RELATIONSHIP OF LUMBAR CURVATURE AND LANDING SURFACE TO GROUND REACTION FORCES DURING GYMNASTIC LANDING

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It is postulated that low back pain is one of the most common complaints of athletes. Stanitski (1982), Micheli (1979), and Smith (1977) noted that athletes with low back pain classically exhibit functional lumbar hyper-lordosis due to tight lumbo-dorsal-fascia in conjunction with weak abdominals. Excess arching of the low back is a typical posture taken by many gymnasts. Trauma to the body has been identified as being related to impact forces (Voloshin & Wosk, 1982). Since gymnastic vaulting requires the absorption of landing forces, the magnitude of these landing forces compared to other activities must be studied. The vertical ground reaction forces during walking are approximately 120 percent of body weight (Marino & Leavitt, 1985). During running these may be 200 percent body weight (Cavanagh & LaFortune, 1980) and in volleyball 400 percent body weight (Adrian & Laughlin, 1983).

Presently, there are no guidelines for the coach to identify the potential risk of injury to the gymnasts during practice of skills requiring repeated landings. In the absence of such guidelines, there remain many unanswered questions. For instance, how many landings should be performed? What type of landing surfaces should be used? What should the position of the trunk be at landing? When can one determine that there is a risk for injury? In order to develop guidelines, some of these questions must be answered. Therefore, the purpose of this research was two-fold:

1. to determine the relationship of lumbar curvature and landing surfaces to ground reaction forces during gymnastics landing, and;
2. to provide the coach with guidelines based on what can be observed using video records and what the gymnast is actually doing.

METHODOLOGY

The subjects for this investigation were 26 gymnasts. There were 10 females and 9 males from the University of Illinois varsity team, and 7 male gymnasts from the Japanese junior national team. Height and weight were measured (table 1). The gymnasts were asked to perform a dismount from a Swedish vaulting box 0.85 meters high, as if they were in competition. The landing surface was a force platform covered with one of two mat surfaces. The sequence of testing was with the stiffer mat first, and the softer mat second. The stiffer mat (mat 1) was 1 cm thick with a coefficient of restitution of 0.78 (as calculated from the rebound height of a dropped ball). The softer mat (mat 2) was 5 cm thick with a coefficient of restitution of 0.53. All trials were videotaped with a VHS having digital real-time accuracies of 0.01 seconds. Force-time histories simultaneously were obtained for each of the mat conditions with a AMTI system.

TABLE 1

SUBJECT CHARACTERISTICS

Subjects (n = 26)	Wt (kg)	Ht (cm)	
1	73.57	170	
2	68.57	167	
3	59.49	159	
4	60.85	166	
5	59.04	166	U of I
6	70.84	172	Men
7	63.12	164	
8	58.58	162	
9	65.85	173	
X	64.44	166.5	
10	56.31	168	
11	52.22	165	
12	56.77	164	Japanese
13	51.77	161	Men
14	56.31	163	
15	51.77	154	
16	54.09	157	
X	54.18	161.7	
17	51.77	153	
18	44.50	158	
19	57.22	164	
20	59.04	172	
21	54.49	155.5	U of I
22	43.60	154	Women
23	54.95	164	
24	55.40	163	
25	64.49	171	
26	52.22	159.6	
X	53.77	161.4	

DATA ANALYSIS

The force-time histories were plotted and the initial impact force was measured and tabulated for each mat condition of each subject. A typical plot is illustrated in Figure 1. The general pattern of vertical force (Fz) was a small sharp peak resulting from the initial impact with the ball of the feet, followed by a larger reaction force used to decelerate the body. Only the initial impact force in the vertical direction was of concern in this investigation. Horizontal forces were minimal compared to vertical forces and resulted from the reaction force used by the gymnasts to maintain balance after landing. From the videotapes, contourograms were obtained by tracing with felt tip pens onto transparency sheets placed over the video monitor during image by image play back. For each trial the following key positions (four all together) were traced: (1) the moment of landing; (2) the maximum depth of the crouch after landing; (3) midway from the crouch to the final standing position; and (4) the final position

TABLE 2

COMPARISON OF TWO MAT CONDITIONS AND VERTICAL GROUND REACTION FORCES DURING LANDING FROM A VAULTING BOX

VARIABLE	N	MEAN (N)	S.D.	S.E.	T-TEST PROBABILITY
ABSOLUTE FORCE					
Mat 1	26	3597	1041	204	0.04
Mat 2	26	3068	1026	201	
RELATIVE FORCE					
Mat 1	26	6.33 *	1.99	0.39	0.03
Mat 2	26	5.35 *	1.73	0.34	

* TIMES BODY WEIGHT

TABLE 3

COMPARISON OF TWO TRUNK POSITIONS AND RELATIVE VERTICAL GROUND REACTION FORCES DURING LANDING FROM A VAULTING BOX

VARIABLE	N	MEAN (N)	S.D.	S.E.	T-TEST PROBABILITY
RELATIVE FORCE					
Flat Trunk	35	5.47 *	1.84	0.31	0.04
Arched Trunk	17	6.62 *	1.86	0.45	

* TIMES BODY WEIGHT

(posed standing position). These positions were selected because they represented visually distinct landing and recovery phases. Descriptive analyses of arm and trunk positions from contourograms were made using the following classification system:

Arm position at landing:
1 = arms overhead
2 = arms upward and behind head
3 = arms upward and forward of head
4 = arms in a down position, less than horizontal

Arm position at the maximum crouch postiion
1 = arms down (vertical)
2 = arms forward below the horizontal
3 = arms horizontal (parallel to the ground)
4 = arms above the horizontal

The trunk position at: (1) landing, (2) maximum crouch position, and (3) final standing position.
1 = flat lumbar
2 = arched or concave lumbar
3 = round or flexed or convex lumbar

This classification system was used based on the assumption that arm and trunk position upon landing was important, not just for maintaining balance, but also for attenuation of forces. Curvatures of the back and position of the trunk for one subject are shown in Figure 2. A flat back occurs only at the midway position (between the maximum crouch and final position). There is an arched back in the other three positions.

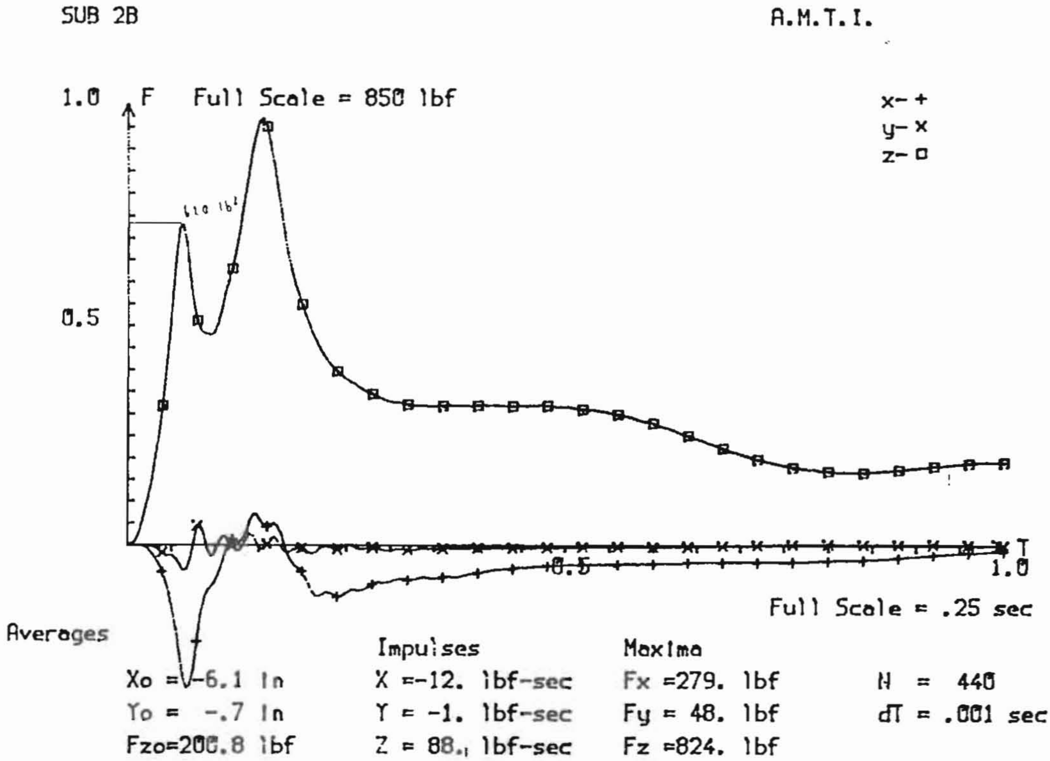

FIGURE 1 SAMPLE FORCE PLATFORM PLOT OF LANDING FROM A VAULTING BOX

RESULTS

Statistically, the two mat conditions were compared with respect to the initial impact forces and standardized with respect to body weight. The following results were obtained using one-tailed t-tests, with all subjects combined. The impact forces on the softer mat (mat 2) were significantly lower ($p < 0.05$) in both absolute and relative forces (standardized for body weight) as compared to the stiffer mat (mat 1). The average landing forces were 3597 and 3068 newtons; which corresponded to 6.33 and 5.35 times body weight for the two mat conditions. respectively. These data are shown in Table 2.

Using the classification system, the contourograms were analyzed and the following frequency distribution was obtained: (1) 8 landings with arms positioned overhead; (2) 14 landings with arms upward and behind the head; (3) 7 landings with arms upward and forward of the head; and (4) 23 landings with arms in a down position.

A t-test was used to determine whether there were any differences in impact forces relative to body weight between landings with a flat trunk and landings with an arched trunk. Combined data from the two mat conditions were used, thus increasing the possible number of landing to 52 (twice the number of subjects). There were 35 flat back and 17 arched back values. It was determined that significant difference in impact forces exist at the 0.05 level between landings with a flat trunk and those with an arched trunk. Subjects landing with a flat trunk (lumbar) displayed lower impact forces (5.5 times body weight was compared to 6.6 times body weight for arched trunk landings). These results are shown in Table 3.

Figure 2. Landing sequence of subject #1, left to right (a)landing, (b)maximum crouch, (c)midway, and (d)final position.(Photo from video).

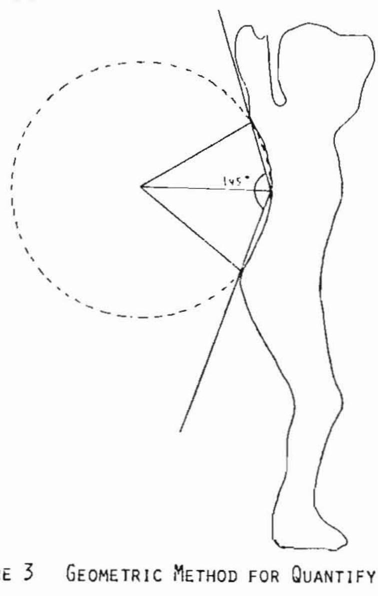

FIGURE 3 GEOMETRIC METHOD FOR QUANTIFYING CURVATURE OF LUMBAR SPINE

The following statistical comparisons using ANOVA's were not significant ($p > 0.05$):

1. the impact forces relative to body weight with different arm positions at landing;
2. the impact forces relative to body weight with the three groups of subjects.

Furthermore, there were no significant interactions in landing forces between subject-group and mat-conditions when tested with a 2-factor ANOVA (3 groups of subject by 2 mat conditions).

DISCUSSION AND SUMMARY

Since the vertical forces of impact can be greater than 6 times body weight, the human body must tolerate and absorb a great deal of stress when landing. Potential for injury for gymnasts landing with an arched lumbar trunk is greater, since greater forces are produced and transmitted upwards through the spine. This would cause greater compressive forces to be placed on the intervertebral-discs and could result in low back problems arising from pinched nerves and/or compressed discs. One may speculate that the greater stress would be to the vertebrae based on evidence documented from the literature regarding the aggravation of existing low back problems by mechanical stress (Berkson, Schultz, Nachemson, & Anderson, 1977; Frymoyer & Pope, 1978; Nachemson, 1977).

One of the most important implications of this study is that the results can be utilized by coaches. The coach could use videography to investigate and chart the lumbar curvature of the gymnast. Information derived could be used to construct training programs for gymnasts. For example, those who land with arched backs can be placed into abdominal strength programs, guided into performing lesser numbers of landing than others, modifying their landings, and/or using softer mats.

In addition to visual inspection, the coach can also utilize the contourogram method to evaluate landing techniques. Quantitative values could be obtained by measuring the angle at the lumbar region and then collected longitudinally for a comparison of changes in the back arch. This procedure is shown in Figure 3 and is based upon the procedure used by Wielki, Stubois, and Wielki (1985).

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