Winter 2001

The Effects of Four Gymnastics Skills on Vertebral Column Hyperextension in Young Female Gymnasts

Tonia McClure Burke

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ABSTRACT

THE EFFECTS OF FOUR GYMNASTICS SKILLS ON VERTEBRAL COLUMN HYPEREXTENSION IN YOUNG FEMALE GYMNASTS.

Tonia McClure Burke
Old Dominion University, 2001
Director: Dr. Donald H. Sussman

There is very limited information available on the effects of gymnastics skills on spinal hyperextension. Eleven young female gymnasts between the ages of 11 and 15 participated in this study. The subjects' height and weight were taken then they were screened for musculoskeletal injuries, normal abdominal and back extensor strength, normal hip flexor and hamstring flexibility, spondylolisthesis, and scoliosis.

Hyperextension of the spinal column was measured during normal standing, hyperextending the spine in standing, and during four different gymnastics skills, using the Peak5 motion analysis system. Each subject performed five acceptable trials of four different gymnastics skill including a back walkover, back handspring, front walkover, and front handspring. Maximum, minimum, and mean descriptive statistics were completed on the different variables to determine the amount of hyperextension at hand contact, peak hyperextension, and hands-off during the four skills. A one way analysis of variance with repeated measures was performed on these individual dependent measures to determine main effects among the four gymnastics skills. If the ANOVA for main effects was significant, a post-hoc Tukey analysis determined differences between group means. Significance was set at the p≤0.05 level. Mean normal standing posture was found to be 7.73±4.00°. Mean standing hyperextension was found to be 44.82±14.03°. There was no significant difference in the means for peak
hyperextension among the four skills (p=0.0830). The greatest mean amount of hyperextension occurred during the peak of the front walkover (63.87±11.63°). There was a significant difference in hyperextension at hand contact among the four skills (p=0.0000). Hyperextension at hand contact was 62.53±12.22° during the back walkover, 49.16±14.75° during the back handspring, 1.05±8.83° during the front handspring, and -16.33±8.74° (flexion) during the front walkover. There was a significant difference in means among the four skills at hands off (p=0.0000). Hyperextension at hands off was 59.93±12.77° during the front walkover, 41.45±11.18° during the front handspring, -24.20±6.20° (flexion) during the back walkover, and -13.09±10.87° (flexion) during the back handspring. Therefore, results show that high amounts of hyperextension are present during at least four gymnastics skills including the back walkover, back handspring, front walkover, and front handspring.
ACKNOWLEDGMENTS

There are many people to thank for their assistance in seeing this research study come to completion. First, I would like to thank my advisor, Dr. Donald Sussman for his wisdom and patience. Many thanks to my committee members, Dr. Elizabeth Dowling and Martha Walker, for setting aside time from their busy schedules to provide guidance and assistance. Special thanks to Martha for her many hours spent assisting me in learning the equipment used in this study, and for guiding me through biomechanical research. My gratitude is extended to Gymstrada Gymnastics, Excalibur Gymnastics, and to the gymnasts who made this project possible. My appreciation is extended to Dennis and Sandy for assisting with set up and data collection. Finally, I would like to thank Dr. Stan Dacko for the extra push to see this come to completion.

This manuscript is dedicated to my husband, Dennis, and to my family, and friends. I would like to sincerely thank them for their continued support. This would not have been possible without each and every one of you.
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CHAPTER I
INTRODUCTION

There is limited information available on the effects of gymnastics skills on spinal hyperextension. There is even less information on the effects of gymnastics skills on spinal hyperextension in young gymnasts. Gymnasts are noted for having frequent incidence of back pain (Garrick, & Requa, 1980; Goldstein, Berger, Windler, & Jackson, 1991; Kujala, Taimela, Oksanen, & Salmimen, 1997, Ohlen, Wredmark, & Spangfort, 1989; Tsai & Wredmark, 1993). This increased incidence of back pain may be due to the repeated hyperextension of the spine experienced during the performance of gymnastics skills.

There are many people who experience low back pain (LBP), including adolescent athletes and gymnasts. Low back pain can be caused by different reasons in children (Micheli, 1979). An increased lumbar lordosis (common in gymnasts) can cause back problems (Micheli, 1979). Lordosis is the normal anterior curve of the lumbar spine. Studies have found that when there is an increase in the amount of lumbar lordosis, hyperextension of the spine becomes limited (Kujala et al., 1997; Micheli, 1979; Ohlen et al., 1989). This limitation can cause LBP in athletes who participate in sports requiring high amounts of hyperextension (Kujala et al., 1997; Micheli, 1979; Ohlen et al., 1989).

Spondylolysis, spondylolisthesis, and scoliosis are spinal pathologies prevalent in gymnasts and other athletes (Goldstein, Berger, Windler, & Jackson, 1991; Ichikawa, Ohara, Morishita, Taniguichi, Koshikawa, & Matsukura, 1982; Jackson, 1979; Jackson, Wiltse, & Cirincione, 1976; Ohlen et al., 1989). Spondylolysis is a developmental
weakness defect in the lamina of the vertebra. As a result of the weakening vertebral lamina, shear forces can occur causing spondylolisthesis (Norkin, & Levangie, 1992). The shear forces can occur at the L4 and L5 vertebral level due to an increased lumbar lordosis (Norkin, & Levangie, 1992). Spondylolisthesis is the anterior slippage of the 4th lumbar vertebrae on the 5th, or the 5th lumbar vertebrae on the sacrum (Norkin, & Levangie, 1992). Scoliosis is a lateral deformity of the spinal column when viewed posteriorly (Anderson, Anderson, & Glanze, 1998). Goldstein et al. (1991) found that the high number of hours spent training per week correlated highly to positive magnetic resonance imaging (MRI) results. Positive results were defined as degenerative or other disc changes, spondylolysis, or spondylolisthesis. Tsai and Wredmark (1993) found that gymnasts had the same incidence of LBP as the control group, and Garrick and Requa (1980) found injuries that occurred in gymnastics were no greater than injuries in other sports.

Due to the skills gymnasts perform, adequate range of motion in the lumbar area of the vertebral column is essential to prevent injury (Kujala et al., 1997). Two studies found that gymnasts had the same or had less lumbar flexibility than the control groups (Kujala et al., 1997; Tsai & Wredmark, 1993).

There has been only one study that investigated the mechanical contribution to lumbar stress injuries in female gymnasts. Hall (1986) examined the amount of hyperextension present during five commonly executed skills, and quantitatively described the impact forces during the landing and/or hand impact of the five skills.

In the interest of safety, the range of motion of the spine in young gymnasts should be studied during different skills because the only study published examined
older college age gymnasts. Therefore, the purpose of this study was to determine the
amount of spinal hyperextension present at the 1) moment of hand impact, 2) peak
hyperextension, and
3) hands-off during a back handspring, back walkover, front handspring, and front
walkover.

**Research Hypotheses**

1. There will be no significant difference in hyperextension at hand contact among
   the four skills.

2. There will be no significant difference in peak hyperextension among the four
   skills.

3. There will be no significant difference in hyperextension at hands-off among the
   four skills.

**Significance of the Study**

This study provided needed insight on the effects of gymnastics skills on the
function of the vertebral column of young female gymnasts. There was a need to
generate quantitative research on younger gymnasts because their skeletal system may
demonstrate different hyperextension patterns during the skills compared to older
gymnasts. The gymnasts involved in the current study are younger than the subjects in
previous research that studied college age gymnasts. Younger gymnasts may
demonstrate greater spinal hyperextension which may lead to a higher incidence of
injuries.
Independent Variables

Eleven young female gymnasts, between the ages of 11 and 15, performed four gymnastics skills. The independent variable was the gymnastic skill. There were four levels to this independent variable: back handspring (BH), front handspring (FH), back walkover (BW), and front walkover (FW).

Dependent Variables

The dependent variable was hyperextension at the point of hand contact (HC) during each gymnastic skill, at peak hyperextension (PH) during each gymnastic skill, and hyperextension at hands-off (HO) during each gymnastic skill.

Operational Definitions

1. Standing posture: This was the position of the spinal column examined using the Peak5 motion analysis system (Peak Performance Technology, Inc.; 7388 South Revere Parkway, Suite 601; Englewood, Colorado 80112) as the gymnasts stood with their feet shoulder width apart, in their “normal” stance. A marker system was used where 3M retroreflective markers (3M Innovation, Inc.; 3m Center, Building 275-4W-02; St. Paul, Minnesota 55144) were placed in the midaxillary line at the level of the eleventh thoracic vertebra, on the superior aspect of the iliac crest, and on the lateral thigh midway between the greater trochanter and the fibular head. The gymnasts were then filmed from the sagittal view to obtain video data for later analysis.

2. Maximal standing hyperextension: This was the position of the spinal column measured using the Peak5 motion analysis system as the gymnasts stood with their feet shoulder width apart, and were asked to hyperextend the spine as far as
possible. Subjects were marked as previously described, and filmed from the sagittal view to obtain video data for later analysis.

3. **Spinal position:** This was the position of the spinal column, measured by the Peak5 motion analysis system during the gymnastics skills. Spinal positioning was measured at hand contact, peak hyperextension, and hands-off of each skill.

4. **Gymnastics skills:** Gymnastics skills included; back walkover (BW), front walkover (FW), back handspring (BH), and front handspring (FH).

5. **Peak hyperextension:** The greatest amount of hyperextension recorded by the Peak5 motion analysis system during each of the four gymnastics skills.

6. **Hand Contact:** The videotaped picture when both of the gymnast’s hands made full contact with the ground. Full contact was when the entire hand (fingers and palm) were in contact with the ground.

7. **Hands Off:** One videotaped picture immediately after the gymnast’s hands left the ground.

**Delimitations**

Eleven young female gymnasts, between the ages of 11 and 15 years of age, participated in the study for one hour of data collection in the Motion Analysis Laboratory at Old Dominion University. Each subject performed five acceptable trials of four different gymnastics skills including a back walkover, front walkover, back handspring, and front handspring. Skills that were acceptable required both hands to completely make contact with the ground simultaneously.
Limitations

The limitations included 1) the large age range of the young female gymnasts 2) the method of measuring hyperextension in comparison with other studies 3) the small number of skills performed due to the lack of more sophisticated gymnastics equipment and space.

Summary

There is very little research on hyperextension during gymnastics skills and no research on hyperextension during gymnastics skills in young female gymnasts. This study provided information on the function of the vertebral column of young gymnasts, and generated quantitative research on the vertebral column during four gymnastics skills. Therefore, the purpose of this study was to determine the amount of spinal hyperextension present at the 1) moment of hand impact, 2) peak hyperextension, and 3) hands-off during a back handspring, back walkover, front handspring, and front walkover.
CHAPTER II
REVIEW OF LITERATURE

Statement of Purpose

The purpose of this study was to determine the amount of spinal hyperextension present at the 1) moment of hand impact, 2) peak hyperextension, and 3) hands-off during a back handspring, back walkover, front handspring, and front walkover.

Vertebral Column Anatomy

General structure

The vertebral column consists of twenty-four moveable vertebrae plus the sacrum and the coccyx (Figure 1). There are seven cervical vertebrae, twelve thoracic vertebrae, and five lumbar vertebrae present in the spinal column. The sacrum consists of five fused vertebrae, while the coccyx consists of four fused vertebrae (Creager, 1992; Chung, 1995; Noore, & Agur, 1995; Norkin, & White, 1985; Williams, Bannister, Berry, Collins, Dyson, Duusse, & Ferguson, 1983).

There are four natural curvatures present in the spinal column that assist in weight-bearing and shock absorption. The cervical and lumbar curvatures are convex from an anterior viewing perspective, while the thoracic and sacral curvatures are concave from an anterior viewing perspective (Figure 1) (Creager, 1992; Chung, 1995; Noore, & Agur, 1995; Norkin, & White, 1985; Williams et al., 1983).

Typically a vertebra has an anterior body and several posterior structures that create a bony arch around the spinal cord (Figure 2). Pedicles form the lateral walls, while the laminae fuse in the midline to form the posterior protection for the spinal cord.
The spinous process projects posteriorly from the arch for muscle attachment and additionally for protection of the spinal cord. Extending laterally from the pedicles are the transverse processes. When all twenty-four vertebrae are put together the vertebral canal is formed by the vertebral foramen that are stacked on top of one another (Creager, 1992; Chung, 1995; Noore, & Agur, 1995; Norkin, & White, 1985; Williams et al., 1983).

Figure 1: Picture of vertebral column and the curvatures of the vertebral column
Articulation of the vertebral column

There are symphyses joint where successive vertebral bodies are connected to intervertebral discs. These joints are designated for weight bearing, but also permit freedom of movement in all planes of motion. Apophyseal or facet joints are found between the articulating superior and inferior articulating processes of the vertebrae and provide increased range of motion for the vertebral column (Creager, 1992; Chung, 1995; Noore, & Agur, 1995; Norkin, & White, 1985; Williams et al., 1983).

Characteristics of the different groups of vertebrae

There are more specific characteristics for each of the different types of vertebrae. The first cervical vertebra is also known as the atlas (Figure 3) and articulates with the occipital condyles of the skull. This articulation forms the atlantooccipital joint, which allows humans to nod their heads as one of its functions. The second cervical vertebra
is known as the axis (Figure 4) which has the dens or odontoid process, which the atlas rotates around allowing humans to rotate their heads. This articulation between the dens and the atlas is known as the atlantoaxial joint. The cervical vertebrae (Figure 5) have the shortest transverse processes. The transverse processes of the cervical vertebrae have a transverse foramen that the vertebral artery, vertebral vein, and autonomic nerves pass through. All of the cervical vertebrae except for the atlas and C7 have bifid or two-pronged spinous processes. The thoracic vertebrae (Figure 6) have long spinous processes and thick stubby transverse processes. The transverse processes in the thoracic region have facets, for articulating with the ribs. The lumbar vertebrae (Figure 7) are the largest with short spinous processes, longer transverse processes, and large superior and inferior articulating processes with lateral articulating surfaces. These lateral articulating surfaces form the apophyseal joints and permit greater mobility in the lumbar region compared to the other regions of the vertebral column (Creager, 1992; Chung, 1995; Noore, & Agur, 1995; Norkin, & White, 1985; Williams et al., 1983).
Figure 3: Pictures of first cervical vertebra or atlas

Superior view of atlas

Inferior view of atlas

- Surface for articulation with skull
- Spinous process
- Surface for articulation with axis (C2)
Figure 4: Pictures of second cervical vertebra or axis

Superior view of axis
- Surface for articulation with atlas (C1)
- Odontoid process or Dens
- Spinous process

Inferior view of axis
- Spinous process
- Surface for articulation with C3

Sagittal view of axis
- Spinous process
- Odontoid process or Dens
- Surface for articulation with atlas (C1)

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Figure 5: Pictures of a cervical vertebra

Superior view of a cervical vertebra

Inferior view of a cervical vertebra

Sagittal view of a cervical vertebra

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Figure 6: Pictures of a thoracic vertebra

Superior view of a thoracic vertebra

Inferior view of a thoracic vertebra

Sagittal view of a thoracic vertebra

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Figure 7: Pictures of a lumbar vertebra

Superior view of a lumbar vertebra

Inferior view of a lumbar vertebra

Sagittal view of a lumbar vertebra

Superior articulating process
Spinous process
Body
Transverse process

Vertebral foramen
Pedicle
Transverse process
Spinous process
Laminae

Inferior articulating process
Spinous process
Transverse process

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The sacrum consists of five fused vertebrae while the coccyx consists of four fused vertebrae (Figure 8). The transverse lines on the anterior aspect of the sacrum represent where fusion of the bodies of the sacral vertebrae took place. The sacrum also has four pairs of pelvic foramen on the anterior aspect and dorsal foramen on the posterior aspect for the exit of the ventral and dorsal primary rami of the first four sacral nerves. On the posterior aspect of the sacrum there is a median sacral crest, which represents the fusion of the spinous processes, and allows for muscle attachment. Lateral to the median crest there are intermediate and lateral sacral crests. There is also a sacral canal, which is a continuation of the vertebral canal. The spinal cord of adults extends to the level of the second lumbar vertebra. A bundle of spinal nerves that is a continuation of the spinal cord, called the cauda equina, extends off the end of the spinal cord. These nerves consist of dorsal and ventral roots of the lumbar and sacral spinal nerves and are free floating in the cerebral spinal fluid (Creager, 1992; Chung, 1995; Noore, & Agur, 1995; Norkin, & White, 1985; Williams et al., 1983).
Figure 8: Pictures of the anterior view of the sacrum and posterior views of the sacrum and coccyx

Anterior view of sacrum

Posterior view of sacrum and coccyx

Transverse lines from fusion of vertebrae

Pelvic foramen

Lateral sacral crest

Median sacral crest

Intermediate sacral crest

Dorsal foramen

Coccyx

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Spinal Column Range of Motion

Adams, Dolan, and Hutton (1988) investigated the lumbar spine in backward bending. They used 21 cadaver spines of individuals, ages 16 through 58 years. The cadaver spines were cut into segments as follows: L1-L2, L2-L3, L3-L4, and L4-L5. There were 44 segments tested in these separate experiments. Experiment one looked at resistance to backward bending. Each of the 44 segments were bent into extension to its structural limit and the resistance to bending was measured by determining what structure was damaged first, and what structure required the most force before it was damaged. The researchers designed an apparatus to apply force and bend the specimens. The same test was then performed after the researchers removed the spinous process. The same test was also performed after removal of the apophyseal joint capsule, and then ligamentum flavum. The apophyseal joint capsule is the capsule that surrounds the individual joints between vertebrae known as apophyseal joints or facet joints (Anderson et al., 1998). The ligamentum flavum is a band of elastic type tissue that begins on the axis and extends to the first segment of the sacrum to connect the lamina of the vertebrae (Anderson et al., 1988). The researchers then performed the test after further sawing through the apophyseal joints. Lastly, the discs were loaded at an angle one-degree beyond the limit of extension. The limit of extension was considered the furthest point the vertebrae could be hyperextended before any of the surrounding structures gave way. The researchers found that the spinous process provided the most resistance to extension. Though, in six of the specimens, the greatest resistance was provided by the bony facets and in 11 by the disc. Bending the segments into extension required an average force of 655 Newtons (N).
Experiment two looked at hyperextension injuries to the discs. The researchers looked at the effect of high compression on a disc taken to the structural limit of hyperextension. The not overly damaged 28 remaining specimen from experiment one were taken to full hyperextension, a compression force was applied and increased at a rate of 1000 N per second until there was a reduction in compressive stiffness. The apparatus the researchers invented to bend and compress the spine was also used in this experiment. The average angle of extension was 5.1 degrees with an average failure load of 7,432 N (range = 3,421 - 12,200 N). It was also noted that most specimens underwent fractures to the vertebral body end plate or the posterior edge of the vertebral body rather than disc rupture.

Experiment three of this study examined fatigue damage to the disc in hyperextension. The researchers wanted to determine if fatigue loading during hyperextension would increase the posterior bulging of the annulus fibrosus. The annulus fibrosus is the outside covering of the disc that encloses the central nucleus pulposus. Sixteen of the specimens from experiment two were still usable as subjects in this test, eight were taken into full extension while the other eight were held at six degrees of flexion as controls. The specimens were then loaded in proportion to the body mass of the cadaver they came from. For example, a 70-kg cadaver required oscillation forces between 500 and 1200 N at a rate of 40 cycles per minute, for 6 hours. The curvature of the lamella was measured by freezing the segment then cutting the disc into slices in the sagittal plane. The researchers designed a method for measuring the bulging of the lamella. It was found that the bulging was greatest in the lower lumbar levels. The average limit of hyperextension of the cadaver spine was 23.6 degrees.
From this study the researchers concluded that individuals with wide spacing between their spinous processes will put more stress on their apophyseal joints. Individuals may also damage their interspinous ligament as it is squeezed between their spinous processes during hyperextension. The researchers also noted that repeated hyperextension could cause disc prolapse and structural lesions in the discs. Disc prolapse occurs when there is a weakening or break in the annulus fibrosus. A structural lesion of a disc is any localized abnormality of pathological change that occurs, such as an injury that occurs to the localized area of a disc.

Hall (1986) used Wielki's (1983) method of measuring curvature to examine the mechanical contribution to lumbar stress injuries in female gymnasts. The purpose of Hall's (1986) study was to determine the amount of hyperextension present during five commonly executed gymnastic skills, and to quantitatively describe the impact forces during the landing and/or hand impact of the five skills. Four team members, of a university gymnastics team, participated in the study. Their heights ranged from 161 to 174 centimeters, and their weight ranged from 507 to 627 Newtons. They performed five skills involving hyperextension and impact forces with their hands or feet, depending on the skill. They performed a front walkover, a back walkover, a front handspring, a back handspring, and a handspring vault.

A force plate covered with a mat was used to acquire the impact forces. The lateral and vertical components of the ground reaction forces were examined by the researcher. The subjects wore tape on T12, L1, L5, and S1 to make the curvatures easy to spot. The curvatures were evaluated by using films and “variation B” of the “radius method” developed by Wielke (1983). Curvature was evaluated by determining the

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radius of a best-fit circle. Lumbar curvature was evaluated during foot impact on the front walkover, hand impact of the back walkover, the apex and foot impact of the front handspring, hand impact of the back handspring, and blocking (hand impact) and foot impact of the handspring vault. The lowest impact forces occurred during the landing (foot impact) of the front walkover (603 N) and back walkover (687 N) while the highest occurred during the landing of the vault (5,789 N). Maximum hyperextension occurred during foot impact of the front walkover (radius = 7.38 cm), during the blocking on the back handspring (radius = 12.22 cm) and back walkover (radius = 8.66 cm), at maximum height during the front handspring (radius = 6.20 cm), and during the block on the vault (radius = 4.16 cm). The back handspring and back walkover had the greatest amount of hyperextension involved. Hall (1986) concluded that the reaction forces are clearly greater than the compressive forces sustained by the spine at landing, since the soft tissue and joints below L5 and S1 attenuate the forces.

**Low Back Pain and Range of Motion**

Kujala, Taimela, Oksanen, and Salminen (1997) studied lumbar mobility and low back pain during adolescence. One hundred sixteen subjects were recruited for the study, ranging in age from 10.3 to 13.3 years. Ninety-eight actually participated in this three-year longitudinal study, 33 non-athletes (16 boys, 17 girls), 34 boy athletes, and 31 girl athletes. The boy athletes participated in ice hockey and soccer, while the girls participated in figure skating and gymnastics. The athletes had been training at least twice a week for two years prior to the start of the study. All athletes had no incidence of back pain requiring a stoppage of training during the previous year. During the three years of the study, training outside the sport was limited to circuit training without extra
weights. All participants filled out a questionnaire during their first visit, and after the first, second, and third follow-up examinations. The questionnaire consisted of questions regarding past and present physical activity, acute injuries causing low back pain, and questions about the occurrence of low back pain. Low back pain was defined as pain interfering with school work or leisure activities for at least one week. Timing, duration, and location also defined the low back pain the subjects reported. Each subject was measured at the beginning and at the three-year follow up for height, weight, lumbar sagittal posture, and flexibility. Lumbar sagittal posture and flexibility were measured using a flexible material that was molded to fit the lumbar area in standing, flexion, and hyperextension. Using the molds, tangents were drawn to flexion, hyperextension, and standing postures at S2, L4, and T12. Two angles were formed by the intersections of these tangents, which were measured with a protractor to one degree of accuracy. Maximal lumbar hyperextension, lumbar flexion, normal standing posture lumbar curvature, and lumbar ROM (full lumbar flexion to full lumbar hyperextension) were measured from T12 - S2. All measurements were performed by the same physical therapist.

The non-athlete boy's mean standing posture was 32° at baseline, and 35° at follow-up. Their mean hyperextension was 60° at baseline and 63° at follow-up. Flexion in the non-athlete boys was 40° at baseline and 44° at follow-up. The boy athletes had a mean standing posture of 35° at baseline and 38° at follow-up. Mean hyperextension was 64° at baseline and 63° at follow-up, while mean flexion was 37° at baseline and 37° at follow-up. The non-athlete girls had a mean standing posture of 36° at baseline and 35° at follow-up. Their mean hyperextension was 77° at baseline and
81° at follow-up, while mean flexion was 38° at baseline and 36° at follow-up. The girl athletes had a mean standing posture of 30° at baseline and 35° at follow-up. Their mean hyperextension was 70° at baseline and 76° at follow-up, while mean flexion was 34° at baseline and 35° at follow-up. In the boys that did not have low back pain during the study, mean maximal lumbar hyperextension was 62° at baseline, and 61° at follow-up. Mean lumbar flexion was 39° at baseline and 41° at follow-up, standing posture was 34° at baseline, and 36° at follow-up. In boys with low back pain during the study, maximal lumbar hyperextension was 66° at baseline, and 64° at follow-up. Mean lumbar flexion was 36° at baseline and 37° at follow-up, and mean standing posture was 33° at baseline and 38° at follow-up. In the girls without low back pain during the study, mean maximal lumbar hyperextension was 76° at baseline and 80° at follow-up. Mean flexion was 37° at baseline and 38° at follow-up. Mean standing posture was 32° at baseline and 35° at follow-up. In the girls with low back pain reported during the study, mean maximal lumbar hyperextension was 66° at baseline and 74° at follow-up. Mean lumbar flexion was 34° at baseline, and 32° at follow-up. Standing posture was 33° at baseline and 36° at follow-up.

During the study, low back pain was reported by 29 athletes (15 boys, 14 girls), and by 6 non-athletes (3 boys, 3 girls). The boys who did report low back pain (LBP) during the study had a mean weight of 40.4 kg at baseline and 60.8 kg at follow-up, while the boys with no reported LBP had a mean weight of 38.0 kg at baseline and 55.4 kg at follow-up. The girls with reported LBP had a mean weight of 39.9 kg at baseline and 55.0 kg at follow-up. The girls without LBP during the study had a mean weight of 37.1 kg at baseline and 52.3 kg at follow-up.
These researchers found that there were no significant differences in flexibility between athlete boys and non-athlete boys at baseline. The girl’s lumbar ROM was significantly higher (p=0.014) among non-athletes than among athletes. The non-athletes also had greater standing lordosis curvature. In the boys there was a greater increase in weight in those with low back pain, compared to those without low back pain. In the multivariate analysis it was determined that among the boys, participation in sports, and low maximal lumbar flexion at baseline predicted low back pain during the follow-up. Among the girls, low maximal lumbar hyperextension, and high body weight were predictive of low back pain.

These researchers concluded that in sports requiring high amounts of lumbar hyperextension, a low amount of hyperextension could lead the athletes to a future of low back pain. The girls who had the lowest maximal lumbar hyperextension at baseline were at a three times higher risk of developing future low back pain. The boys participated in sports that required more flexion, therefore, they were at greater risk for developing low back pain if they had decreased lumbar flexion (Kujala et al., 1997).

Ohlen, Wredmark, and Spangfort (1989) studied sagittal spinal configuration and mobility related to low-back pain in female gymnasts. The purpose of their study was to correlate low-back complaints in 64 female gymnasts to sagittal spinal configuration and mobility as measured by two methods. The gymnasts were an average age of 11.9 years, and practiced an average of 12.3 hours per week, and had been active gymnasts for an average of 4.3 years. An interview was conducted for previous back problems, height, weight, years in competition, and hours of practice per week. In this study, the researchers used the neutral standing position as the baseline, or
starting position, for the range of motion of the spine. With the gymnasts standing with
the heels together, and arms relaxed at their sides all spinal curvatures and sagittal
mobility were measured using an inclinometer (Figure 9), and also with a kyphometer
(Figure 10). An inclinometer is a devise that looks like a compass with a flat side to
place on the spine. Inside the inclinometer is a round needle pendulum that takes an
angular reading. A kyphometer has two arms that project off a protractor type base.
The free ends of the two arms are placed on the spine so an angular reading can be
obtained. Kyphosis was measured between the spinous processes of the second and
third thoracic vertebrae and the 11th and 12th thoracic vertebrae. Kyphosis is the normal
posterior curvature that is formed by the thoracic spine (Anderson et al., 1998). This
curve is accentuated and becomes pathological when poor posture is present, or in some
disease states such as osteoporosis (Anderson et al., 1998). The two moving arms of the
kyphometer were placed on each of these landmarks, and an angle was measured. The
inclinometer was placed directly between the two landmarks and an angular reading was
measured. Lordosis was measured between T11-S2 also using the kyphometer and
inclinometer. Lordosis is the normal anterior curvature of the lumbar spine (Anderson
et al., 1998). The researchers also compared the results between the two instruments
used to measure spinal curvature. The sagittal ranges of motion were studied separately
in the thoracic and lumbar spine. The total forward flexion and backward
hyperextension were recorded using the kyphometer and inclinometer, and total sagittal
range of motion was calculated by adding flexion and hyperextension together. A
physical examination of the back was also performed looking for asymmetry of the
lumbar spine and scoliosis. If asymmetry or scoliosis was found, radiological
examinations were performed. Radiological examinations were performed on 11 consenting gymnasts with pathological findings during the clinical evaluation.

Figure 9: Picture of an inclinometer

![Inclinometer](image)

Figure 10: Drawing of a kyphometer

![Kyphometer](image)
The researchers found that the mean thoracic kyphosis was 30.6 degrees with the kyphometer and 33.1 degrees with the inclinometer. The mean lumbar lordosis was 35.6 degrees with the kyphometer and 35.2 degrees with the inclinometer. The researchers found that the average range of motion in the thoracic spine was 57.3 degrees with the kyphometer, with forward flexion and backward hyperextension almost equal. In the lumbar spine the average sagittal range of motion was 113.0 degrees, with forward flexion at 75.3 degrees and hyperextension 37.8 degrees. The inclinometer was used for hyperextension because hyperextension went beyond the range of the kyphometer. There was a positive linear correlation between the degree of lordosis and the range of forward lumbar motion, \( r = 0.33 \). There was a negative correlation between the degree of lordosis and the range of hyperextension, \( r = -0.38 \). The researchers found no significant correlation between the degree of kyphosis and the total sagittal thoracic mobility in this study. Clinical evaluations found a palpable spondylolisthesis at the L5-S1 level, in six girls and scoliosis in eight girls. Scoliosis is found when the spine forms an S or C curvature when viewed posteriorly (Anderson et al., 1998). X-ray findings revealed one case of spondylolysis, six cases of spina bifida, and four normal spines. Spina bifida is a congenital neural tube defect characterized by a developmental anomaly in which one or more vertebral lamina does not form completely (Anderson et al., 1998). If the lack of formation is severe enough the contents of the vertebral canal can protrude posteriorly (Anderson et al., 1998).

Back complaints were reported by 30 (47%) of the girls. Stiffness after practice complaints were reported in 17 (27%) of the girls and low back pain in 13 (20%) of the girls. The 13 with low back pain had a mean lordosis of 40.6 degrees, while the 17
gymnasts with stiffness had a mean lordosis of 31.8 degrees. The gymnasts with no reports of back problems had a mean lordosis of 35.4 degrees.

This study found that on average, one degree of the total sagittal lumbar mobility is lost for every one degree of increased lordosis. The researchers stated that there was a significant correlation between the increased degree of lordosis and complaints of low back pain, but no r-values were given. The researchers state that one explanation for the increased LBP and increased lordosis, may be an increased risk of overloading the lumbar spine in maximal hyperextension, particularly since an increased lordosis was also significantly correlated to a decrease range of lumbar hyperextension (r = -0.69). Due to the fact that an increased lordosis has the subject in an already hyperextended position, there is a decrease in total lumbar range of motion (Ohlen et al., 1989).

Tsai and Wredmark (1993) examined spinal posture, sagittal mobility, and subjective rating of back problems in former female elite gymnasts. The purpose of this study was to subjectively assess back problems, and clinically evaluate spinal posture in former elite gymnasts and in age matched female controls. The researchers selected 100 former elite gymnasts who had participated in the Swedish National Championships or at a higher level of competition. Of the 100 questionnaires sent to these gymnasts, 77 were retrieved, and of these 13 were excluded because they did not meet the age criteria of 25 to 43 years old. The mean age of the 64 ex-gymnasts that participated in the study was 33 years of age. During their gymnastic careers, the ex-gymnasts practiced an average of 10 hours per week for an average of 10 years. The control group consisted of 29 age-matched women who had not been active in gymnastics. Thirty eight percent of
the control group had never been involved in sports, and 52% participated in recreational sports, while 10% had been involved in competitive swimming or squash.

All the subjects were given a questionnaire on the following: age when training began, average amount of training hours per week, duration of performance at competition level, average amount of resistance training performed per week, complaints of back problems during training, and complaints of current back problems. The physical examination used an inclinometer to measured kyphosis using the third and fourth thoracic vertebrae and the eleventh and twelfth thoracic vertebrae as the measuring landmarks. The two arms of the kyphometer were placed on each of the landmarks and an angular measurement was taken of the kyphosis present. Lumbar mobility was measured between the 11th and 12th thoracic vertebrae and the first sacral vertebra also using the kyphometer. All the measurements were done in standing posture with the subject's bare feet together. Maximal flexion and hyperextension of the spine were measured using the landmarks mentioned above. The results of this study showed that 48% of the gymnasts had never experienced back problems, 27% currently had back problems, and 47% had experienced back problems previously. There was no significant difference found between the average amount of training or resistance training on subjective back problems. Thirty eight percent of the control subjects had never experienced back problems, while 58% had a history of previous back problems, and 38% had current back problems.

The mean thoracic kyphosis for the gymnasts was 21 degrees, while the mean thoracic kyphosis was 30 degrees for the control group. Thoracic mobility was 30 degrees of flexion, for normal standing, and 16 degrees of hyperextension, for normal
standing, in the gymnasts. Thoracic mobility in the control group was 27 degrees of flexion, for normal standing, and 21 degrees of hyperextension. Lumbar hyperextension was 16 degrees, for normal standing in the gymnasts, compared to 17 degrees in the control group. The total range of thoracic motion was 46 degrees in the gymnasts, compared to 48 degrees in the control group. Total lumbar mobility was 70 degrees in the gymnasts, compared to 75 degrees in the control group.

From this study it was determined that the gymnasts did not have more current back problems compared to the control group. In conclusion, the former elite gymnasts participating in this study did not have more back problems compared to an age matched control group (Tsai, & Wredmark, 1993).

Micheli (1979) discussed the different causes of back problems in children. The first major cause of back pain in children was due to acute or chronic musculotendinitis or ligamentous injuries of the spine. It was reported that most of this type of injury is due to hyperlordosis of the lumbar spine. Hyperlordosis is any amount of lordosis that appears to be beyond the normal curvature of the lumbar spine (Norkin, & Levangie, 1992). The second cause of back pain in adolescents was localized injury to the vertebral growth plates. This occurred most frequently at the thoracolumbar junction. According to Micheli (1979), injury to the vertebral growth plate and bony deformations of the vertebrae may be caused by increased lumbar lordosis, and repeated flexion and extension exercises, such as those observed in gymnastics events. The third cause of back pain, according to Micheli (1979), is a herniated lumbar disc. A herniated disc is observed when the disk is displaced from between the vertebrae. Micheli (1979) reported that spondylolysis and spondylolisthesis were the fourth most prevalent cause
of back pain in adolescents. Spondylolysis is a developmental defect in the lamina of the vertebra. It is common in the lumbar area but can occur in other areas of the spine. As a result of the weakened lamina an increase in shear forces can occur and cause the anterior slippage of a vertebra resulting in spondylolisthesis (Norkin, & Levangie, 1992). Spondylolisthesis is a condition where L4 or L5 vertebrae slide anteriorly on the sacrum (Norkin, & Levangie, 1992). These individuals may acquire these conditions by the repeated flexion and extension of the low back causing stress fractures of the pars interarticularis of the spine. The fifth cause of back pain was direct injury or trauma to the back.

Micheli (1979) also discussed predisposing factors to back pain in young athletes. He divided these predisposing factors into intrinsic and extrinsic factors. Intrinsic factors are those occurring within the athlete including bony, or soft tissue factors. Extrinsic factors include the sports themselves and how they are played. The primary intrinsic factor was the growth spurt where the growth of the soft tissues, ligaments and tendons cannot keep up with the growth of the bony elements. This results in an imbalance across joints including the spine, which may lead to decreased muscle function and pain. The second intrinsic factor was the increased susceptibility of the growth tissues to injury, such as vertebral growth plates. The extrinsic factors were the sports themselves and how often they are played, including errors in the performance of the skills of the sport or overtraining. Performing the skills of the sport incorrectly, or errors in the sport can cause back injury if the spine is exposed to repeated correct or incorrect motion, or if the spine is taken into a position beyond its
normal range of motion. When combined with the forces on the body, errors can easily cause back pain.

Micheli (1979) also discussed the rehabilitation programs for these individuals. It is recommended to stretch the back muscles such as the erector spinae, and the fascia of the back along with the hamstrings. It is also recommended to stretch the neck muscles such as the trapezius and levator scapulae for cervical injuries, and hip muscles such as the iliopsoas, and quadriceps for lumbar injuries. In order to assist with decreasing hyperlordosis if present, abdominal strengthening and pelvic muscle strengthening may also be necessary. Later in the rehabilitation program, weight training involving back strengthening should be utilized to prepare the muscles for sports activity. Micheli (1979) states that swimming can be an excellent rehabilitation choice for most back patients because it decreases the weight on the joints of the back, and promotes use of many different muscles in the body.

Jackson (1979) discussed low back pain in young athletes and the evaluation of stress reaction and disc problems. According to Jackson (1979), a high number of athletes under 18 years of age, get low back pain. Most of the time the problem resolves itself in two to three weeks. Forty percent of the athletes with chronic back pain for at least three months, were diagnosed with some type of symptomatic process related to their pars interarticularis in the lumbar spine. Ten percent were diagnosed with spondylolisthesis, and 10% were diagnosed with a symptomatic disc. The remaining 40% were diagnosed with end plate fractures, growth plate injuries, altered disc spaces at multiple levels, neoplasms, or a non-confirmed diagnosis. End plate fractures are fractures that occur to the epiphyseal plate or growth plate that can cause improper
growth or no bone growth in children. Growth plate injuries are damage that occurs to the end of the bone in children resulting in improper growth or no bone growth. Altered disc spaces are when the disc spaces are pathologically different at multiple levels. Neoplasms are abnormal growths of new tissue that can be benign or malignant. In gymnasts, symptomatic discs can be due to a disease called Scheuermann's epiphysitis. This condition occurs when there is a herniation of the disc, at multiple vertebral levels, usually skipping every other disc, due to narrowing of the disc space. Jackson (1979) also discusses the treatment of symptomatic discs, including bed rest, and/or epidural cortisone injections.

Chronic pain in athletes may be due to the stress reaction of the sport. These stresses may cause problems with the pars interarticularis or spondylolisthesis. Fractures of the pars interarticularis are usually diagnosed as an aching in the low back. This aching is usually unilateral, and the aching is increased by motion, usually twisting and hyperextension. Diagnosis of this can be discovered through a bone scan. If the test is positive, the athlete may be "sidelined" for three months or more. Treatment should involve eliminating lumbar pain, and preventing further progression of spondylolisthesis or pars interarticularis fractures (Jackson, 1979).

**Spinal Gymnastics Injuries**

Goldstein, Berger, Windler, and Jackson (1991) studied spine injuries in gymnasts and swimmers. They compared female gymnasts competing at the pre-elite and elite levels with female swimmers competing at AA, AAA, and national levels of competition. Eleven pre-elite, 14 elite, and 8 national level gymnasts participated in the study. Eight swimmers at the AA or AAA level and 11 national level swimmers
participated in the study. The researchers randomly selected subjects with previous back problems and some without previous back problems from a pool of subjects. The following information was collected from the participants: age, weight, height, years of training, hours of training per week, history of scoliosis, previous spinal injury, time off related to back complaints, physician involvement for prior back injury, and current back symptoms. Magnetic resonance imaging (MRI) data was collected in the sagittal plane at the level of T12 - S1, and in the transverse plane from L3 - S1. The MRI's were read by a radiologist that specialized in the spine. Positive MRI results were defined as degenerative or other disc changes, spondylolysis or spondylolisthesis.

The researchers found that the pre-elite gymnasts had an average age of 11.8 years, body mass index (BMI) of 16.8, and trained 18.2 hours per week. Elite gymnasts had an average age of 16.6, BMI of 19.3, and trained 23.2 hours per week. National gymnasts had an average age of 25.7, a BMI of 20.9, and trained 22.1 hours per week. The AA and AAA swimmers had an average age of 14.6 years, BMI of 19.8, and trained 11.3 hours per week. The nationally ranked swimmers had an average age of 18.6 years, a BMI of 21.3, and trained 16.4 hours per week. As age and hours of training increased, positive MRI results were more frequent. MRI positive subjects had degenerative or other disc changes, or spondylolysis or spondylolisthesis. Eighty percent of athletes with positive MRI results trained 15 hours or more per week. No statistical statement could be made regarding the rate of injury of swimmers relative to gymnasts because the gymnasts trained more hours per week than the swimmers (Goldstein et al., 1991).
Jackson, Wiltse, and Cirincione (1976) evaluated 100 gymnasts for back and spinal problems. The study involved 100 young caucasian female gymnasts between the ages of 6 and 24 years that competed in class four (IV) to elite. Class VI was the lowest level of competition followed by class III, II, I, then elite was the highest level of competition. The gymnasts completed medical questionnaires involving age, height, weight, years in competition, and hours of practice per week. A series of lumbar and sacral spine x-rays were taken to determine if the repeated stress of the sport caused spinal problems in the gymnasts. The stresses the researchers listed included repeated hyperextension, dismount forces, twisting forces and general forces of gymnastics on the body. Repeated hyperextension was the hyperextension of the spine that occurred in most gymnastics skills. Dismount forces are the forces that are sent through the gymnast’s body when they land on their feet after leaving any piece of equipment. It was determined that 11 subjects had interarticularis defects, 19 subjects had low back pain, 6 subjects had spondylosis, 38 subjects had spina bifida, and other injuries were noted such as, defects creating vertebral displacement, and fractures. The researchers also found that there was a four times higher incidence of pars interarticularis defects compared to the 2.3 percent reported in the general caucasian female population Jackson et al., 1976).

Garrick and Requa (1980) studied the epidemiology of women’s gymnastics injuries. The purpose of their study was to determine what types, how often, and on what events gymnastics injuries occur. Athletic trainers in the Seattle area evaluated the injuries of 98 participants in high school gymnastics over a 2 years span. They then expanded the study to incorporate 12 high schools, 2 colleges, and 3 private clubs.
There were 221 high school participants, and 317 total participants. The trainers were to record injuries according to the event in which the injury occurred, and the injury type. The most frequent type of injury, at the high school level, was a sprain (43%), followed by contusions (21%) and strains (18%). More than half of these injuries occurred to the head, neck and spine. One third of these injuries involved the lumbar region of the back. When the researchers examined all groups combined, sprains were again the highest percentage (38%), followed by strains (30%), fractures (10%), and contusions (5%). The head, neck and spine injuries occurred less frequently (17%) in this group. The lower extremities had a higher injury percentage (52%) than the upper extremities (31%). Garrick and Requa (1980) noted that strains and sprains involving the back, particularly in the lumbar region occur more frequently in women’s gymnastics than in most other interscholastic athletic activities. The authors did not determine if this is from the extreme lordosis posture of the gymnasts, from the extreme flexibility required for the skills in the sport, or the high impact forces during some of the movements. According to this study, the injuries that occur in women’s gymnastics are equivalent to the injuries that occur in other women’s sports such as softball, and cross-country (Garrick, & Requa, 1980).

Ichikawa, Ohara, Morishita, Taniguichi, Koshikawa, and Matsukura (1982) studied spondylosis from a biomechanical aspect. The purpose of this study was to determine if the athletes involved in the different sports currently had spondylolysis, and to evaluate their lumbar index. Lumbar index was measured by dividing the height of the anterior aspect of the vertebral body, by the height of the posterior aspect of the vertebral body and was used as a measure of lordosis. The researchers also performed
biomechanical tests on fresh cadaver spines to back up the data collected. The total number of subjects who participated in this study was 607.

The athletes were divided into three groups. Group one was involved with axial stress on the spine, group 2 was involved with rotational stress, and group 3 was involved with bending stress. Axial stress sports were those sports that involved forces applied longitudinally down the spinal column, like in weightlifting above the head. Rotational stress sports were those that caused the spine to twist during a skill, like in hitting a baseball. Bending stress sports were those that required constant flexion and extension of the spine like the skills in gymnastics. The subjects were grouped according to their sports. Group 1 included subjects participating in rugby, weightlifting, and judo. Group 2 included subjects participating in baseball, basketball, soccer, boxing, volleyball, tennis, and table tennis. Group 3 included subjects participating in kendo, swimming, athletics, gymnastics, and rowing. The researchers divided the investigation as follows: 1) sports and X-ray findings, and 2) sports and physical findings. X-rays were taken on each of the subject’s spines, and they were evaluated for spondyloysis, and for lumbar index. A lumbar index below 80% was considered as a decrease in the height of the front structural elements of the spine. It was found that group 1 had the highest percentage of spinal process tenderness, and group 2 had the highest percent of scoliosis. It was also determined that group 1 had the greatest incidence (8.7%) of lumbar index less than 80% followed by group 3 (5.2%), and group 2 (3.8%). Group 3 had a 20% incidence of spondyloysis, while group 1 had a 25.9% incidence of spondyloysis, and group 2 had a 14.4% incidence of spondyloysis.
Thawed cadaver lumbo-pelvic blocks were utilized for the biomechanical tests. The specimens were placed in a device that applied axial compression, anteroposterior bending, and rotational stressing. Axial compression was defined as compression applied straight down through the specimen from the top. Anteroposterior bending was defined as flexing and hyperextending the spinal column and rotational stressing was applied by rotating the top portion of the specimen while the bottom stayed stationary. To measure deformation of the specimen, transducers were constructed and attached at the anterior and posterior parts of the spinal body and intervertebral disc.

The axial compression testing showed deformation of the anterior part of the spinal body. The antero-posterior bending test showed the deformation at each of the transducer positions. The rotational tests demonstrated that as the rotational angle increased, the deformity values at each point increased, and as the axial compression load increased these deformity values became even larger. The clinical and experimental tests demonstrated that the anterior part of the spinal body underwent maximum deformity with the repetition of axial compression.

The researchers also found that spondylolysis was present in 20% of the athletes investigated. In this 20% with spondylolysis, 77% suffered lumbar disturbances, and 23% did not. In the antero-posterior loading tests, the deformity of the pars interarticularis caused compressive strain during extension of the spinal column, and tensile strain while in the neutral position (Ichikawa et al., 1982).

**Summary**

Research has been performed on normal range of motion of the spine in cadavers (Adams et al., 1988), and on college age gymnasts during gymnastics skills.
There is research on range of motion and low back pain in athletes (Jackson, 1979; Kujala et al., 1997; Micheli, 1979; Ohlen et al., 1989; Tsai, & Wredmark, 1989), and research on injuries in gymnastics and injuries in other sports (Garrick, & Requa, 1980; Goldstein et al., 1991; Ichikawa et al., 1982, Jackson et al., 1976). There is also research regarding types of gymnastics injuries and where they occur (Garrick, & Requa, 1980), and on the causes of back pain in athletes (Micheli, 1979). However, there is only one study on the biomechanical effects of gymnastics on the lumbar spine of female gymnasts (Hall, 1986), and none to be found on young female gymnasts. Therefore, information regarding the biomechanics of the spine during gymnastics skills will be helpful to help describe the skills, and aid future research.

Therefore, the purpose of this study was to determine the amount of spinal hyperextension present at the 1) moment of hand impact, 2) peak hyperextension, and 3) hands-off during a back handspring, back walkover, front handspring, and front walkover.
CHAPTER III

METHODOLOGY

Statement of Purpose

The purpose of this study was to determine the amount of spinal hyperextension present at the 1) moment of hand impact, 2) peak hyperextension, and 3) hands-off during a back handspring, back walkover, front handspring, and front walkover.

Subject Characteristics

Before beginning the research, permission was obtained from the Human Subjects/Internal Review Board at Old Dominion University. This study involved eleven young female gymnasts randomly selected from the local gymnastics training centers in the Hampton Roads area of Virginia.

1. Subjects were between 11 and 15 years of age.

2. Subjects were competing for one of the local gyms in the greater Hampton Roads region.

3. Subjects were currently ranked as level eight, nine, ten, or elite, on the one to ten level ranking scale with elite being the highest for competitive gymnastic ability (Pearson, Tom. Gymnastics coach, “personal interview,” January 1998).

4. Subjects could not have back pain in the past year, palpable or visible signs of spondylolisthesis or scoliosis, or joint or musculoskeletal injuries present at the time of the study.
5. Subjects had normal abdominal strength and back extensor strength, and normal hamstring flexibility and hip flexor flexibility.

**Gymnastics Skills**

Four different gymnastics skills served as the independent variable and were examined in this study. These skills included a back handspring (BH), back walkover (BW), front handspring (FH), and a front walkover (FW). The back handspring (Figure 11) required the gymnast to start with a standing posture with their feet together, elbows extended, and shoulders in 180 degrees of shoulder flexion or 90 degrees of shoulder flexion. The gymnasts then flexed their knees while swinging the arms into shoulder extension. The gymnasts then jumped up and backward hyperextending the back to reach for the ground with their hands. The hands hit the ground with the entire spine in a hyperextended position, the elbows extended, the shoulders at 180 degrees, and the feet off the ground. The gymnasts then whipped their legs over and landed on their feet with their knees slightly flexed, their elbows extended overhead with the shoulders flexed 180 degrees.

The back walkover (Figure 12) required the gymnasts to start with a standing posture with their elbows in extension, their shoulders flexed 180 degrees, and one leg and foot pointed straight out directly in front of them. They then arched back, hyperextending the spine until their hands hit the floor. One foot was already in the air and the other foot was on the ground during hand contact. The foot on the floor was then pulled over and one foot came down at a time while the hands were lifted off the ground. The finishing position was standing with one foot in front of the other, elbows extended and the shoulders flexed 180 degrees.
Figure 11: Pictures of a back handspring
Figure 12: Pictures of a back walkover
The front handspring (Figure 13) required the gymnasts to start by taking few steps and a hurdle into the skill. A hurdle is a slight jump on the gymnast's non-dominant foot, leaving the dominant foot free to help execute the skill. Their arms started overhead and the gymnasts placed them on the floor in front of them while their feet and legs were being whipped together and over in the air placing the back in a hyperextended position. The gymnast then blocked or pushed off the floor with their hands to land on both feet, with their elbows extended and shoulders flexed 180 degrees.

The front walkover (Figure 14) was started in the standing position with their elbows extended, shoulders flexed 180 degrees, and one foot pointed directly in front of the gymnast. The gymnasts then flexed their trunk forward placing their hands on the floor with their elbows extended and the shoulders flexed 180 degrees. Their feet then kicked over while the hand placement was taking place. The spine continued to hyperextend until one foot touched the ground while the hands were still on the floor. The hands were then lifted off the floor to bring the gymnasts back to a standing position with one foot pointed directly in front of them, elbows extended, and shoulders flexed 180 degrees.

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Figure 13: Pictures of a front handspring

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Figure 14: Pictures of a front walkover
Physical Examination of Subjects

The procedures and risks of the test were explained to the subjects and their legal guardians; and prior to participation in the study, an informed consent (Appendix A) was obtained in accordance with University guidelines. Musculoskeletal injuries and joint injuries were determined using a medical questionnaire (Appendix B). Body weight and height were measured using a calibrated Health-O-Meter scale with stadiometer ruler. Normal abdominal and back extensor strength were measured using manual muscle testing. Normal hip flexor range of motion was evaluated using the Thomas Test. The gymnast being able to achieve 90 degrees of hip flexion with the knee straight in the supine position evaluated normal hamstring flexibility. Evaluation for spondylolisthesis was determined by palpating for a dip at the L4-L5 or L5-S1 spinous processes. Scoliosis evaluation was done by palpation of the spinous processes and by observing for abnormal rib raising with standing trunk flexion. The gymnast’s normal standing posture, standing spinal hyperextension, and spinal position during the skills were determined by using the Peak Performance Technologies, Incorporated Peak5 motion measurement system in order to track the 3M retroreflective markers placed on each subject.

Body weight and height

Body weight was measured to the nearest 0.1 kg using a Health-O-Meter 159.0-kg capacity scale. The girls were instructed to wear black tights or stretch pants, and a black leotard or black tight fitting top, and bare feet or beam shoes. Height was
measured in bare feet or beam shoes, and appropriate clothing to the nearest centimeter using a 198.0-cm stadiometer.

**Abdominal strength**

Abdominal strength was evaluated using manual muscle testing (Figure 15). The gymnast had to be able to achieve normal status for abdominal strength. Normal status required the gymnasts to achieve the criteria described as follows: testing took place supine with the hands behind the neck. The legs were straight and the tester stabilized the lower limbs. The gymnast “curled-up” through the full range of motion with the scapula raised from the table. Performance of this task placed the gymnast in normal status (Daniels, & Worthingham, 1986).

**Back extensor strength**

The back extensor muscles were evaluated using manual muscle testing (Figure 16). The gymnasts were required to achieve normal status for trunk extension. Normal status required the gymnasts to achieve the criteria described as follows: the gymnasts were positioned prone and the tester stabilized the pelvis by applying pressure with one hand. The arms and shoulders of the gymnast cleared the table to prevent use in extending the trunk. The gymnast extended the trunk until the caudal portion of the thorax was off the table. Resistance was given to the caudal portion of the thoracic region with the tester’s free hand. Performing the test in this manner achieved normal status (Daniels & Worthingham, 1986).
Figure 15: Pictures of abdominal strength testing

Starting position

Ending position

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Figure 16: Pictures of back extensor strength testing

Starting position

Ending position
**Hip flexor flexibility**

Hip flexor flexibility was measured using the Thomas Test (Figure 17). The gymnasts had to have normal hip flexor flexibility to participate in the study. The gymnasts were positioned supine on the table with their legs hanging off the end of the table. In the supine position, the gymnast hugged one knee into the chest while the other leg hung off the end of the table. If the free leg remained flat or dropped below table level while the gymnast hugged the opposite leg into the chest, then the hip flexors were within normal limits. If the free leg was raised above the table while the opposite leg was being hugged to the chest, then the hip flexors were tight and the gymnast did not participate in the study. This test was performed on each hip (Magee, 1992).

**Hamstring flexibility**

Hamstring flexibility was evaluated using the straight leg raise test (Figure 18). The gymnast was required to achieve normal status to participate in the study. The gymnasts were in the supine position with the lower extremities fully extended. They then flexed one leg at the hip to 90 degrees while keeping the knee in full extension. They then grabbed behind the knee of the leg in the air. To achieve normal status the knee had to be extended within 20 degrees of full extension. This was repeated on both legs. The gymnasts had to achieve 90 degrees or greater of hip flexion with the opposite leg remaining flat on the ground (Magee, 1992). If this was not achieved, the hamstring muscles were considered tight and the gymnast did not participate in the study. If the knees were bent when the gymnasts had them to their full extension, a manual goniometer was utilized to determine if subjects achieved normal status. To measure knee flexion the fulcrum of a manual goniometer was placed over the lateral epicondyle...
of the femur. The moving arm of the goniometer was aligned with the lateral midline of
the fibula, using the lateral malleolus as a reference. The stationary arm of the
goniometer was aligned with the lateral midline of the femur, using the greater
trochanter as a reference (Norkin, & White, 1985).
Figure 17: Pictures of the Thomas Test as used to test hip flexor flexibility

Starting position

Ending position
Figure 18: Pictures of hamstring flexibility testing

Starting position

Ending position
Evaluation for spondylolisthesis

To participate in the study, subjects had to be free of palpable signs of spondylolisthesis. To determine if spondylolisthesis was present, the gymnast stood with feet shoulder width apart and the arms hanging freely at the side. The tester palpated (Figure 19) the lumbar and sacral spinous processes for a dip at the L4-L5 or L5-S1 level (Magee, 1992). If a palpable dip was present the gymnast was thought to have spondylolisthesis, and, therefore did not participate in the study.

Evaluation for scoliosis

The subjects did not take part in the study if scoliosis was present. To test for scoliosis the subject stood in normal standing posture with feet shoulder width apart. The tester palpated (Figure 20) starting at the seventh cervical vertebrae to the sacrum feeling and looking for a lateral curvature of the spine (Magee, 1992). The subject then flexed forward at the hips. While the subject was in the flexed position, the tester looked for the ribcage to raise on either side (Magee, 1992) (Figure 20). If lateral curvature was present or the ribcage was raised on either side, scoliosis was present, and the gymnast did not participate in the study.
Figure 19: Picture of testing for spondylolisthesis

Palpation for spondylolisthesis
Figure 20: Pictures of testing for scoliosis

Palpation of the spine for scoliosis

Observation for rib raising in scoliosis
Normal standing posture

Normal standing posture (Figure 21) was evaluated using the Peak Performance Technologies Incorporated, Peak5 computer motion analysis system. The subjects were evaluated while wearing laboratory standard black tight fitting outfits and bare feet or beam shoes. The 3M retroreflective markers were placed on the most superior aspect of the iliac crest, the level of the 11th thoracic vertebrae in the midaxillary line, and lateral thigh at the midpoint between the greater trochanter and the head of the fibula (Figure 22). Gymnasts who performed the skills by leading with their left leg were left starters, while gymnasts who performed the skills by leading with their right leg were right starters. The lead leg is used to propel the subjects into the skills, therefore the lead leg is not always in a position to show hyperextension. Gymnasts who were left starters had the markers placed on their right side, while gymnasts who were right starters had the markers placed on their left side. One gymnast performed skills using different starting positions for the different tricks. She was marked on both sides of her body and was filmed on the non-starting side. Standing posture was considered standing as normal as possible with the feet placed shoulder width apart and the toes facing forward. The gymnasts also held their arms abducted approximately 90 degrees in order to make all markers visible during standing.

Each gymnast was videotaped from the sagittal view in normal standing posture with the 3M retroreflective markers on the most superior aspect of the iliac crest, in the midaxillary line at the level of the 11th thoracic vertebrae, and mid lateral thigh between the fibular head and the greater trochanter. Gymnasts who were left starters were videotaped from the right side, while gymnasts that were right starters were videotaped
from the left side. The PEAK5 motion analysis system software was utilized to assign X-Y coordinates to the designated markers. From these X-Y coordinates, standing posture back angles were calculated.
Figure 21: Pictures of subject during normal standing posture and during standing hyperextension

Normal standing

Standing hyperextension

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Figure 22: Placement of the 3M retroreflective markers at the level of T11 in the midaxillary line, on the superior iliac crest, and on the lateral thigh midway between the greater trochanter and fibular head.
Standing spinal hyperextension

Hyperextension was measured using Peak Performance Technologies Incorporated, Peak5 motion measurement system. The 3M-retroreflective markers were already in place from the normal standing posture analysis. Hyperextension was measured with the feet placed shoulder width apart and the shoulders abducted approximately 90 degrees. To measure hyperextension the gymnast then hyperextended the spine as far as possible without bending the knees, while keeping the hips as stable as possible. Video recordings were made from the right or left sagittal view, depending on the right and left starters, and the angle between the three markers was determined from the digitized videotape records. The PEAK5 motion analysis system software was utilized to assign X-Y coordinates to the designated markers. From these coordinates, standing posture back angles were calculated.

Spinal positioning

Back positioning (Figure 23) was measured using 3M retroreflective markers placed on the most superior aspect of the iliac crest, midpoint of the thigh, and in the midaxillary line. The position of the spinal column was measured throughout the four skills, during the touchdown or impact phase of the hands, and at hands off. Camera placement was in such a way that the camera’s field of view was perpendicular to the plane of motion. The angle of the back was determined from the digitized videotaped records. The PEAK5 motion analysis system software was utilized to assign X-Y coordinates to the designated markers. From these X-Y coordinated, back angles during the skills were calculated.
Figure 23: Picture of spinal positioning during a gymnastics skill
Data Collection Procedures

There were four different phases of data collection. The phase names were as follows:

1. Pre-screening and question answering at local gyms
2. Informed consent
3. Screening and lab familiarization
4. Familiarization and data collection

Phase 1: Pre-screening and question answering at local gyms: Prospective subjects were screened in local gyms to determine if they met the basic criteria. If the prospective subject was currently competing at level 8 or higher, did not have back pain in the past year, did not have musculoskeletal or joint injuries, and the legal guardian agreed to the subjects participation, the subjects were scheduled for phase 2. Questions from the subjects and their legal guardians regarding this study and the procedures were also answered at this time. Informed consent documents were given to the prospective subjects and their legal guardians in order to review at home. Additionally, the prospective subject was asked to wear black tights or black stretch pants, and a black leotard or a tight black shirt to phase 2, or this was provided by the researcher. They were asked to bring beam shoes if they are normally worn in competition, and to wear the hair up so it does not block markers during the data collection.

Phase 2: Informed Consent: This phase took place at the gym or in the Motion Analysis Laboratory at Old Dominion University, depending on the parents attending the data collection session. The tester went through the informed consent document with each subject and their legal guardian. A detailed description of the testing procedures was
presented to each subject and their legal guardian. A question and answer session took
place when necessary. The legal guardian, subject, witness, and the tester then signed
the informed consent. Once written informed consent was obtained, the subjects were
permitted to enter phase 3 of the data collection.

**Phase 3: Screening and lab familiarization:** This phase took place in the Motion
Analysis Laboratory at Old Dominion University. The subject’s height and weight were
taken. Each subject was then asked brief medical questions, and underwent testing for
abdominal strength and back extensor strength. Each subject’s hip flexor flexibility and
hamstring flexibility were then evaluated. The examination for spondylolisthesis, and
scoliosis then took place. The 3M retroreflective markers were placed on the previously
designated anatomical landmarks, and each subject underwent the normal standing
posture and standing hyperextension testing with the PEAK Performance Technologies
Incorporated, PEAK5 motion measurement system recording the data on videotape for
later analysis. Once this phase was concluded, subjects were moved to phase 4.

**Phase 4: Familiarization and Data Collection:** The gymnast performed whatever
personal warm-up and stretching routines were needed before performing the skills.
Prior to data collection, on each individual skill, the gymnast performed a few warm ups
to familiarize themselves with proper hand placement in the field of the camera. Each
skill was performed and recorded until five acceptable trials for each skill were
obtained. An acceptable trial required both hands to hit the target area at the same time.
The videotaped trial was analyzed for data at a later time. The order of the gymnastics
skills that were performed by each gymnast were counter balanced to insure no learning
took place.
Typical Data Collection Session

The group of gymnasts and their coach or parents arrived at the Motion Analysis Laboratory at Old Dominion University. The informed consent had been discussed, reviewed, and signed by the parents at the local gyms, or upon arrival to the laboratory. At the time of arrival to the Motion Analysis Laboratory, the testing procedures were reviewed with the subjects, parents, and coaches. Each gymnast changed into the proper attire, including black leotards and black tights or stretch pants, hair back, and beam shoes or bare feet. Height (cm) and weight (kg) for each subject was recorded by the primary tester. Next the primary tester went through and filled out the medical questionnaire (Appendix B) with each subject. The primary tester then tested each subject for spondylolisthesis, scoliosis, hip flexor flexibility, abdominal strength, and back extensor strength. The primary tester then placed the 3M-retroreflective markers on the previously designated landmarks. Standing posture and standing hyperextension were then filmed using the PEAK5 system. The primary tester controlled the PEAK5 system during all video-recorded trials. The gymnasts warmed up and stretched while the testers got into position and the paperwork was sorted. The assistant tester had different counterbalanced lists of the skills for each gymnast. A list was randomly assigned as the subjects volunteered for the order in which they would be tested. The assistant tester was in charge of making sure each subject performed an acceptable trial, with both hands hitting the ground at the same time, and counting to make sure 5 acceptable trials were recorded by the primary tester. The assistant tester also kept a paper log of which of the trials were considered acceptable and which were not, for reference when it was time to analyze the videotaped data. The first subject was then
ready to perform the skills for data collection. The first subject would then perform a few warm-up trials of their first skill. The warm up was done in the field of view of the camera and with the hands placed on the target area, so they could familiarize themselves with the surfaces. The first skill was then performed for five acceptable trials. The subject then performed a few warm-ups for the second skill and five acceptable trials were recorded. This was then done for the third and fourth skills. The next subject then repeated the sequence above with the skills in a different order. This was repeated until all the subjects had been videotaped. Figure 24 shows a schematic drawing of the data collection set up.

**Research Design and Statistical Analysis Procedures**

A repeated measures research design was used in this study. Each subject served as her own control by participating in each level of the independent variable. Descriptive statistics were performed on the different dependent variables to determine the mean amount of hyperextension at hand contact, peak hyperextension, and hands-off. A one way analysis of variance (ANOVA) with repeated measures was performed on these individual dependent measures. Where significant differences were observed, a post hoc Tukey honestly significant difference (HSD) test was performed. Significance was set at the $p \leq 0.05$ level.
Figure 24: Schematic drawing of data collection setup
Summary

Eleven female gymnasts between the ages of 11 and 15 participated in this study. The subjects were currently training at local gyms and competing at levels 8 - elite. After an informed consent was obtained for each subject, the gymnast’s height and weight were obtained and brief medical questions were asked and answered. The gymnasts were then examined for signs of back pain, signs of spondylolisthesis, or scoliosis, joint or musculoskeletal injuries, normal abdominal and back extensor strength, and normal hamstring and hip flexor flexibility. Retroreflective markers were placed in the midaxillary line at the level of T11, on the superior iliac crest, and on the lateral thigh midway between the greater trochanter and the fibular head. Video recordings of standing posture, and standing hyperextension were obtained and analyzed at a later date. Hyperextension throughout the back walkover, front walkover, back handspring, and front handspring were obtained using five good trials for each of the skills. The data obtained was digitized at a later date. Analysis of the data was done including descriptive statistics, and a one way analysis of variance with repeated measures for each of the individual dependant measures. The dependent measures were hyperextension at HC, PH, and HO. When the main effects of the ANOVA for a dependent measure was significant, a post hoc Tukey HSD test was performed to determine where the differences were among the skills.
CHAPTER IV

RESULTS AND DISCUSSION

Statement of Purpose

The purpose of this study was to determine the amount of spinal hyperextension present at the 1) moment of hand impact, 2) peak hyperextension, and 3) hands-off during a back handspring, back walkover, front handspring, and front walkover.

Results

Table (1) shows the subjects age, height, weight, and competitive level. While, table (2) shows the maximum, minimum, mean, and standard deviations of hyperextension for normal standing, and standing hyperextension. Mean standing hyperextension was found to deviate $7.73 \pm 4.00^\circ$ from the straight position of $180^\circ$. Mean bending hyperextension was found to deviate $44.82 \pm 14.03^\circ$ from the straight position of $180^\circ$.

Table 1. Subjects age, height, weight and competitive level.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (yr.)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Competitive Level</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>143.0</td>
<td>37.0</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>11</td>
<td>142.0</td>
<td>39.0</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>137.0</td>
<td>30.5</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>14</td>
<td>150.0</td>
<td>40.5</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>14</td>
<td>152.0</td>
<td>48.5</td>
<td>9</td>
</tr>
<tr>
<td>6</td>
<td>11</td>
<td>147.0</td>
<td>44.5</td>
<td>8</td>
</tr>
<tr>
<td>7</td>
<td>14</td>
<td>158.0</td>
<td>54.0</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>13</td>
<td>147.0</td>
<td>40.0</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>13</td>
<td>157.5</td>
<td>48.0</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>15</td>
<td>145.0</td>
<td>37.0</td>
<td>elite</td>
</tr>
<tr>
<td>11</td>
<td>12</td>
<td>139.0</td>
<td>32.0</td>
<td>10</td>
</tr>
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</table>
Table 2. Maximum degrees, minimum degrees, mean degrees, and standard deviation of standing posture and standing hyperextension.

<table>
<thead>
<tr>
<th>Hyperextension (degrees)</th>
<th>N</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stand</td>
<td>11</td>
<td>166.00 (14.00)</td>
<td>179.0 (1.00)</td>
<td>172.27</td>
<td>4.002</td>
</tr>
<tr>
<td>Bend</td>
<td>11</td>
<td>116.0 (64.00)</td>
<td>154.0 (26.00)</td>
<td>135.18</td>
<td>14.027</td>
</tr>
</tbody>
</table>

*The number outside of parentheses is the angle between the midaxillary line, iliac crest and mid thigh. The number inside parentheses is the acute angle starting from the upright position of 180 degrees to the position of hyperextension or flexion.

Table (3) shows the maximums, minimums, means, and standard deviations of hyperextension for the back walkover, front walkover, back handspring, and front handspring. The greatest amount of hyperextension occurred at peak of the front walkover (63.87 ± 11.63°), followed by peak of the back walkover (63.49 ± 12.26°).

A one way ANOVA (Table 4) was conducted on each variable to determine possible differences among the different skills for the dependent variable of hyperextension. The ANOVA showed that there was a significant difference in hyperextension among the different skills during hand contact (F=120.142) and at hands-off (F=166.189). There was not a significant difference in hyperextension among the skills at peak hyperextension (F=2.388).
Table 3. Maximum degrees, minimum degrees, mean degrees, and standard deviation of hyperextension during peak, contact, and hands-off of the back walkover, front walkover, back handspring, and front handspring.

<table>
<thead>
<tr>
<th>Hyperextension (degrees)</th>
<th>N</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back walkover</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak</td>
<td>11</td>
<td>101.80</td>
<td>139.60</td>
<td>116.509</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>(78.20)</td>
<td>(40.40)</td>
<td>(63.49)</td>
<td></td>
</tr>
<tr>
<td>Contact</td>
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<td>102.80</td>
<td>140.40</td>
<td>117.473</td>
<td>12.215</td>
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<td>(77.20)</td>
<td>(39.60)</td>
<td>(62.53)</td>
<td></td>
</tr>
<tr>
<td>Hands-off</td>
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<td>213.00</td>
<td>204.200</td>
<td>6.198</td>
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<td></td>
<td></td>
<td>(-12.80)</td>
<td>(-33.00)</td>
<td>(-24.20)</td>
<td></td>
</tr>
<tr>
<td>Front walkover</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak</td>
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<td>99.40</td>
<td>140.00</td>
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<td>11.631</td>
</tr>
<tr>
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<td>210.60</td>
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<td>(-5.2)</td>
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<td>Hands-off</td>
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<td>143.20</td>
<td>120.073</td>
<td>12.771</td>
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<td></td>
<td>(80.4)</td>
<td>(36.80)</td>
<td>(59.93)</td>
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<tr>
<td>Back handspring</td>
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<td></td>
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<td>142.20</td>
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<td>(77.40)</td>
<td>(37.80)</td>
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<td>178.945</td>
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<td>(-16.00)</td>
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<tr>
<td>Hands-off</td>
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<td>159.80</td>
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<tr>
<td></td>
<td></td>
<td>(58.80)</td>
<td>(20.20)</td>
<td>(41.45)</td>
<td></td>
</tr>
</tbody>
</table>

*The number outside of parentheses is the angle between the midaxillary line, iliac crest and mid thigh. The number inside parentheses is the acute angle starting from the upright position of 180 degrees to the position of hyperextension or flexion. Positive numbers represent hyperextension of the trunk, while negative numbers represent flexion of the trunk.

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Table 4. Summary of one way ANOVA for significance in hyperextension

<table>
<thead>
<tr>
<th>Hyperextension</th>
<th>Degrees of Freedom</th>
<th>F value</th>
<th>p value</th>
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<td>3</td>
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<td>0.000</td>
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<tr>
<td>HANDS-OFF</td>
<td>3</td>
<td>166.189</td>
<td>0.000</td>
</tr>
</tbody>
</table>

The Tukey HSD post hoc analysis (Table 5) of significant F values did show a significant difference among all four of the skills at hand contact. The Tukey HSD post hoc analysis of significant F values did show that the difference in hyperextension at hands off was between the BW and FW, the BW and FH, the FW and BH, the FW and FH, FW and BH, BH and FH, and the FH and FW conditions. There was not a significant difference in the hyperextension at hands-off between the BW and BH conditions. The Tukey HSD post hoc analysis of significant F values showed no significant differences among the skills at peak hyperextension.
Table 5. Tukey HSD post hoc analysis of significant F values for peak hyperextension, hand contact hyperextension, hands-off hyperextension.

<table>
<thead>
<tr>
<th>Hyperextension</th>
<th>Skill</th>
<th>Skill</th>
<th>Mean Difference (I-J)</th>
<th>Significance</th>
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</thead>
<tbody>
<tr>
<td>PEAK</td>
<td>BW</td>
<td>FW</td>
<td>0.382</td>
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<td></td>
<td></td>
<td>BH</td>
<td>-7.800</td>
<td>0.455</td>
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<td></td>
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<td>0.165</td>
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<td>BW</td>
<td>11.109</td>
<td>0.165</td>
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<td>0.143</td>
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<td>0.922</td>
</tr>
<tr>
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<td>FH</td>
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<td></td>
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<td>FH</td>
<td>17.382*</td>
<td>0.005</td>
</tr>
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<td>BW</td>
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<td>0.005</td>
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<td></td>
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<td>BH</td>
<td>48.109*</td>
<td>0.000</td>
</tr>
</tbody>
</table>

* The mean difference is significant at the 0.05 level
Table 5. Continued

<table>
<thead>
<tr>
<th>Hyperextension</th>
<th>Skill</th>
<th>Skill</th>
<th>Mean Difference (I-J)</th>
<th>Significance</th>
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<td>FH</td>
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<td>18.473*</td>
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<tr>
<td></td>
<td>BH</td>
<td>FW</td>
<td>-54.545*</td>
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</tr>
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</table>

* The mean difference is significant at the 0.05 level

Discussion

Range of motion of the lumbar spine

In the current study, it was found that the mean standing position of the lumbar spine was 172.27° (Table 2). Therefore, the mean amount of hyperextension or lordosis present, in normal standing was 7.73° from the perfectly straight position of 180.00° (180.00° - 172.27°). In the current study, the mean standing lumbar hyperextension present during backward bending was 135.18° (Table 2). This is 44.82° (Table 2) of backwards bending from the straight position of 180.00° (180.00° - 135.18°).
Kujala et al. (1997) found standing lumbar lordosis in female gymnasts and skaters, mean age of 10.3 to 13.3, to be 30.0°. The researchers remeasured the same subjects at a 3-year follow-up and found standing lumbar lordosis to be 35.0°. They also found standing hyperextension to be 70.0° at baseline, and 76.0° at the 3 year follow-up. The method of measurement involved a flexible material that was molded to the lumbar spine and then tangents were drawn to find the amount of curvature present. The results of the current study for standing hyperextension did agree with this research that used a different method to measure lumbar mobility. The current study found mean hyperextension to be 37.09° (44.82° of hyperextension - 7.73° of standing posture).

Kujala et al (1997) found hyperextension from the starting position of 30° of lordosis, to be 40° (70° - 30°) at baseline, and 41° (76° - 35°) at the three year follow-up. The measurements by Kujala et al. (1997) for standing hyperextension were only 2.91° and 3.91° greater than the current study. Normal standing posture in the current study was 7.73°. Kujala et al (1997) found normal standing posture or lordosis to be 30° at baseline, and 35° at the three year follow up. The 27.27° and 22.27° difference could be due to the different measurement techniques in the two studies. The landmarks used in the current study were the most superior aspect of the iliac crest, the level of the 11th thoracic vertebra in the midaxillary line, and the lateral thigh midway between the fibular head and the greater trochanter. The current study measured overall flexion and hyperextension of the trunk during standing, standing hyperextension, and during the gymnastics skills. Therefore, the current study measured gross trunk mobility. Total trunk mobility does incorporate the lumbar spine, but it is not a direct measure of isolated lumbar mobility. The markers were purposefully placed in midline; therefore
results were expected to show measurements close to the straight position of 180° for normal standing posture.

Ohlen, Wredmark, and Spangfort (1989) also measured standing lumbar lordosis and backwards bending using an inclinometer and kyphometer. Lordosis was measured between T11 and S2. These researchers found the mean lumbar lordosis or standing posture of gymnasts, with a mean age of 11.9 years to be 35.6° with a kyphometer, and 35.2° with an inclinometer. Kujala et al. (1997) found normal standing posture or lordosis to be 30° at baseline, and 35° at the three year follow up. The results of lordosis for Kujala et al. (1997) and Ohlen et al. (1989) are similar. The current study found standing posture or lordosis to be 7.73°, which is 27.90° and 27.47° lower than the results of Ohlen et al. (1989). This difference could again be due to the different measurement technique of the current study. Hyperextension in the study by Ohlen et al. (1989) was found to be 37.8° with an inclinometer. Hyperextension was not measured with the kyphometer. The results of the current study for standing hyperextension also agreed with Ohlen et al. (1989). The current study found mean hyperextension to be 37.09°. Kujala et al. (1997) found mean hyperextension to be 40° at baseline and 41° at three year follow up, while Ohlen et al. (1989) found hyperextension to be 37.8°. The standing hyperextension results of Kujala et al. (1997) were 3.2° and 2.2° greater than Ohlen et al. (1989), while the results of Ohlen et al. (1989) were 0.71° greater than the current study.

Tsai and Wredmark (1993) also measured standing backward bending in ex-gymnasts with a mean age of 33 years. They used a kyphometer and found standing hyperextension to be 16.0°. The current study found hyperextension to be 37.09°,
which is 21.09° greater than Tsai et al. (1993). Kujala et al. (1997) found mean hyperextension to be 40° at baseline and 41° at three year follow up, while Ohlen et al. (1989) found hyperextension to be 37.8°. This could have been due Tsai et al. (1993) using ex-gymnasts, and the age of the gymnasts. The current study, and the studies by Kujala et al. (1997) and Ohlen et al. (1989) involved young currently practicing gymnasts, while Tsai et al. (1993) measured ex-gymnasts with a mean age of 33.

Adams, Dolan and Hutton (1988) used cadaver segments to measure maximum hyperextension of the spine. The cadavers ranged in age from 16 to 58 years. They found the mean amount of hyperextension of the spine to be 23.6° from the straight up position of 180.0°. The method of measurement involved a device that directly took spinal segments into hyperextension, due to the non-living specimen used. The research done by Adams et al. (1988) did not agree with the current study, Kujala et al. (1997) or Ohlen et al. (1989). The differences may be due to the spines being measured after disarticulation, and because the subjects were non-living. Also, once the spinal segments were removed from the cadaver, there was a lack of muscle tissue that may contribute to or limit hyperextension.

Hyperextension and gymnastics skills

The current study, found no significant difference in peak hyperextension among the four skills (p= 0.83). Therefore, the hypothesis that there will be no significant difference in peak hyperextension among the four skills is retained. The maximum mean amount of hyperextension of 63.87 ± 11.63°, occurred at peak hyperextension in the front walkover (Table 3). This peak hyperextension of the front walkover occurred immediately following hands off. The maximum hyperextension was very closely
followed by the peak hyperextension of $63.49 \pm 12.26^\circ$, during the back walkover (Table 3). This peak hyperextension of the back walkover occurred immediately before hand contact.

The current study found that there was a significant difference in hyperextension at hand contact among the four skills ($p = 0.00$). Therefore, the hypothesis, that there would be no significant difference among the four skills at hand contact was rejected. At hand contact the greatest amount of mean hyperextension, of $62.53 \pm 12.21^\circ$, was during the back walkover, followed by $49.16 \pm 14.75^\circ$ during the back handspring, and $1.05 \pm 8.83^\circ$ during the front handspring (Table 3). The spine was in the flexed position during hand contact of the front walkover ($-16.33 \pm 8.74^\circ$).

Hall (1986) used the radius of the lumbar spine to determine differences among five gymnastics skills performed. Four college age gymnasts participated in the study. Hall (1986) found the greatest amount of hyperextension occurred during hand impact of the back handspring (radius = 12.22 cm), followed by hand impact of the back walkover (radius = 8.66 cm) then foot impact of the front walkover (radius = 7.38 cm). The current study found the maximum amount of hyperextension occurred at peak hyperextension of the front walkover (approximately at hands off), followed by peak hyperextension of the back walkover (approximately hand contact). Therefore, the current study and Hall (1986) agreed as to when the greatest magnitude of hyperextension occurred during the back walkover. The current study also agreed with Hall (1986) on maximum hyperextension of the front walkover because, foot impact of the front walkover (Hall, 1986) occurs at approximately the same time as hands off (current study). The current study used more and younger subjects compared to Hall’s
(1986) study. The younger age of the gymnasts and the increased level of difficulty of gymnastics since 1986 may have played a role in the results of the current study. Though the results of Hall's (1986) study and the current study cannot be quantitatively compared because a conversion factor for Hall's (1986) study could not be found.

It was also determined by the current study that there was a significant difference among the four skills at hands off ($p = 0.00$). Therefore, the hypothesis, that there was no significant difference among the four skills at hands off, was rejected. The maximum amount of hyperextension at hands off occurred during the front walkover ($59.93 \pm 12.77^\circ$), followed by the front handspring ($41.45 \pm 11.18^\circ$). The spine was in a flexed position during hands off during the back walkover ($-24.20 \pm 6.20^\circ$), and back handspring ($-13.09 \pm 10.87^\circ$).

Several of the studies reviewed, related a large amount of standing lumbar lordosis to a decrease in the amount of standing lumbar hyperextension (Kajala et al., 1997; Micheli, 1979; Ohlen, & Wredmark, 1989). The current study found no relationship (Table 6) between increased lumbar lordosis and standing hyperextension ($p = 0.651$). However, the standing position measurement in the current study was not a reflection of pure lumbar lordosis.
Table 6: Pearson Product Correlation among normal standing posture and hyperextension range of motion.

<table>
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<th>Standing position</th>
<th>Range of motion from standing posture to hyperextension</th>
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</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
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</tr>
<tr>
<td></td>
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<tr>
<td>RANGE</td>
<td>Pearson Correlation</td>
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<td>Sig. (2-tailed)</td>
<td>0.651</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>11</td>
</tr>
</tbody>
</table>

Gymnasts are noted for having frequent incidence of back pain (Garrick, & Requa, 1980; Goldstein et al., 1991; Kujala et al., 1997; Ohlen et al., 1989; Tsai, & Wredmark, 1993). This pain could be due to the high amounts of hyperextension that occurs during gymnastics skills. The current study looked at subjects with no low back pain and found the greatest amount of hyperextension occurred at peak of the front walkover (63.87 ± 11.63°), followed by peak of the back walkover (63.49 ± 12.26°). Once standing posture or lordosis is removed, the maximum amount of hyperextension that occurred was 56.14° (63.87° – 7.73°) and 55.76° (63.49° – 7.73°). This is a high amount of hyperextension compared to normal standing hyperextension of 37.09° in the current study. To achieve this amount of hyperextension during the skills the gymnasts had to go 19.05° beyond normal standing hyperextension. From this it can be concluded that high amounts of hyperextension are needed for the four gymnastics skills in the current study. Kujala et al. (1997) concluded that in sports requiring high amounts of lumbar hyperextension, a low amount of hyperextension could lead to low back pain.
They also concluded that the girls that participated in their study with the lowest amount of hyperextension were at a three times greater risk for developing low back pain. Ohlen et al. (1989) found that the gymnasts in their study with an increase in lordosis had a decrease in lumbar range of motion. They also state that there was a significant correlation between incidence of LBP and increased lordosis. Micheli (1979) reported that hyperlordosis of the lumbar spine can cause acute or chronic musculotendinitis or ligamentous injuries to the spine and that spondylololisthesis or spondylolysis may occur as a result of repeated flexion and extension of the spine. Garrick and Requa (1980) noted that strains and sprains involving the lumbar region of the back occurred more frequently in gymnastics than in other interscholastic athletic activities. From this they did not determine if the cause was hyperlordosis, the extreme flexibility of the sport, or the impact forces of the force. In comparing the high amount of hyperextension during the skills found in the current study with the findings in other studies, it can be concluded that high amounts of hyperextension are required for the four gymnastics skills tested, and that hyperextension and hyperlordosis may cause low back pain.
CHAPTER V

CONCLUSION

The following conclusions may be drawn from the results of this investigation:

1. The amount of hyperextension present at hand contact is significantly different among the four gymnastics skills. There was a significant difference among all four gymnastics skills (Table 5).

2. The amount of hyperextension present at hands off is significantly different among the four skills. The significant difference was found among the BW and BH groups (Table 5).

3. The amount of peak hyperextension that occurs during each of the skills is not significantly different among the four skills. There was no significant difference found among all four skills (Table 5).

Recommendations

In previous studies the methods for measuring hyperextension of the vertebral column were very complicated (Adams et al., 1988; Hall, 1986; Kujala et al., 1997; Ohlen et al., 1989). It would be nice to have a simple method to do this, therefore, the method used in the current study was used as a quicker way to measure hyperextension of the vertebral column. The design of this study focused on the amount of hyperextension that took place during standing, backwards bending in standing, and during a back handspring, back walkover, front handspring, and front walkover. Hyperextension of the spine was measured by placing markers on the lateral thigh, superior iliac crest, and in the midaxillary line. Based on this information and the results of the statistical analysis the following recommendations are proposed:
1. Develop a method of measuring spinal hyperextension, where the markers can be
directly placed on the spinal column.

2. Measure hand impact forces that occur during the skills.

3. Investigate more gymnastics skills that take place on different pieces of gymnastics
equipment.

4. Investigate incidence of low back pain and the mechanism of injury that previously
occurred in the subjects.

**Summary**

The results of this study do agree with Hall (1986) that the maximum amounts of
hyperextension occurs during hand contact of the back walkover, and hands off of the
front walkover. The quantitative results of Hall’s (1986) study could not be compared
to the current study due to different methodology. The current study is not in agreement
with studies that examined the lordosis of the lumbar spine in standing due to the
current studies measurements not reflecting pure lumbar lordosis. Though, standing
hyperextension in the current study did agree with the results of Kajala et al. (1997) and
Ohlen et al. (1989). The gymnastics skills in the current study did require high amounts
of hyperextension, which may cause LBP in gymnasts with lower amounts of lumbar
flexibility. Due to the current study not obtaining isolated measurements of lumbar
hyperextension during the gymnastics skills, there is further need for investigation of
this topic utilizing a better method of measurement of hyperextension of the lumbar
spine.
REFERENCES


APPENDICES
TITLE OF RESEARCH: The Effects of Four Gymnastics Skills on Hand Impact Forces and Vertebral Column Hyperextension in Young Female Gymnasts

INVESTIGATORS: Tonia Dawn McClure, Master's student, BS
Dr. Donald H. Sussman, Assistant Professor, PhD
Dr. Elizabeth A. Dowling, Assistant Professor, PhD
Martha L. Walker, Associate Professor, MS

DESCRIPTION OF RESEARCH:

Several studies have been conducted testing the mechanical contribution to the stress placed on the spine resulting in injuries in female gymnasts. The purpose of this investigation is to evaluate the effects of the back handspring, front handspring, back walkover, and front walkover on the measurements of forces and spine positioning during the gymnastics tricks.

I, ________________________, have agreed to participate as a subject in this study. I understand that I will be participating in a study involving measuring the force of hand impact and the arch in the back during a back handspring, front handspring, back walkover, and front walkover. I will be expected to perform 5 good trials of each of the gymnastics maneuvers. A good trial will be considered when the hands make full contact with the force plate (a square plate built in to the floor). I will be required to wear black tights or black stretch pants, a black leotard or black tight shirt, and beam shoes or bare feet. Reflective markers will be placed on my right hip, leg, and upper body. Spinal posture will be evaluated by looking at my back, and the curve in my back will be examined throughout the skills and during the point when my hands touch the ground during the five gymnastics maneuvers.
EXCLUSIONARY CRITERIA:

I have completed a medical history questionnaire. To the best of my knowledge, I am not aware of any joint, musculature or back injuries that would prohibit my participation in this study.

RISKS AND BENEFITS:

The testing procedures that I will undergo may result in injury such as bone breaks, muscle strains, or ligament sprains to any aspect of the body including the wrists, elbows, back, neck, hips, knees, and ankles. There also exists the possibility that I may be subject to risks that have not yet been defined. I understand that the main benefit to accrue from this study is the attainment of information relative to the effects of the gymnastics maneuvers on hand impact and back hyperextension (arching). I also understand that pertinent information relative to my responses to this study will be discussed with me by one of the investigators of this study.

COSTS AND PAYMENTS:

I understand that my efforts in this study are voluntary, and I will not receive any remuneration to help defray incidental expenses associated with my participation.

NEW INFORMATION:

I understand that any new information obtained during the course of this research that is directly related to my willingness to continue to participate in this study will be provided to me.

CONFIDENTIALITY:

I understand that any information obtained about me from this research, including questionnaires, medical history, and laboratory findings will be kept strictly confidential. I also understand that the data derived from this study could be used in reports, presentations, and publications, but that I will not be individually identified. I do understand, however, that my records may be subpoenaed by court order or may be inspected by federal regulatory authorities.
WITHDRAWAL PRIVILEGE:

I understand that I am free to refuse to participate in this study or to withdraw at any time and that my decision to withdraw will not adversely affect my care at this institution or cause a loss of benefits to which I might otherwise be entitled. I also realize that the investigators reserve the right to withdraw my participation at any time throughout this investigation if they observe any contraindication to my continued participation.

COMPENSATION FOR ILLNESS AND INJURY:

I understand that in the event of injury or illness resulting from the research protocol, no monetary compensation will be made, but any immediate emergency medical treatment which may be necessary will be available to me without charge by an investigator certified in First Aid. I am advised that if any injury should result from my participation in this research project, Old Dominion University does not provide insurance coverage free medical care or any other compensation for such injury. In the event that I have suffered injury as a result of my participation in any research project, I may contact Tonia D. McClure (Home 416-1836, Work 496-1800), Dr. Donald H. Sussman (683-3545), Dr. Elizabeth A. Dowling (683-4514), or Martha L. Walker (683-4519) at Old Dominion University, who will be glad to review the matter with me.

VOLUNTARY CONSENT:

I certify that I have read the preceding sections of this document, or it has been read to me; that I understand the contents; and that any questions I have pertaining to the research have been, or will be answered by Tonia McClure (Home 416-1836, Work 496-1800), Dr. Donald Sussman (683-3545), Dr. Elizabeth Dowling (683-4514), or Martha Walker (683-4519). If I have any concerns, I can express them to the University Institutional Review Board (Dr. Val Derlega 683-3118). A copy of this informed consent form has been given to me. My signature below indicated that I have freely agreed to participate in this investigation.
INVESTIGATOR’S STATEMENT:

I certify that I have explained to the subject whose signature appears above the nature and purpose of the potential benefits and possible risks associated with participation in this study. I have answered any questions that have been raised by the subject and have encouraged him/her to ask additional questions at any time during the course of this study.

____________________________  ________________
Investigator’s Signature       Date
MEDICAL QUESTIONNAIRE AND INITIAL EVALUATION

Name: ___________________________ Age: _________________

Competitive Level: ___________

Name of Gymnastics Training Center: _______________________________

Height: ______ cm Weight: __________ kg

Medical Questionnaire

Yes  No  1. Have you had any back pain in the past year?

Yes  No  2. Do you currently have any injuries to any joints, muscles, bones or any other type of injuries not listed?

Yes  No  3. Do you currently have known scoliosis or spondylolisthesis?

Initial Evaluation

Yes  No  Normal abdominal strength? Yes  No  Normal hip flexor flexibility?

Yes  No  Normal back extensor strength? Yes  No  Presence of scoliosis?

Yes  No  Normal hamstring flexibility? Yes  No  Presence of spondylolisthesis?
VITA

TONIA MCCLURE BURKE
Old Dominion University
Department of Exercise Science,
Physical Education, and Recreation
Norfolk, VA 23529

EDUCATION

- Master of Science in Exercise Science, Old Dominion University, Norfolk, VA- Anticipated, December 2001
- Master of Science in Physical Therapy, Thomas Jefferson University, Philadelphia, PA - August 2001
- Bachelor of Science in Physical Therapy, Thomas Jefferson University, Philadelphia, PA - August 2001
- Bachelor of Science in Sports Medicine, Old Dominion University, Norfolk, VA - May 1995

PROFESSIONAL CERTIFICATIONS/LICENSURES

- Physical Therapist License – State of Virginia
- Health Fitness Instructor - American College of Sports Medicine (ACSM)
- CPR-Health Provider - American Heart Association
- Certified Aerobics Instructor - American Council on Exercise (ACE)

RESEARCH EXPERIENCE

- “The physical fitness levels of men who are currently homeless”, Tonia Burke, Christa Conway, Gary Sylvester, Michael Vile, co-investigators; Diane Comman-Levy, faculty advisor; Dr. Roger Nelson, member and Dr. Marcus Besser, member (Thomas Jefferson University, 2001).

EDUCATIONAL EXPERIENCE

August 2000 to May 2001 Graduate Assistant, Physical Therapy Department, Thomas Jefferson University

August 1997 to May 1998 Adjunct Faculty, Physical Education Department, Old Dominion University

August 1997 to May 1998 Graduate Assistant, Wellness Institute and Research Center Old Dominion University

August 1996 to August 1997 Graduate Assistant, Recreational Sports Department Old Dominion University