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A Paediatric Perspective Of Biomechanical Analysis Of Female Gymnasts' Landings: Safety Considerations

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PAEDIATRIC PERSPECTIVE OF BIOMECHANICAL ANALYSIS OF FEMALE GYMNASTS' LANDINGS: SAFETY CONSIDERATIONS

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INTRODUCTION

In the last decade an increased interest in gymnastics has occured in Australia. There is also a trend to begin training at a young age (4-6 years), and gymnasts are achieving high levels of skill development much sooner than in the past. Gymnastics training and competition places a considerable load on the musculo-skeletal system. It creates the potential for injury due to the forces applied to the body during performance and more importantly loading. The incidence of low back pain,for example, in gymnasts is considered high. The forces and moments that produce the greatest load on body structures are experienced during landings (Nigg et. al., cited in Brueggemann, 1987; Adrian and Cooper, 1989). The magnitude of these loads becomes considerable at high velocities. Therefore, the reduction in the likelihood of injury necessitates thoughtful planning and progressive physical preparation and conditioning of gymnasts. Every serious injury that occurs to a young gymnast imposes unnecessary trauma to those involved and decreases the enjoyment obtained from being physically active.

LITERATURE REVIEW

Modern women's artistic gymnastics has a reputation for injury (Brueggemann, 1987; McNitt-Gray, 1991, 1993; McNitt-Gray, Yokoi and Millward, 1994; Snook, 1979). The increase in participation, the difficulty and complexity of skills, the increased training hours, and the concurrent decrease in age of competitors have contributed to increased incidences of injury in this sport. Caine & Lindner (1985) suggested that injuries were the consequence of coaches' high expectations, for example young gymnasts being pushed too hard and prematurely.

Low back pain is a common complaint among gymnasts. Repeated and excessive arching of the lumbar spine is a typical posture in the routines (Adrian and Cooper, 1989). The lumbar spine is responsible for the coordinated transfer of power through the body from legs to torso and plays an important role in the landing process. If a significant arch occurs during landings it is likely to contribute to injury. The greater the landing forces, the greater the risk of injury. An increase in load causes an increase in the strain of biological tissues. Thus, a body will continue to deform as increased forces are applied, possibly until it fractures. Leglise (1987) indicated that this increase in stress was often followed by an increase in chronic injuries. While the incidence of spondylolysis and spondylolisthesis occurs in about 5-7 percent of the general population, it is present in 11 percent of European gymnasts and 29.4 percent of Japanese gymnasts. This and the fact that 37.95 percent of gymnasts in general suffer lumbar problems, highlights the vulnerability of gymnasts to these types of problems . Jackson et al. (1976) examined the lumbar spine of 100 gymnasts between the ages 6-24 years using radiographic images, and found that the prevalence of spondylolysis in female gymnasts was almost four times higher than the 2.3% believed to occur in white females. Rossi (cited in Meeusen & Borms, 1992) reviewed 1430 lumbar spine radiographs of Italian Olympic athletes and found signs of spondylolysis in 32.8% of 132 gymnasts and spondylolisthesis in 8.9%.

In their study of female gymnasts, Garrick & Requa (1980) found that 12.2% of injuries occurred in the spine . Goldstein et al. (1991) studied three groups of top level female gymnasts (age 8 - 18)of pre-elite, elite, national and olympic caliber with regard to back pain and injury. The groups were compared to a similar group of national caliber female swimmers. The study revealed that 9% of pre-elite, 43% of elite, and 63% of olympic level gymnasts had spine abnormalities, while only 15.8% of all swimmers had spine abnormalities. A study cited in Kolt (1992), on Canadian elite female gymnasts reported that 83% of the gymnasts sustained at least one injury in the duration of the study.

Back pain in gymnasts may be due to a variety of causes, ranging from a hyperlordic back to vertebral body fractures and disorders of the invertebral disc (Micheli, 1985). Back problems seem to result not only from single episodes of macrotrauma, but also from the repeated microtrauma in gymnastic movements (turns, twists and hyperextensions). Pollhaene (cited in Brueggemann, 1992) analysed 49 female gymnasts and found that 81.7% of the gymnasts showed pathological alterations of the spinal columns.

To date, the majority of studies investigating the epidemiology of gymnastic injuries have failed to include the spinal injuries associated with landing force. Lower back injury in the young adolescent should never be taken lightly, since the longer the young gymnast has significant lumbar symptoms, the longer it usually takes for them to be resolved (Meeusen & Borms, 1992). Although such skills have been studied in the past in young female and male gymnasts (Payne and Parker, 1976; Too and Adrian, 1987; Knoll and Krug, 1990; Brueggemann, 1993), few studies have examined kinematic and kinetic properties related to potential injuries, particularly to the lumbar spine. Therefore, there is a need to accumulate kinematic and kinetic data of such skills to furnish normative information on various levels of performance.

Purpose

The purpose of the study was to:

- measure the magnitude of PVGRF as an indication of the loads placed on the musculo-skeletal system
- investigate the relationship between forces and linear and angular kinematics involved in the execution of the skills performed
- identify landing techniques which reduce PVGRF and consequently reduce the load on the lumbar spine.

METHOD

Subjects

Ten female sub-junior elite gymnasts (age 9 - 11) from the Victorian Institute of Sport (VIS), Women's Artistic Gymnastic (WAG) Centre Cheltenham, and four Australian Gymnastics Federation level-eight female gymnasts volunteered as subjects. Informed consent was obtained from subjects and parents. Personal descriptive data of the of the gymnasts is presented in Table 1.

Table 1. Descriptive Data of the Female Gymnasts

	Age (years)	Height (m)	Weight (kg)
Range	9-15	1.25-1.63	23.8-53
Mean	12.2	1.45	33.8

Experimental Procedures

All subjects were provided with the opportunity to become familiar with the experimental set-up. Explanations were given as to the exact task to be performed and emphasis on technical requirements and safety considerations were provided. After a traditional warm-up period, all subjects had 3-5 practice trials prior to data collection in order to familiarize themselves with each task.

Each subject from the VIS group was required to perform one task: three jumps from a standing position on a spotting block 0.88 m high onto the force platform. Before data collection, all subjects were required to practice the jump several times on the floor followed by three practice jumps, jumping off the spotting block.

The level eight group gymnasts were required to perform three tasks. Firstly, three trials of round-off backward somersault, landing on the force platform; -the gymnasts were instructed to take three running steps before the round-off. Secondly, three trials of standing backward somersaults with take-off and landing on the force platform, and thirdly, three jumps from a spotting block 1.18 m high onto the force platform. For this task, the subjects were instructed to perform an armcircle backwards, starting with the arms held in a sideward position, prior to jumping off the block. The subjects were instructed to 'stick' the landing as they do in competitions.

Data Collection

All data collection was performed at the Biomechanics Laboratory, Department of Physical Education and Recreation, Victoria University of Technology, Flinders Street Campus.

Data was captured on video, in 3-D using two panasonic F15 video cameras at a rate of 50 fields per second. The cameras were synchronised (genlocked). The skills performed contained no excessively large frequencies that would have required a sample rate of greater than 50 Hz. A high speed shutter was engaged which provided a near instantaneous, sharp (1/1000th of a second) picture on each field. A PEAK system calibration frame, a structure of 24 spheres and rods of known co-ordinates was used to obtain a calibration and scaling factor. This provided a real life size scaling factor and facilitated 3-D analysis. The cameras were mounted on rigid tripods at fixed points in the laboratory.The separation angle between the two cameras was 70°. Operation of the cameras was performed from the control station as shown in Fig 1.

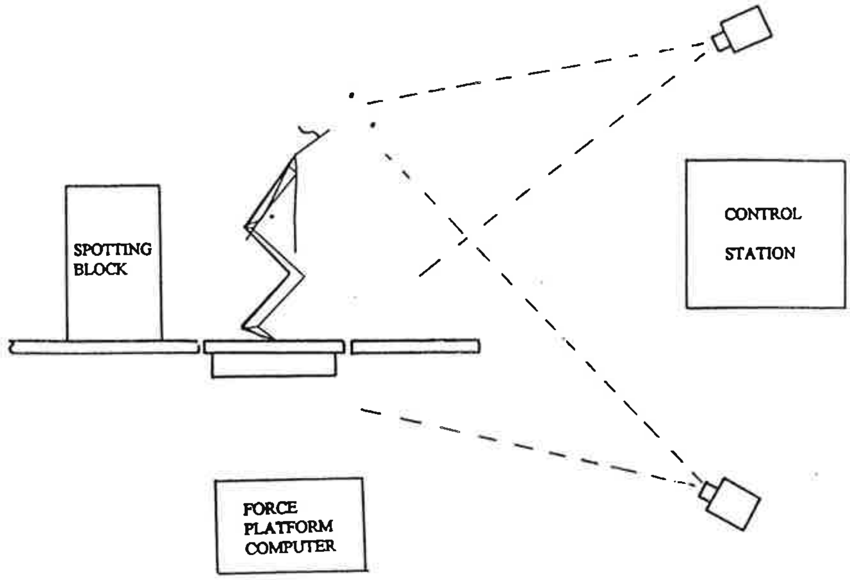

Fig 1. Schematic diagram of experimental set-up

The ground reaction forces (x, y, z) were measured by an AMTI force platform measuring 0.61 x 1.22m and registered on a 386 PC. The force platform was mounted in the floor of the laboratory and was covered with a specially designed sprung floor section, enabling measurements under realistic conditions (Fig 2).

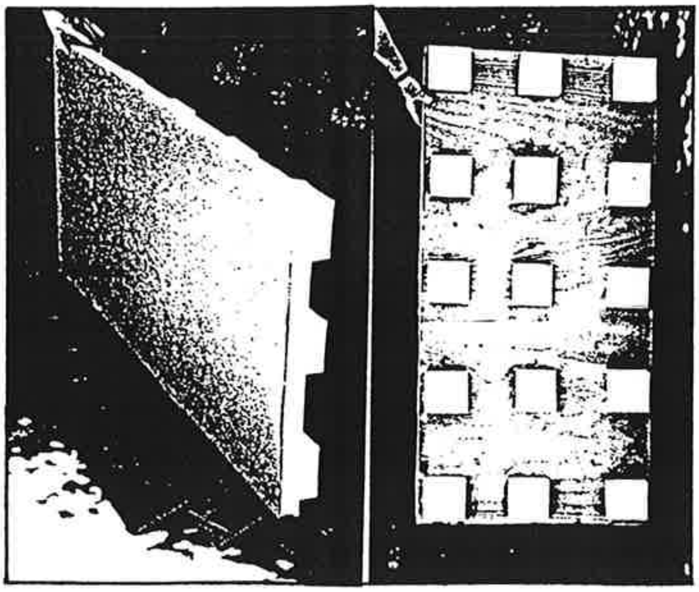

Fig 2. Sprung floor section used to cover the force platform

Data Analysis

The best performance of each subject (determined by qualitative analysis) of each skill sequence recorded was then encoded and analysed using a video data aquisition system (Peak Performance Technologies, Inc.- Peak 5, 3-D Motion Analysis System). The process included tape encoding (frame numbering and tape identification), spatial model development, using published body segment data from Dempster (1955), anthropometrics and angular orientation; project set-up (cameras used, lens, scaling factor, frame rate, picture per field etc). The raw data files were filtered using a fourth-order Butterworth recursive filter with optimal cut-off frequencies (3-6 Hertz) as determined by the software.

Digitisation generated positional data which when combined with the temporal data generated kinematic parameters; linear and angular positions, displacement and velocities on the three axes as well as a resultant. After the kinematic data was obtained, they were cascaded with the spatial model to generate line model diagrams with the kinematic graphics as well as synchronised with the videotapes to provide the real life view and data characterisation. These outputs were then processed to video for reporting as well as hard paper copy.

RESULTS

Analysis of the linear and angular kinematics and PVGRF-time data of the landing phase characteristics of the tasks "jump from a spotting block", "round-off back somersault" and "standing back somersault", were performed.

Reaction Forces

Peak Vertical Ground Reaction Force-Time Characteristics (PVGRF). Analysis of the PVGRF data indicated a considerable increase with increased impact velocity. Mean PVGRF for the "level eight group gymnasts" performing the JSBLFP were 1849 N (4.3 BW), for the ROBSLFP 1472 N (3.4 BW), and for the SBSTOLFP 1281 N (3.0 BW). The mean rise times to PVGRF after touch-down were 32, 37 and 22 ms, respectively. Mean PVGRF for the "VIS gymnasts" performing the JSBLFP were 1063 N (4.25 BW) and the mean rise time to PVGRF after touch-down was 29 ms.

Table 2. Mean PVGRF-Time Data

	JSBLFP VIS n=4	JSBLFP level eight n=4	ROBSLFP level eight n=4	SBSTOLFP level eight n=4
PVGRF (N)	1063	1849	1472	1281
PVGRF in Bodyweight (BW)	4.25	4.3	3.4	3.0
Rise Times to PVGRF (ms)	29	32	37	22
Duration max. CM height to touch-down (ms)	47	54	39	33
Duration from touch-down to min. (ms)	16	24	05	09

Positions, Displacement and Landing Phase Duration

CM positions, displacement and landing phase duration for "jumping off the spotting block to landing on the force platform" (JSBLFP). The mean CM positions for the "level eight group gymnasts" were measured at the start of the jump,- standing on the spotting block, max. CM height during jump, CM height at touch-down, and minimum CM vertical position during landing. The mean values were 2.03 m, 2.35 m, 0.93 m and 0.61 m , respectively. The duration from the max. CM height to touch-down was 0.54 sec., and from touch-down to min. CM position 0.24 sec.

The mean values for the VIS gymnasts were 1.53 m, 1.79 m, 0.78 m and 0.55 m, respectively. The duration from the max. CM height to touch-down was 0.47 sec., and from touch-down to min. CM position 0.16 sec.

CM positions,displacement and landing phase duration for the level eight gymnasts performing a "round-off and back somersault to landing on the force platform" (ROBSLFP). The mean CM positions were measured at take-off for the back somersault, maximum CM height during somersault, CM height at touch-down, and minimum CM vertical position during landing. The mean values were 1.04m, 1.50m, 0.82m and 0.72m respectively. The duration from the maximum CM height to touch-down was 0.39 sec., and from touch-down to minimum CM position 0.05 seconds.

CM positions displacement and landing phase duration for the level eight gymnasts performing a "standing back somersault with take-off and landing on the force platform" (SBSTOLFP). The mean CM positions measured at take-off was 1.03m, max. CM height was 1.20m, CM height at touch-down was0.65m and the min. CM vertical position at landing was 0.56m. The duration from the max. CM height to touch-down was 0.33 sec., and from touch-down to min. CM position 0.09 seconds.

Table 3. Mean CM Positions, Displacement and Landing Phase Durations

	JSBLFP VIS n=4	JSBLFP level eight n=4	ROBSLFP level eight n=4	SBSTOLFP level eight n=4
CM height-standing on Spotting Block (m)	1.53	2.03	1.04	1.03
Max. CM height during jump (m)	1.79	2.35	1.50	1.20
CM height at touch-down (m)	0.78	0.93	0.82	0.65
Minimum CM height during landing (m)	0.55	0.61	0.72	0.56
Duration CM height to touch-down (sec)	0.47	0.54	0.39	0.33
Duration touch-down to minimum (sec)	0.16	0.24	0.05	0.09

Landing Angles

Touch-down and minimum angles for "jumping off the spotting block to landing on the force platform" (JSBLFP). The angle formed by the CM to the ground contact (toes) and the horizontal was measured at touch-down and referred to as touchdown angle. CM to ground contact, knee, trunk to horizontal, and thigh to horizontal mean angles were measured for both touch-down and minimum during landing.

The mean values at touch-down for the "level eight gymnasts" were 100°,160°, 83° and 71° (Fig 3. 1-4), and minimum during landing were 94°, 85°,53° and 30°(Fig 3. 5-8), respectively.

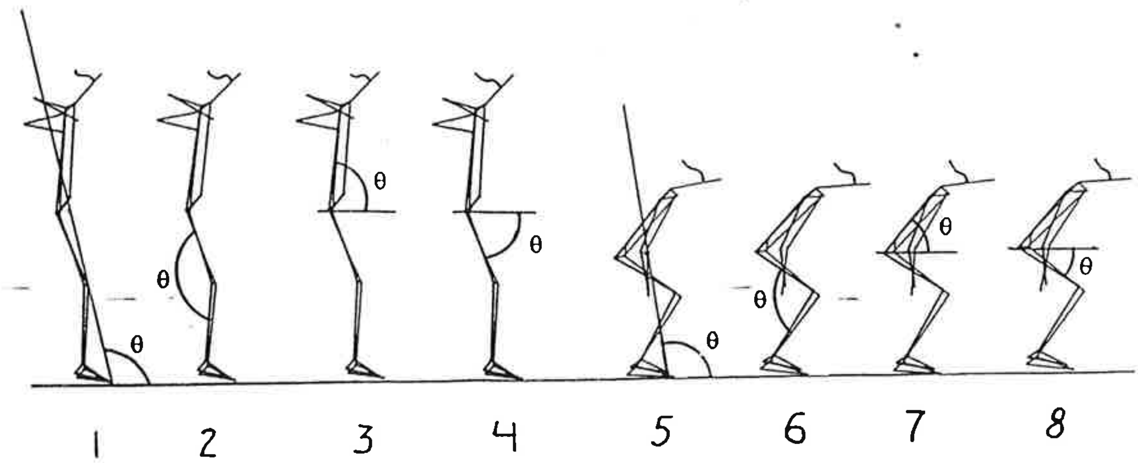

Fig 3. Mean Touch- down and Minimum Angles for ""Jumping off the Spotting Block to Landing on the Force Platform"

The mean values at touch-down for the "VIS gymnasts" were 101°, 169°, 85° and 76° (Fig 3. 1-4), and minimum during landing were 91°, 88°, 70° and 39° (Fig 3. 5-8), respectively.
Touch-down and minimum angles for "round-off back somersault to landing on the force platform" (ROBSLFP). The mean values at touch-down for the "level eight gymnasts" were 109°, 170°, 31° and 79°, and minimum during landing were 100°, 126°, 31° and 79°, respectively.
Touch-down and minimum angles for "standing back somersault with take-off and landing on the force platform" (SBSTOLFP). The mean values at touch-down for the "level eight gymnasts" were 81°, 142°, -24° and 90°, and minimum during landing were 81°, 105°, -24° and 79°, respectively.

Table 4. Landing Angles at Touch-down and Minimum CM Height

(°)		JSBLFP VIS n=4	JSBLFP level eight n=4	ROBSLFP level eight n=4	SBSTOLFP level eight n=4
CM to toe	touch-down	101	100	109	81
and horizontal	min.	91	94	100	81
Knee	touch-down	169	160	170	142
	min.	88	85	126	105
Trunk to hori.	touch-down	85	83	31	-24
	min.	70	53	31	-24
Thigh to hori.	touch-down	76	71	79	90
	min.	39	30	79	79

Landing Velocities
Vertical and horizontal velocity-time histories of the CM, hip, knee and ankle joints for "jumping off the spotting block to landing on the force platform" (JSBLFP). The mean max. vertical and horizontal velocity values at impact for the "level eight gymnasts" were -4.75, -4.98, -4.99 -4.93 and1.06, 1.20, 1.55 and 1.66 m/s for CM, hip, knee and ankle, respectively. The values for the "VIS gymnasts" were -4.14, -4.56, -4.21, -4.24 and 1.35, 2.09, 2.48 and 2.37 m/s, respectively.
Angular velocity-time histories of the hip, knee and ankle joints are-6.02, -13.00, -18.39 and -3.25, -9.51 and -13.21 rad/sec, for the level eight and VIS gymnasts, respectively.
Vertical, horizontal and angular velocity-time histories of the CM, hip, knee and ankle joints for "round-off back somersault to landing on the force platform" (ROBSLFP) and "standing back somersault with take-off and landing on the force platform"(SBSTOLFP) for the level eight gymnasts. The mean max. vertical velocity values at impact were -3.50, -4.65, -5.45, -9.69 and -3.04, -4.04, -5.00 and -10.82 m/s, respectively. The mean max. horizontal velocity values at impact were

3.81, 5.12, 8.29, 9.07 and 0.64, 1.43, 1.63, and 1.89 m/s, respectively. The mean max. angular velocity values at impact were -3.59, -4.39, -17.83 and -3.59, -9.06 and -4.19 rad/sec, respectively.

Table 5. Mean Vertical, Horizontal and Angular Impact Velocity Data for CM, Hip, Knee and Ankle Joints

(ms^{-1})	JSBLFP VIS n=4	JSBLFP level eight n=4	ROBSLFP level eight n=4	SBSTOLFP level eight n=4
Vertical impact velocity				
CM	-4.14	-4.75	-3.50	-3.04
Hip	-4.56	-4.98	-4.65	-4.04
Knee	-4.21	-4.99	-5.45	-5.00
Ankle	-4.24	-4.93	-9.69	-10.82
Horizontal impact velocity				
CM	1.35	1.06	3.81	0.64
Hip	2.09	1.20	5.12	1.43
Knee	2.48	1.55	8.29	1.63
Ankle	2.37	1.66	9.07	1.89
Angular impact velocity (rad/sec)				
Hip	-3.25	-6.02	-3.59	-3.59
Knee	-9.51	-13.00	-4.39	-9.06
Ankle	-13.21	-18.39	-17.83	-4.19

DISCUSSION

Selected kinematic parameters and vertical ground reaction forces in landings were examined to gain an insight into stresses and loads experienced by the gymnasts during the landing process. In this study, two groups of female gymnasts performed a simple landing task, a jump from a spotting block from different heights and two different types of back somersaults. For this particular skill, the gymnasts had a choice of landing techniques available. The landing surface resembled that of a gymnastics floor area. Comparisons of the analysed kinematic and PVGRF data of the VIS and level eight gymnasts performing the "jump off the spotting block to landing on the force platform" indicated that the PVGRF increased with increases in impact velocity. The level eight gymnasts tended to experience marginal higher mean peak impact forces (4.3 BW) compared to the VIS gymnasts (4.25 BW) in the JSBLFP, but recorded considerable differences in impact velocities (VIS gymnasts 4.14 and level eight gymnasts 4.75 m/s). These differences in reaction forces and impact velocities were probably due to the higher drop height (0.3m) for the level eight gymnasts. Too and Adrian (1987) found PVGRF values of 5-6 times body weight (BW) during landings from a vaulting box 0.85 meters high. In their study a comparison was made of those gymnasts landing with a flat trunk (no increased curvature at the lumbar spine) and those with an arched trunk (increased curvature at the lumbar spine). Mean PVGRF were 5.47 BW and 6.62 BW for flat trunk and arched trunk respectively. Rise times to PVGRF after touch-down were 32 ms and 29 ms for the level eight and VIS gymnasts, respectively. This findings are consistent with the study of Panzer et al. (1988) who reported that the time to PVGRF always occured 30-50 ms after touch-down and the softer the landing surface, the longer the delay of the time to PVGRF. The mounted sprung floor section on the force platform reduced the PVGRF and increased the rise-time to PVGRF. Landing techniques favoring slightly increased knee (VIS gymnasts 81° and level eight gymnasts 75°) and 50% more trunk to horizontal flexion (VIS gymnasts 15° and level eight gymnasts 30°) were preferred by the level eight gymnasts, when landing with higher impact velocities.

In this observation it was also noted that during the landing, when the impact forces were just past max., approx. 40-60 ms after touch-down, the knee angle was at minimum. However, the trunk was still moving forward and downward, subsequently placing high loads and stresses on the lumbar region through its momentum. If this occurs repeatedly over a long period of time, risk of injury is likely to occur.

Landing phase durations, defined as the elapsed time from touch-down to minimum CM height during landing, were compared between both groups across impact velocities. Impact velocities and landing phase durations were higher for the level eight gymnasts. Smaller minimum hip angles were observed for this group (VIS gymnasts 109°, level eight gymnasts 83°) and small differences in the minimum knee angles for both groups were recorded (VIS gymnasts 88°, level eight gymnasts 85°). This result suggests that the gymnasts adjust to the landing impact by absorbing the landing forces over a longer period of time. The increase in landing phase time, due to increased drop height observed between the two groups of female gymnasts in this study, is consistent with the trend observed by McNitt-Gray (1991). Therefore, in order to minimize the stress placed on the musculo-skeletal system during landings, the gymnast must effectively dissipate the large forces encountered during the landing phase. Examination of the video recordings indicates that landing techniques employed by the gymnasts differ across both groups. The temporal patterns showed that joints most proximal to the feet (point of initial contact) were brought to rest prior to joints more distal. All subjects used multijoint motion during landing from the two different heights.
The extended position of the joints at touch-down provides the subject with the option of using a large range of joint motion during the landing phase. The

availabilty of large joint ranges of motion provided the subject with the opportunity of using a number of joint flexion strategies. This may create a large safety margin, particularly, if the subjects need to modify their strategy during the landing. Joints closest to the point of force application demonstrated larger peak angular velocities than those positioned further away as observed in the JSBLFP and ROBSLFP. This was consistent with the findings of McNitt-Gray (1991). However, this was not the case for the SBSTOLFP where the knee angular velocity was more than 50% greater than that of the hip and ankle angular velocity. For example, if the hip joint is flexed prior to touchdown, as in landing a standing back somersault lacking sufficient rotation, less hip joint motion is available during the landing phase. If insufficient hip range (66°) motion is available, the knee joint is expected to play a greater role. The ROBSLFP which has linear and angular momentum before take-off, is very difficult to control during landings. The small landing target made it an increased challenge and subsequently more difficult for the gymnasts to "stick" the landing. The need to control the angular momentum during landings of somersaults may prohibit the use of extensive trunk motion. If the trunk and hips approach full flexion, landings from even low heights may significantly load the structures of the hip and lumbar area. This problem could be magnified during landings from greater heights and also applies to all joints of the lower extremities. In effect, the most crucial mechanical factors at landings are the maximum CM height before the landing, and the displacement from touch-down to the lowest CM position.
In conclusion, it is reasonable to assume, that in landings from a higher drop height, the degree of joint flexion, rate of joint flexion, impact peak velocities and landing phase times tend to increase. More research under more realistic conditions such as landings in competitions is required, to determine the changing role of joints and muscles during the force attenuation phase of landings, particularly if the ability of a particular body joint is compromised due to injury. This study may provide thoughts for modification of competition landings that provides safer landings and subsequently reduce the risk of injury particularly to young female gymnasts as the vertebral arches may not be completely ossified.

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Health, Culture and Well-being

Asian-Pacific Paediatric Nursing Conference
22nd and 23rd June 1995

CERTIFICATE OF ATTENDANCE

This is to certify that

Helmut Geiblinger

attended the Asian-Pacific Paediatric Nursing Conference and presented a paper entitled,

"A Paediatric Perspective Of Biomedical Analysis Of Female Gymnasts' Landings: Safety Considerations"

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Dated 7/7/95