 135 degrees of shoulder joint flexion. The peak torque values ranged from 44 (subject 2) to 49 (subject 5) percent of their respective shoulder joint torques required to hold the planche position. The torque value at the terminal position ranged from zero (subject 5) to approximately 32 per cent (subject 1) of each subject's planche torque. In summary, the pattern of the recorded dynamic torques showed similarities at the beginning of the movement, but differed at the latter phases of shoulder joint flexion.

Table 3 presents the results of the Cybex isometric measurements. Considering torque a measure of strength, four subjects (1, 2, 4, and 5) proved to be the strongest at 90 degrees of shoulder joint flexion. Subject three, being consistent with the dynamic measurements, was strongest at 135 degrees of shoulder joint flexion. Comparison of the dynamic and isometric results did not show a recognizable pattern. In contrast, one finds inconsistencies, such as with the second subject who demonstrated the smallest maximum dynamic torque (44 per cent), but had the largest isometric torque (59 per cent). This suggests that when comparisons between subjects are made, no extrapolation from dynamic to isometric measurements and vise versa can be made. The "strongest" person under dynamic conditions is not necessarily "strongest" under isometric conditions as well.

TABLE 3
(n = 5)

Isometric Shoulder Joint Torques
(% of planche torque)

Subject	Shoulder J. Angle (degrees) 30	45	90	135
1	51.8	50.7	52.4	42.2
2	35.1	48.0	59.4	55.6
3	28.2	33.0	42.3	43.6
4	44.1	43.7	49.5	36.0
5	44.9	43.4	50.7	49.7

Straight Arms/Flexed Hips Press

Table 4 presents joint angles at selected positions and temporal results. Notice and compare the magnitude of the hip and shoulder joint angles of the third subject to the corresponding angles of the other subjects at the point of greater hip joint flexion (GHJF): the subject had the smallest hip joint angle (36 degrees) and the largest shoulder joint angle (135 degrees). This means that among all subjects, subject 3 one demonstrated best the mechanical principles and the coaches' and other practitioners' suggestions and recommendations mentioned in the introduction. It should be mentioned here that the first four subjects achieved (on film) aesthetically pleasing body configurations at the final position (FP). The relatively large deviations of the measured body angles from the ideal, (i.e. 180 degrees of hip and shoulder joint angles, and 90 degrees from the right horizontal for the wrist angle), were more likely the result of experimental error. The temporal results revealed that the first three subjects needed roughly one third of their total time to complete the portion of the movement between initial position (IP) and GHJF, while the fourth subject needed slightly less time. Of course, since the fifth subject did not complete the skill, no attempt should be made to compare parts of his data to the data of the rest of the subjects --especially the per cent of total time (TT) from GHJF to FP and the body configuration at the FP.

For comparison purposes, Figure 3 presents stick figure sequences of the five performances. Likewise, Figure 4 presents the normalized shoulder joint torques for the analyzed trials. In general, all torques showed an initial increase, which was warranted in light of the progressively larger inertial forces that the shoulder joint musculature had to overcome as shoulder joint flexion was occurring, and the need to control the magnitude of the angular velocity. Consequently, plateaus of varying lengths were observed with smaller or larger peaks at the later stages of the movement. Peak torque values ranged from 45 (subject 3) to 63 (subject 5) per cent of the respective planche torque occurring at different shoulder joint angles among subjects. However, our data (not shown here) suggests that for each gymnast, the torque magnitudes were proportional to the moment arm of the combined trunk/lower extremities segments about the shoulder joint. Likewise, it is suggested that the second peaking, shown more clearly in subject four, was necessary to stabilize the shoulder joint at a moment of rather rapid hip joint extension according to the action-reaction law of physics. For example, counterclockwise rotation of the lower extremities will result in clockwise rotation of the interconnected trunk segment. If the latter motion is not desired, additional muscular forces should be used at the shoulder joint in order to inhibit the trunk's undesirable rotation. Of course, the faster the lower extremities rotate, the larger the counteractive shoulder joint forces must be.

The fifth press is of particular interest. Referral to Figure 4 reveals that the subject's shoulder joint torque gradually began to decline after a peak at approximately 60 degrees of shoulder joint flexion. Shortly thereafter, GHJF was realized and rapid hip joint

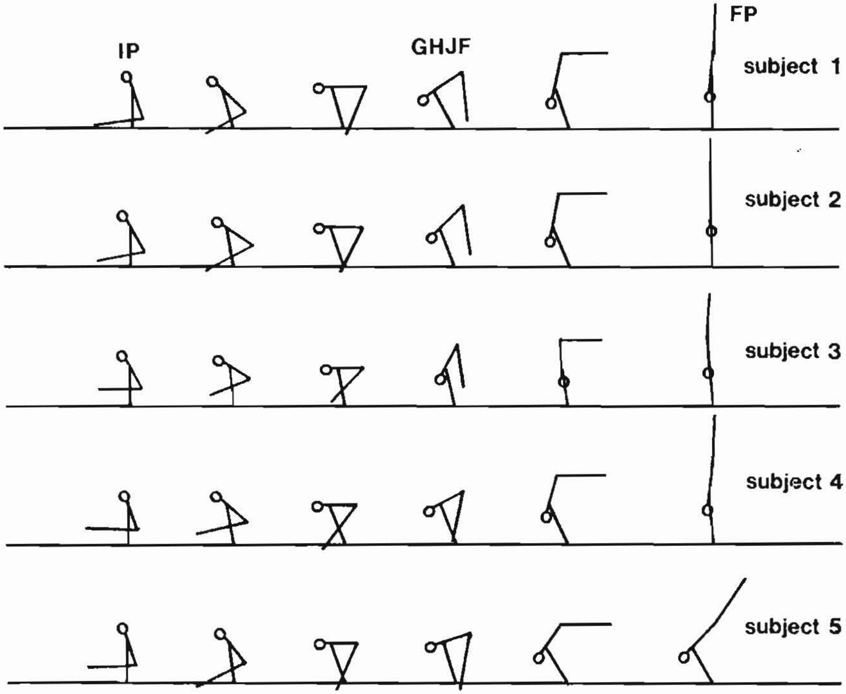

FIGURE 3. SAFHP: stick figures

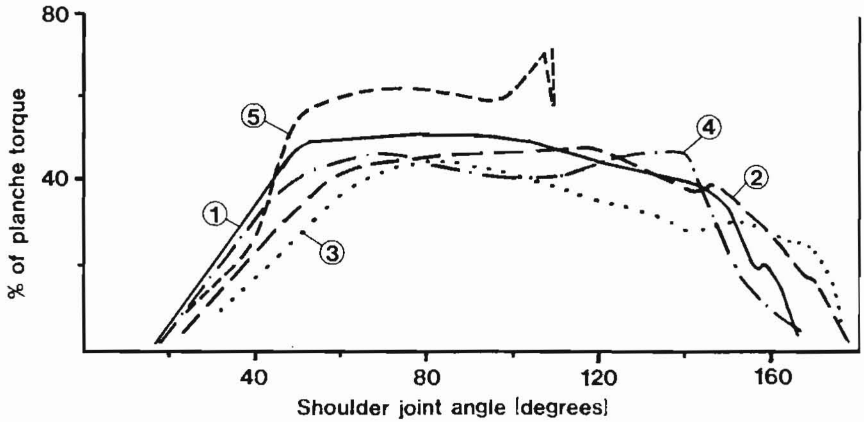

FIGURE 4. SAFHP: shoulder joint torques

TABLE 4
(n = 5)

Selected Parameters of the SAFHP
(Joint angles (JA) and center of mass (CM) positions in deg.)

	Subject 1	2	3	4	5
At IP					
Wrist JA	90	92	90	90	90
Shoulder JA	16	25	31	18	23
Hip JA	81	69	58	67	74
CM position	94	92	85	96	72
At GHJF					
Wrist JA	117	111	106	113	117
Shoulder JA	98	114	135	96	90
Hip JA	64	53	36	47	61
CM position	87	86	88	89	86
At FP					
Wrist JA	97	92	96	97	119
Shoulder JA	167	179	175	168	106
Hip JA	186	180	174	183	191
CM position	91	91	92	91	86
Time (min)					
Total Time (TT)	6	5.5	6	5.3	3.7
% of TT from IP to GHJF	37	33	35	28	43
% of TT from GHJF to FP	63	67	65	72	57

extension was immediately undertaken (Figure 3). This rapid hip joint extension greatly increased the gymnast's moment arm of the trunk/lower extremities segments about the shoulder joint since it was not accompanied by an equally rapid and properly timed increase in shoulder joint angle. The subject, however, attempted to complete the movement in this approximately straight body configuration by repeatedly increasing the shoulder joint torque. These increases, however, were not of sufficient magnitude to counteract the rapidly increasing moment arm and, as a result, the subject began to fail.

DISCUSSION

The primary purpose of this study was to investigate the the relationship between shoulder joint strength, hip joint flexibility, and timing to the press handstand. For reasons explained previously, particular focus was given to the shoulder joint torque. Since torque and moment of inertia are directly related kinematically and since the latter parameter is a function of body configuration about a particular axis of rotation, hip joint flexibility measurements were taken. During execution of a SAFHP a gymnast's moment of inertia about the shoulder joint and hence the magnitude of the shoulder joint torque depends on:

(1) the magnitude of hip joint flexion, and (2) the time history of the hip joint angle in relation to the shoulder joint angle. In other words, the shoulder joint torque can be either larger or smaller depending on the degree of hip joint and lower vertebral column flexibility, and on the timing of the reversal of the hip joint motion.

The relationships between the hip joint angles obtained during flexibility measurements and during performance of the SAFHP were presented and compared in Table 2. With regard to the time history of the hip/shoulder joint angles, the movement pattern of the fifth subject (unsuccessful attempt of the SAFHP), from the point that GHJF was realized and thereafter, is characteristic of not only beginning gymnasts, but sometimes of more experienced ones. In fact, this phenomenon was one of the stimuli for undertaking this investigation. As it was mentioned previously, premature and rapid hip joint extension (as in subject 5) greatly increases the muscular demands on the shoulder joint by increasing the gymnast's moment arm of the trunk/lower extremities segments about the shoulder joint and by requiring additional "stabilizing" forces to counteract the trunk segment's undesirable counterrotation. In addition, even if the gymnast possesses the muscular strength to complete the movement in the resulting "semi-extented" body configuration he would be penalized by the judges for improper execution.

Although it is beyond the scope of this study to discuss motor learning and the related mechanisms in great lengths, it could be speculated that in the beginner's case the underlying motor program is not yet fully developed. According to theory, repeated practice accompanied with reinforcement in the form of audiovisual feedback will fine tune the control mechanisms resulting in superior performance (Adams, 1971; Schmidt, 1975). The case of the more advanced gymnast, however, is quite puzzling. If practice and reinforcement are the roots to the development and refinement of the motor control programs, why do some individuals, when attempting to execute the SAFHP, initiate hip joint extension prematurely in spite of months and sometimes years of practicing and repeated and variable reinforcement? The answer to this question is left to the motor learning specialist with the remark that some individuals (as the advanced gymnast who encounters difficulties in learning the SAFHP) experience difficulty passing from the cognitive to associative and autonomous phases of learning (Schmidt, 1982).

Although timing is critical in executing the press handstand, the factor of strength should not be overlooked. The demands placed upon the shoulder joint flexors are quite heavy. Thus, the purpose of the Cybex measurements was to provide a practical method of comparing the torques required to execute the press handstand (calculated from film data or, as a possible alternative, from computer simulation of the movement) to the torques obtained from a direct strength measurement device such as the Cybex. If the Cybex torque was found to be larger it meant that the gymnast possessed the necessary muscular force to complete the movement and should concentrate on working on "technique." If, on the other hand the Cybex torque was smaller, the gymnast should be advised to first develop the necessary strength before he attempts to learn the skill. Unfortunately, the dynamic and isometric Cybex data obtained in this investigation (Figure 2, and Table 3) did not compare in a logical manner to the shoulder joint torque derived from the film analysis. In Figure 2, for example, the value of the Cybex shoulder joint torque for subject 4 at 140 degrees of shoulder joint flexion is about 25% of the planche torque. In Figure 4, at the same position, it is larger than 40%. Also, the peak (dynamic and isometric) Cybex torque measurements for subject 5 are considerably smaller than the corresponding peak film torque. It was recognized, of course, from the beginning that shoulder joint flexion as it occurs in press handstands, is quite different than the motion occurring in Cybex testing. In the first case, the upper extremities are rather fixed and a "reverse", so to speak, shoulder joint flexion occurs by rotating the trunk segment. In Cybex testing the trunk is fixed and the upper extremity rotates about shoulder joint center. However, even making due allowance for these differences in body segment movement, it is extremely difficult to explain the aforementioned large discrepancies between the Cybex and film torques observed in this study. The task of explaining these discrepancies becomes even harder in light of pilot electromyographic data that showed that the EMG potentials of the anterior deltoid, pectoralis major, biceps brachii (shoulder joint flexors) and trapezius (shoulder girdle stabilizer) obtained during performance of the planche on the parallel bars and during a "simulated" planche on the Cybex apparatus did not differ substantially either in magnitude or in pattern. Thus, torques obtained on the Cybex apparatus could not, unfortunately, be compared logically to the respective film torques. They could not, then, be utilized as an aid to improve performance of the press handstand in the manner outlined above. However, peak dynamic and isometric Cybex torque values for subject 3 occurred at later stages of shoulder joint flexion, which suggest that increased levels of strength at this point of the movement might be a prerequisite for satisfactory execution of the skill. The latter argument might also be supported by the dynamic measurements of the other skilled subjects (1, 2, and, to a lesser extent, subject 4).

Figure 5 summarizes the press handstands that were investigated. Speaking in relative terms, the SAFHP of subject 3 should be considered the best, since it is revealed in the Figure that the subject almost completed the shoulder joint flexion before hip joint extension was initiated. In contrast, subject 5 began hip joint extension nearly midway into shoulder joint flexion which, for reasons discussed previously, definitely contributed to the subject's failure to complete the skill. A point should be made here that with respect the SAFHP, a common perfect performance (with regard to body configuration) can not realistically be defined since it depends on the degree of hip joint and vertebral column flexibility. It is known that even among gymnasts, the degree of that flexibility varies. Another point that should be made is that although Figure 5 can be used by coaches and athletes as a guide for differentiating various levels of performance quality for the the SAFHP, it does not present a complete description. Proper body configuration is only one of the factors that determines the awarding of the full amount of designated skill points by the judges. Before a given press handstand can be adapted as a model of proper performance, other factors, such as completion time, fluency of the movement, and general aesthetic perceptions should be known and considered.

SUMMARY AND CONCLUSIONS

The primary purpose of this study was to investigate the relationship between shoulder joint strength, hip joint flexibility, and timing to the SAFHP. Five gymnasts of differing abilities served as subjects. Kinematic and kinetic parameters for five SAFHPs were determined from film analysis. All gymnasts were tested on a Cybex II Isokinetic Dynamometer for maximum dynamic and, at selected positions, static shoulder joint torques. They were also tested for passive, restricted, and unrestricted active hip and vertebral column flexibility. In this study the normalized dynamic and isometric Cybex torques did not compare logically to the respective torques of the SAFHP. Consequently, the Cybex torque measurements could not specify the source of error for gymnasts experiencing difficulties in learning the skill. However, it appears that increased levels of strength at the later stages of shoulder joint flexion might be one of the prerequisites for proper execution of the press handstand. Comparison of the hip joint angles obtained during the flexibility measurements to the hip joint angle at the point of greater hip joint flexion (SAFHP) reveales that gymnasts during performance do not reach their potentials in attaining the smallest possible hip angle, assuming that small hip angle is an advantage. Therefore, gymnasts could theoretically reduce the demands placed upon the shoulder joint musculature by better utilizing -- and, of course, by increasing --existing hip joint flexibility.

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