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Effect of Sex on the Coordination Patterns of Athletes During Dynamic Activities

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THE EFFECTS OF SEX ON COORDINATION PATTERNS OF ATHLETES DURING DYNAMIC ACTIVITES

by

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Under the direction of Bryan Riemann, Ph.D

Current research has largely focused on the specific actions of individual joints while neglecting the overall pattern of motion and interaction between body segments. Therefore, the purpose of this study was to compare coordination patterns between man and woman collegiate athletes during static and dynamic activities. Thirty healthy collegiate division-one man and woman athletes participated. They completed a battery of tasks, including the single-leg squat and lateral step-downs while three-dimensional kinematics of the pelvis, thigh, knee, and shank were collected. Using a dynamic systems analysis, coordination patterns were calculated and statistically compared between the sexes. Additionally the stability of the patterns across multiple trials were compared. The results revealed distinct task dependent patterns within each plane of motion however no sex dependent patterns. The underlying etiology for sex related differences requires further study. This information will ultimately contribute to advancing the scientific rationale for neuromuscular training programs striving to prevent injuries.

Index words: Sex differences, coordination patterns, dynamic systems analysis, single leg squat, lateral step down, static limb characteristics

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Table of Contents

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

Recent research reveals differences between the sexes in lower extremity kinematics during dynamic tasks such as landing and hopping. Specifically, women tend to display significantly less knee flexion during these tasks and maximum angular displacement during shock absorption. [1,2,3,4] In addition to knee flexion differences, women maintain a more valgus knee position than men throughout.[5]

Common to all these studies was the use of discrete variables, such as joint position, displacement, and velocity, which attempt to isolate and characterize motion in one or two dimensions. While accomplishing this goal successfully, they fail to reveal interactions occurring between body segments.[6,7] In contrast to a discrete variable approach, a dynamic systems approach employs an examination that considers the entire motion, with multiple degrees of freedom. In other words, a dynamic systems approach characterizes the entire motion, rather than a moment in time. Motion is thus analyzed as interactions between segments that arise as a result of environmental, internal and task specific constraints thus established patterns of movement, or coordination tendencies may be examined.[8,9] Research using a dynamical system approach has largely considered the effects of task manipulation on coordination patterns. For example, as the velocity of a task, specifically walking or running, increases, the stability of the coordination pattern decreases.[10,11,9] Li et al. found that large velocity changes, in most dynamic activities caused individuals to employ a completely different motor pattern.[9]

To date, limited research has been conducted examining the coordination patterns during tasks relevant to sports medicine. Rather than manipulating the task characteristics (e.g. walking velocity), from a sports medicine perspective, understanding the effects of various intrinsic constraints associated with injury, such as muscle strength, range of motion, and ligamentous laxity, are more relevant. For example, van Uden et al revealed that while patients with reconstructed anterior cruciate ligaments (ACLR) and healthy individuals self-selected similar hopping frequencies, the ACLR group demonstrated a different segmental pattern containing less stability.[12]

Research with the step down and single leg squat has demonstrated sex related differences with discrete variables which researchers theorized were due to several intrinsic sex-related differences. These differences include such as muscle strength imbalances and motor control pattern variations, as being responsible for the dissimilarities.[1,13,14] Muscle strength has received the most attention as the explanation for discrete variable differences between sexes. Relevant to the control of knee displacement is the strength of the lumbo-pelvis muscle groups such as the gluteus medius and quadratus lumborum. Women have been documented as having less gluteus medius strength in comparison to men. Thus, the gluteus medius has been speculated to be partly responsible for the discrete knee valgus variables.[15]

To date, no investigations have established the full coordination patterns of men or women during dynamic activities, although they are referenced widely in sex difference literature. Therefore, the purpose of this study was to compare the pelvis-trunk, pelvis-thigh, shank-thigh, and foot-shank segmental coordination patterns of the stabilizing limb between man and woman collegiate athletes during the single leg squat, and lateral step down and determine if the stability of these was correlated to static limb characteristics.

CHAPTER 2: METHODS

Participants

Twenty man and twenty woman Division I collegiate athletes were recruited to participate in this study. Participation was limited to athletes with no history of knee, ankle, back, hip, or leg injuries during the past six months as determined through a medical history survey. In addition, athletes with any history of lower extremity or back injuries that would affect their neuromuscular abilities, as determined by the clinicians, including surgeries or ligament deficiencies, were excluded. Demographic information is found in Table 1.

Design

This investigation used a two group ex post facto design. The athletes were scheduled for one testing day. They were first given an overview of the research with a demonstration of the testing procedures. Next, the athletes read and signed a university Institutional Review Board approved informed consent. A static limb characteristic screen followed in which leg length, lower leg alignment, and foot type were examined as done previously by Gross.[16] Finally, athletes completed a battery of dynamic tasks on their stabilizing limb. Their stabilizing limb was defined as the leg they stand on, when they kick a soccer ball.

Procedures

Static Limb Characteristics Measurements*:* The athletes began by undergoing a thorough static limb characteristics measurements. The purpose of this was to document any anthropometrics that may alter coordination patterns.[16] The principal investigator, a certified athletic trainer, performed all static limb characteristic measurements, to ensure clinical competence throughout. The screen consisted of the following tasks:

Navicular drop/drift test: This test was performed by marking the height of the navicular tuberosity in a non-weight bearing position and measuring its change in position once the athletes stood become weight bearing.[16,17] This measure of sagittal plane motion can reveal the presence of excessive subtalar joint pronation or ligament laxity.[17] In addition, the amount of drift or motion by the navicular in the transverse plane, was recorded for observation purposes only.

Rearfoot/ leg orientation: The athletes were standing for this examination. The angle between a line representing the rearfoot's orientation and a line bisecting the lower leg was recorded.[16] This test can again indicate excessive subtalar joint pronation or some eversion of the talus.[16]

Subtalar joint positioning and rearfoot and forefoot alignments: The athletes were tested both standing and lying prone. The medial and lateral borders of the talus were located and the ankle was actively pronated and supinated until the talus is in a neutral position. A neutral talus is defined as the point where the talus is felt on the medial and lateral sides of the ankle equally. The orientation of the rearfoot and forefoot in relation to the neutral subtalar was measured joint using a goniometer.[16] The orientation of athletes' subtalar joint, rearfoot and forefoot can reveal excessive foot pronation, a pathology which can lead to lower leg rotation altering dynamic coordination activities.

Femoral anteversion/ retroversion: The athletes were also examined for rotation of their femur. This was determined by Craig's test, as described by Magee.[18] Athletes were prone, with their knees flexed to 90 degrees. The examiner palpated the greater trochanter on the lateral thigh and passively internally and externally rotated the hip. At the point where the greater trochanter protrudes the most laterally, the angle was measured using a goniometer. This angle was defined as the angle between the lower leg and a line perpendicular to the table. Any angles greater than 20 degrees are defined as anterverted femurs and any angles less than ten degrees are defined as retroverted femurs. No athletes were found to fall into either category.

Tibial Torsion: The athletes were also examined for rotation of their tibia. This was determined by placing the athlete prone, on the table, with their knee bent to 90 degrees. From this position, the angle between the condyles of the femur and the medial and lateral malleoi was measured from above.[18] No athletes had a tibial torsion greater than 15 degrees, therefore none were considered abnormal.

Dynamic Battery of Tasks*:* All of the dynamic battery tests were performed barefoot on the stabilizing limb. The dynamic tasks included were:

Single Leg Squat: The athletes were instructed to perform a single leg squat following procedures from previous research.[5,26] In short, athletes were instructed to stand on their stabilizing limb and squat down as far as possible. Each squat was completed in two seconds as indicated by a metronome. Eight squats were performed continuously however, only the four most similar trials were used for analysis as determined by displacement graphs.

Lateral Step Down: The athletes were instructed to stand with stabilizing limb on the edge of the step with their contralateral foot hanging off and their hands on their hips. The step height was 20% of their leg length as determined in the static limb characteristic measurements.[27] The athletes were instructed to bend their knee so that their contralateral heel touched the force plate at a pace of 60 beats per minute as indicated by the metronome (0.5Hz) for 90 seconds or until exhaustion. Four similar trials were used for analysis and were selected based on displacement graphs.

Data Collection

Instrumentation*:* During the dynamic battery of tasks, three-dimensional kinematic data was collected using an extended range electromagnetic tracking system (MotionStar, Ascension, Inc., Vermont) with all the hardware settings in the default mode. Data from the electromagnetic tracking system was collected at 100 Hz for the lateral step down and stance and at 140 Hz for the single leg squat. All tasks utilized the Motion Monitor acquisition software package (Innovative Sports Training, Inc; Chicago Il). Sensors were attached to the athlete's seventh cervical vertebra's spinous processes, sacrum (specifically, S2), both feet, shanks and thighs using double sided tape and elastic tape prior to completing the task battery. During subject setup, the ankle, and knee joint centers were calculated by taking midpoints between contralateral points at each respective joint. The hip joint center was established using a series of eight points along a circumduction cycle for each hip to estimate femoral motion, not pelvis motion.[28]

Athletes' height and weight were also recorded for anthropometric calculations required for locating each segment's center of mass using the Dempster parameters as reported by Winter. Absolute three dimensional angles were used to calculate segmental orientation with respect to the horizontal in the frontal (abduction), sagittal (flexion), and transverse (rotation) planes. Because the sensor on the seventh cervical spinous process defined the trunk segment, the trunk angle was representative of an estimation of the overall sum vertebral movements occurring from the sacrum to the seventh cervical vertebra.[11] Position data was filtered using a zero-phase lag Butterworth filter (10 Hz cutoff).

Data Reduction

For the single leg squat and lateral step downs, both the decent and ascent phases were considered. Using a custom written MATLAB based Graphical User Interface, four repetitions of each exercise were selected for analyses based on the vertical trajectory of the total body center of mass (TBCM).

For each repetition, the absolute angular displacements and angular velocities of the trunk, pelvis, thigh, shank and foot were calculated. Next, phase plots were established with angular velocity on the vertical axis and angular displacement on the horizontal axis (Figure 1). The Cartesian coordinates were then transformed to polar coordinates to determine phase angle and time normalized (100 points) to determine segmental coordination (Figure 2). The phase angle of the proximal segment was subtracted from the phase angle of the distal segment to compute the relative phase. These procedures were repeated in all three planes of motion, between pelvis-trunk, thigh-pelvis, shank-thigh and shank-foot. The relative phase angles were ensemble averaged across the four repetitions. The average of the ensemble is the mean absolute relative phase (MARP) with its standard deviation, the deviation phase (DP) (Figure 3).

MARP served to identify whether segments were in or out of phase while the DP indicated the stability of the pattern. MARP and DP values were calculated separately for each phase of the tasks, descent and ascent.

In addition to the MARP and DP values, the trajectory of the TBCM was also time normalized and ensemble averaged across the four repetitions. Three additional dependent variables were calculated, total repetition time, percent cycle descent/ascent transition, and vertical TBCM displacement.

Data Analysis

Separate two factor analysis of variance (ANOVA) with repeated measures were used to analyze the MARP and DP values for each plane and task/phase combination. Thus, a total of 12 ANOVA were conducted. For each, the between subjects factor was sex with two levels and the within subject factor was segment with four levels (pelvis-trunk, thigh-pelvis, shank-thigh and foot-shank). Statistical significance for the ANOVA were considered at $P<.05$. Significant main effects and interactions were followed up with a Tukey Post Hoc analyses. Independent t-tests were conducted on the total repetition time, percent cycle descent/ascent transition and vertical TBCM displacement to determine sex-related differences. Finally, correlational analyses were conducted between the MARP and DP values and limb characteristics. Within each task, statistical significance for the correlational analyses was adjusted to $P<.006$

Table 1: Demographic Information on Subjects

Measurement	*Men*	*Women*
Age	20.6 +/- 1.4 years	19.6 +/- .8 years
Height	181.2 +/- 5.1 cm	169.7 +/- 8.7 cm
Weight	97.2 +/- 22.4 kg	72.1 +/- 11.1 kg
Leg Length	96.1 +/- 3.9 cm	89.1 +/- 6.4 cm

Figure 1: Phase portrait for trunk flexion during the single leg squat

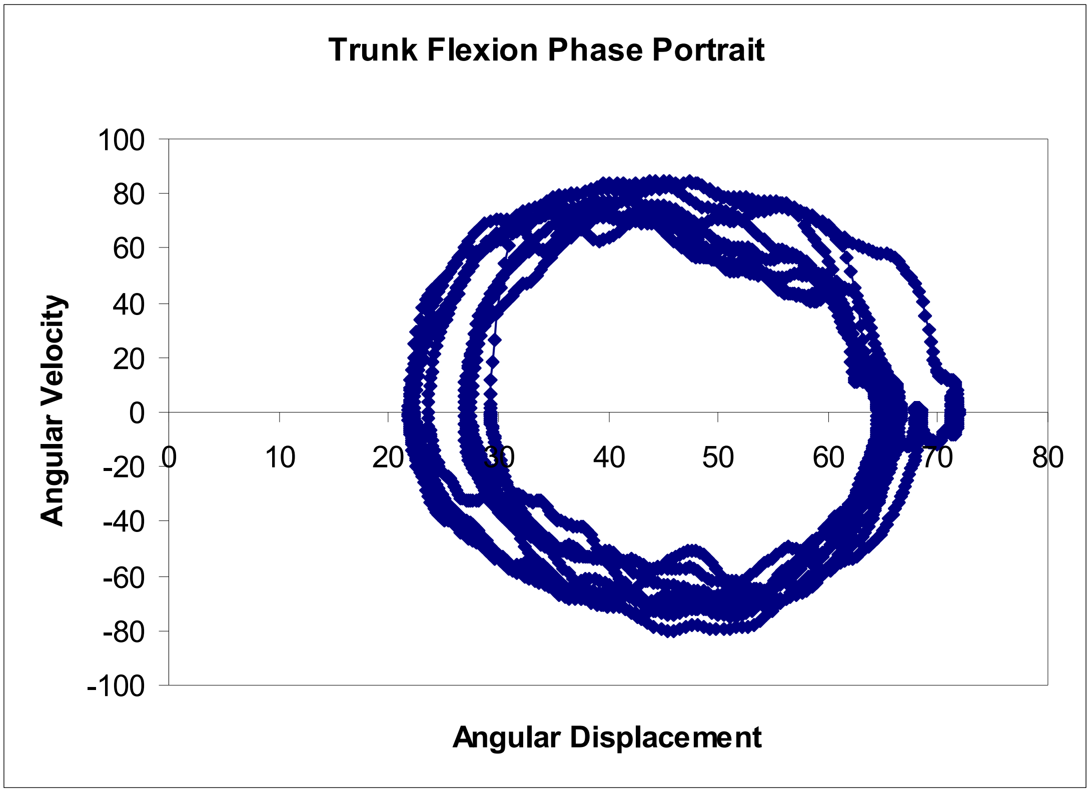


Figure 2: Phase angle of the pelvis in the sagittal plane during four trials of the single leg squat test

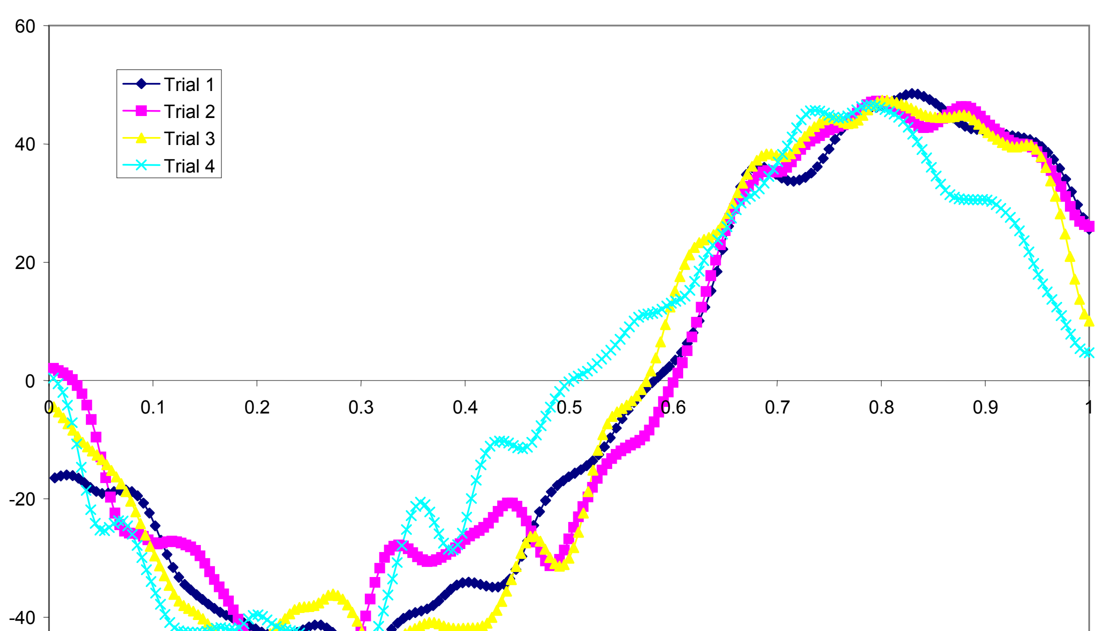
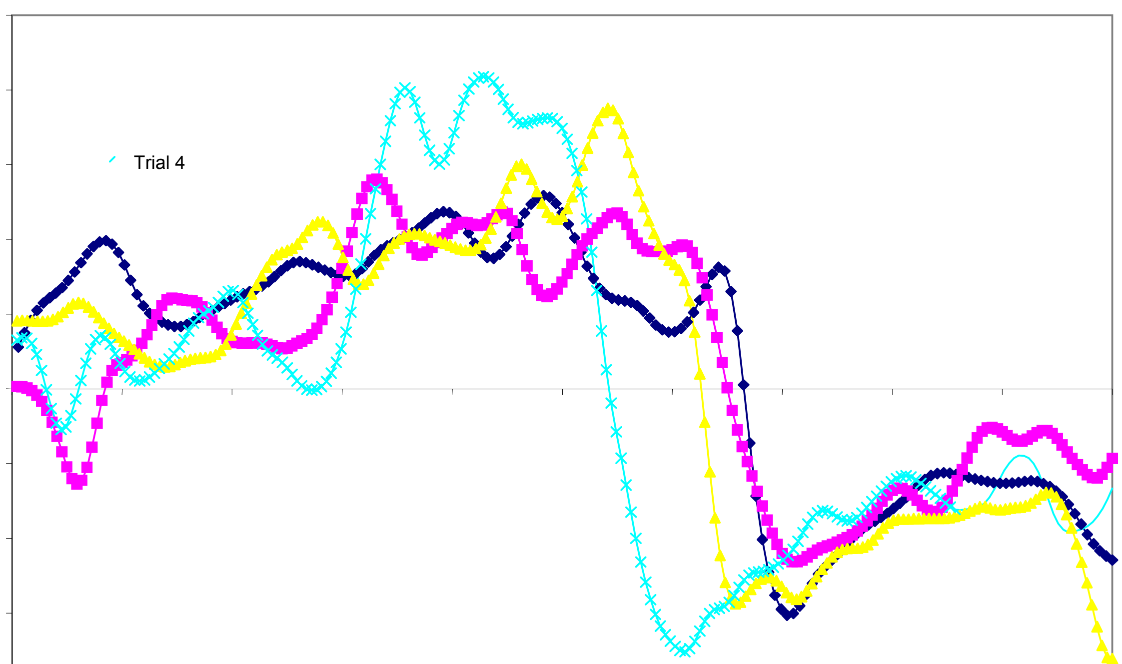


Figure 3: Relative Phase of the trunk in relation to the pelvis during four trials of the single leg squat exercise in the sagittal plane



CHAPTER 3: RESULTS

Lateral Step Downs: Temporal/Spatial Characteristics

Means and standard deviations for the lateral step down temporal/spatial characteristics are presented in Table 2. There were no significant differences between sex with respect to percent cycle descent/ascent (t_{28}=-1.49, *P*=.148) and vertical TBCM displacement (t_{28}=.025, *P*=.980). The women completed the lateral step downs at a slightly slower, but statistically significant, pace (t_{28}=-2.068, *P*=.048).

Lateral Step Downs: Ascent

Lateral step down ascents are graphically represented in figures 4-9.

Sagittal Plane: During the ascent of the lateral step downs, there were no significant differences in MARP values between men and women at the pelvis-trunk, thigh-pelvis, shank-thigh, or foot-shank as evidenced by the sex by segment interaction ($F_{3,\ 84}$= .03, *P*= .99) and main effect for sex ($F_{1,28}$=.85, *P*=.37). There was a significant segment main effect ($F_{3,84}$=89.44, *P*< .01) with the results of the Tukey Post Hoc ($HSD_{4,84}$= 11.9, *P*< .05) illustrated in Figure 4. There were no significant differences in the DP values between men and women as evidenced by the sex by segment interaction ($F_{3,84}$= 1.44, *P* = 0.24) and main effect for sex ($F_{1,28}$ =.10, *P*=.76).There was a significant segment main effect ($F_{1,28}$=188.12, *P*<0.01) with the results of the Tukey Post Hoc (*P*<.05, $HSD_{4,84}$ = 1.63) illustrated in Figure 5.

Frontal Plane: During the ascent of the lateral step downs, there were no significant differences in MARP values between men and women at the pelvis-trunk, thigh-pelvis, shank-thigh, or foot-shank as evidenced by the sex by segment ($F_{3,84}$=1.2, *P* = 0.28) and main effect for sex ($F_{1,28}$=.124, *P*=.73). There was no segment main effect

(*P*= 0.09) as illustrated in Figure 6. There were no significant differences in the DP values between the men and women as evidenced by the sex by segment interaction ($F_{3,84}$ = .91, *P*= .44) and main effect for sex ($F_{1,28}$=.27, *P*=.61). There was a significant segment main effect ($F_{3,84}$=8.62, *P*<0.01) with the results of the Tukey Post Hoc (*P*<.05, $HSD_{4,84}$=1.93) illustrated in Figure 7.

Transverse Plane: During the ascent of the lateral step downs, there were no significant differences in the MARP values between men and women at the pelvis-trunk, thigh-pelvis, shank-thigh, or foot-shank as evidenced by the sex by segment interaction ($F_{3,84}$=.44, *P* = .73) and main effect for sex ($F_{1,28}$=.05, *P*=.836). There was a significant segment main effect ($F_{3,84}$=7.73, *P*< 0.01) with the results of the Tukey Post Hoc (*P*<.05, $HSD_{4,84}$= 8.03) illustrated in Figure 8. There were no significant differences in the DP values between the men and the women as evidenced by the sex by segment interaction ($F_{3,84}$ = .33, *P*=.81) and main effect for sex ($F_{1,28}$=.29, *P*=.10). There was a significant segment main effect ($F_{3,84}$ =5.3, *P*<0.01) with the results of the Tukey Post Hoc (*P*<.05, $HSD_{4,84}$=1.93) illustrated in Figure 9.

Lateral Step Downs: Descent

Lateral step down descents are graphically represented in figures 10-15.

Sagittal Plane: During the descent of the lateral step downs, there were no significant differences in MARP values between men and women at the pelvis-trunk, thigh-pelvis, shank-thigh, or foot-shank as evidenced by the sex by segment interaction ($F_{3, 84}$= .01, *P* .99) and main effect for sex ($F_{1,28}$=.27, *P*=.608). There was a significant segment main effect ($F_{3,84}$ =88.65, *P*<0.01) with the results of the Tukey Post Hoc (*P*<.05, $HSD_{4,84}$=1.64) illustrated in Figure 10. There were no significant differences in the DP values between men and women as evidenced by the sex by segment interaction ($F_{3,84}$= 1.05, *P* = .37) and main effect for sex ($F_{1,28}$<.01, *P*=.997).There was a significant segment main effect ($F_{3,84}$ =16.564, *P*<0.01) with the results of the Tukey Post Hoc (*P*<.05, $HSD_{4,84}$=1.64) illustrated in Figure 11.

Frontal Plane: During the descent of the lateral step downs, there were no significant differences in MARP values between men and women at the pelvis-trunk, thigh-pelvis, shank-thigh, or foot-shank as evidenced by the sex by segment interaction ($F_{3,84}$=1.16, *P* = 0.33) and main effect for sex ($F_{1,28}$ = .341 *P*=.564). There was no significant segment main effect (*P*= 0.27) as illustrated in Figure 12. There were no significant differences in the DP values between the men and women as evidenced by the sex by segment interaction ($F_{3,84}$ = 1.12, *P*= 0.35) and main effect for sex ($F_{1,28}$ = .01, *P*= .935). There was a significant segment main effect ($F_{3,84}$ = 15.82, *P*<0.01) with the results of the Tukey Post Hoc (*P*<.05, $HSD_{4,84}$=1.76) illustrated in Figure 13.

Transverse Plane: During the descent of the lateral step downs, there were no significant differences in the MARP values between men and women at the pelvis-trunk, thigh-pelvis, shank-thigh, or foot-shank as evidenced by the sex by segment interaction ($F_{3,84}$=.57, *P* = .64) and main effect for sex ($F_{1,28}$ = .15, *P*= .706). There was a significant segment main effect ($F_{3,84}$=7.59, *P*< 0.01) with the results of the Tukey Post Hoc (*P*<.05, $HSD_{4,84}$= 7.62) illustrated in Figure 14. There were no significant differences in the DP values between the men and the women as evidenced by the sex by segment interaction ($F_{3,84}$ = 0.48, *P*=0.70) and main effect for sex ($F_{1,28}$ = 2.39, *P*= .133). There was a significant segment main effect ($F_{3,84}$=8.05, *P*<0.01) with the results of the Tukey Post Hoc (*P*<.05, $HSD_{4,84}$=3.23) illustrated in Figure 15.

Single Leg Squat: Temporal/Spatial Characteristics

Means and standard deviations for the single leg squat temporal/spatial characteristics are presented in Table 3. There were no significant differences between sex with respect to average repetition time (t_{28}=1.17, *P*=.273), percent cycle descent/ascent (t_{28}=1.05, *P*=.303), and vertical TBCM displacement (t_{28}=1.66, *P*=.109).

Single Leg Squat: Ascent

Single leg squat ascents are graphically represented in figures 16-21.

Sagittal Plane: During the ascent of the single leg squat, there were no significant differences in MARP values between men and women at the pelvis-trunk, thigh-pelvis, shank-thigh, or foot-shank as evidenced by the sex by segment interaction ($F_{3, 84}$= .68, *P* .57) and main effect for sex and main effect for sex ($F_{1,28}$ = .002, *P*= .96). There was a significant segment main effect ($F_{3, 84}$= 52.97, *P*< .01) with the results of the Tukey Post Hoc (*P*<.05, $HSD_{4,84}$= 11.46) illustrated in Figure 16. There were no significant differences in the DP values between men and women as evidenced by the sex by segment interaction ($F_{3,84}$= 1.14, *P* = .34) and main effect for sex ($F_{3,84}$=.04, *P*=.84). There was a significant segment main effect ($F_{3, 84}$= 52.97, *P*< .01) with the results of the Tukey Post Hoc ($HSD_{4,84}$ =3.97, *P*<.05) illustrated in Figure 17.

Frontal Plane: During the ascent of the single leg squat, there were no differences in MARP values between men and women at the pelvis-trunk, thigh-pelvis, shank-thigh, or foot-shank as evidenced by the sex by segment interaction ($F_{3,84}$=1.57, *P* =.203) and main effect for sex ($F_{1,28}$= 1.22, *P*=.27). There was a significant segment main effect ($F_{3, 84}$= 8.07, *P*< 0.01) with the results of the Tukey Post Hoc ($HSD_{4,84}$= 3.71, *P*< 0.05) illustrated in Figure 18. There were no significant differences in the DP values between the men and women as evidenced by the sex by segment interaction ($F_{3,84}$ = 1.75, *P*= 0.16) and main effect for sex ($F_{1,28}$= .004, *P*=.95). There was a significant segment main effect ($F_{3,84}$=10.93, *P*<0.01) with the results of the Tukey Post Hoc ($HSD_{4,84}$=1.88, *P*<.05) illustrated in Figure 19.

Transverse Plane: During the ascent of the single leg squat, there were no significant differences in the MARP values between men and women at the pelvis-trunk, thigh-pelvis, shank-thigh, or foot-shank as evidenced by the sex by segment interaction ($F_{3,84}$=1.19, *P* = .32) and main effect for sex ($F_{1,28}$= 1.02, *P*= .322). There were significant segment main effect ($F_{3, 84}$= 4.764, *P*< 0.01) with the results of the Tukey Post Hoc ($HSD_{4,84}$= 3.66, *P*<.05) illustrated in Figure 20. There were no significant differences in the DP values between the men and the women as evidenced by the sex by segment interaction ($F_{3,84}$ = 2.69, *P*=0.05) and main effect for sex ($F_{1,28}$= 1.04, *P*= .315). There was a significant segment main effect ($F_{3,84}$= 9.95, *P*< 0.01) with the results of the Tukey Post Hoc ($HSD_{4,84}$=2.07, *P*<.05) illustrated in Figure 21.

Single Leg Squat: Descent

Single leg squat descents are graphically represented in figures 22-27.

Sagittal Plane: During the descent of the single leg squat, there were no significant differences in MARP values between men and women at the pelvis-trunk, thigh-pelvis, shank-thigh, or foot-shank as evidenced by the sex by segment interaction ($F_{3, 84}$= 0.22, *P*= 0.88) and main effect for sex ($F_{1,28}$= 0.46, *P*=.51). There was a significant segment main effect ($F_{3, 84}$= 71.48, *P*< 0.01) with the results of the Tukey Post Hoc ($HSD_{4,84}$= 10.70, *P*<.05) illustrated in Figure 22. There were no significant differences in the DP values between men and women as evidenced by the sex by segment interaction ($F_{3,84}$= 0.65, P = 0.59) and main effect for sex ($F_{1,28}$= 0.39, P = 0.54). There was a significant segment main effect ($F_{3,84}$= 27.96, P<0.01) with the results of the Tukey Post Hoc ($HSD_{4,84}$ =3.50, P<.05) illustrated in Figure 23.

Frontal Plane: During the descent of the single leg squat, there were no significant differences in MARP values between men and women at the pelvis-trunk, thigh-pelvis, shank-thigh, or foot-shank as evidenced by the segment by sex interaction ($F_{3,84}$=1.54, P = 0.21) and main effect for sex ($F_{1,28}$ = .62, P= 0.44). There was a significant segment main effect ($F_{3,84}$=7.94, P< 0.01) with the results of the Tukey Post Hoc ($HSD_{4,84}$= 3.68, P<.05) illustrated in Figure 24. There were no significant differences in the DP values between the men and women as evidenced by the segment by sex interaction ($F_{3,84}$ = .65, P= 0.59) and main effect for sex ($F_{1,28}$ = .248, P= 0.622). There was a significant segment main effect ($F_{3,84}$ = 13.74, P<0.01) with the results of the Tukey Post Hoc ($HSD_{4,84}$=1.52, P<.05) illustrated in Figure 25.

Transverse Plane: During the descent of the single leg squat, there were no significant differences in the MARP values between men and women at the pelvis-trunk, thigh-pelvis, shank-thigh, or foot-shank as evidenced by the sex by segment interaction ($F_{3,84}$=1.01, P = .39) and main effect for sex ($F_{1,28}$ = .125, P=.73). There was no significant segment main effect ($F_{3,84}$ = 5.84, P=0.16) as illustrated in Figure 26. There were no significant differences in the DP values between the men and the women as evidenced by the sex by segment interaction ($F_{3,84}$ = 2.58, P=0.06) and main effect for sex ($F_{1,28}$ = 1.35, P=.26). There was a significant segment main effect ($F_{3,84}$ = 9.62, P<0.01) with the results of the Tukey Post Hoc ($HSD_{4,84}$=1.70, P<.05) illustrated in Figure 27.

Limb Characteristics

Tables 6, 7, 8, 9, 10, 11 and 12 summarize the findings of the correlations between the limb characteristics and the MARP and DP within the transverse and frontal planes, during the lateral step down ascent and descent and the single leg squats ascent and descent.

Table 2: Spatial/Temporal characteristics for the lateral step downs. Only repetition time was statistically different between the sexes (*P*=.048).

Variable	*Men*	*Women*
Repetition Time (s)	0.98 ± 0.03	1.04 ± 0.11
Percent Cycle	49.7 ± 2.8	50.9 ± 1.9
Vertical TBCM displacement (m)	0.14 ± 0.02	0.14 ± 0.02

Table 3: Spatial/Temporal characteristics for the single leg squats downs. There were no statistically significant differences between sexes.

Variable	*Men*	*Women*
Repetition Time (s)	1.45 ± 0.18	1.39 ± 0.10
Percent Cycle	53.6 ± 4.2	52.0 ± 4.2
Vertical TBCM displacement (m)	0.15 ± 0.04	0.14 ± 0.4

Table 4: Lateral Step Down MARP and DP Significant Results. Table summarizes Figures 4-15

Plane	*DV*	*Ascent*	*Descent*
Sagittal	MARP	Foot-shank < Pelvis-trunk < shank-thigh Thigh- pelvis	Foot-shank Shank-thigh < Pelvis-trunk < Thigh-pelvis
	DP	Foot-shank, Thigh-pelvis < Shank-thigh Pelvis-trunk Foot-shank < Thigh-Pelvis	Foot-shank Thigh-pelvis < Shank-thigh Pelvis-trunk Foot-shank < Foot-shank
Frontal	MARP	None	None
	DP	Foot-shank Pelvis-trunk < Shank-thigh Thigh-pelvis	Thigh-pelvis Pelvis-trunk < < Foot-shank Shank-Thigh
Transverse	MARP	Pelvis-trunk < Foot-shank, Thigh-pelvis	Foot-shank, Pelvis-trunk < Thigh-pelvis
	DP	Shank-thigh, pelvis-trunk < Thigh-pelvis	Shank-thigh < Foot-shank < Thigh-pelvis Pelvis trunk

Table 5: Single Leg Squats MARP and DP Significant Results: Table summarizes figures 16-27

Plane	*DV*	*Ascent*	*Descent*
Sagittal	MARP	Foot-Shank, Pelvis-trunk < Shank-thigh Thigh-pelvis Thigh-pelvis< Pelvis-trunk	Foot-shank Shank-thigh < Pelvis-trunk < Thigh-pelvis
	DP	Foot-shank Pelvis-trunk < Shank-thigh Thigh-pelvis Pelvis-trunk < Foot-shank	Thigh-Pelvis < Foot-shank < Shank-thigh Pelvis-Trunk
Frontal	MARP	Foot-shank < Pelvis-trunk Thigh-pelvis	Shank-thigh Foot-shank < Pelvis-trunk Thigh-pelvis
	DP	Thigh-pelvis Foot-shank < Pelvis-Trunk Shank-thigh	Foot-shank Pelvis-trunk < < Shank-Thigh Thigh-pelvis
Transverse	MARP	Shank-thigh < Foot-shank Pelvis-trunk	Foot-shank Pelvis-trunk < Shank-thigh Thigh-pelvis
	DP	Foot-shank Pelvis-trunk < Shank-thigh Thigh-pelvis	Foot-shank Pelvis-trunk < Shank-thigh Thigh-pelvis

Table 6: Correlations between MARP and DP values and limb characteristics for the ascent of the lateral step down in the frontal plane. Asterisk indicates a significant correlation

Limb Characteristics	*MARP:* *Foot-shank*	*Shank-thigh*	*Thigh-pelvis*	*Pelvis-trunk*	*DP:* *Foot-shank*	*Shank-thigh*	*Thigh-pelvis*	*Pelvis-trunk*
Navicular Drop	r= .05 *P*=.79	r=-.05 *P*=.80	r=-.03 *P*=.88	r=.09 *P*=.66	r= -.27 *P*=.15	r=-.22 *P*=.24	r=-.11 *P*=.57	r=-.07 *P*=.72
Navicular Drift	r= -.01 *P*=.96	r=-.11 *P*=.58	r=.08 *P*=.67	r=0 *P*=.99	r= .21 *P*=.27	r= .33 *P*=.08	r= .34 *P*=.07	r= .08 *P*=.69
Rearfoot to lower leg	r= -.01 *P*=.95	r=.14 *P*=.47	r=-.09 *P*=.61	r=-.12 *P*=.55	r=-.23 *P*=.23	r= .26 *P*=.16	r= .23 *P*=.23	r= .26 *P*=.17
Rearfoot to forefoot	r= .17 *P*=.38	r=.15 *P*=.44	r=-.14 *P*=.45	r=.04 *P*=.82	r=-.18 *P*=.35	r= -.04 *P*=.86	r= .07 *P*=.73	r= .14 *P*=.47
Femoral anteversion	r= -.14 *P*=.45	r=.23 *P*=.21	r= .02 *P*=.94	r= .21 *P*=.26	r= .30 *P*=.11	r= .09 *P*=.63	r= -.10 *P*=.62	r= -.11 *P*=.57
Tibial Torsion	r= -.52* *P*=.004	r=-.09 *P*=.63	r=.34 *P*=.07	r=-.426 *P*=.02	r= .43 *P*=.02	r= .35 *P*=.06	r= .18 *P*=.34	r=-.08 *P*=.67

Table 7: Correlations between MARP and DP values and limb characteristics for the ascent of the lateral step down in the transverse plane. Asterisk indicates a significant correlation

Limb Characteristics	*MARP:*				*DP:*			
	Foot-shank	*Shank-thigh*	*Thigh-pelvis*	*Pelvis-trunk*	*Foot-shank*	*Shank-thigh*	*Thigh-pelvis*	*Pelvis-trunk*
Navicular Drop	r= -.02 *P*=.91	r=-.001 *P*=.99	r=-.09 *P*=.63	r=-.09 *P*=.633	r=-.27 *P*=.15	r=-.22 *P*=.24	r=-.11 *P*=.57	r=-.07 *P*=.72
Navicular Drift	r= -.15 *P*=.42	r=.04 *P*=.83	r=.32 *P*=.09	r=.32 *P*=.09	r=21. *P*=.27	r= 33. *P*=.08	r=.34 *P*=.07	r=.08 *P*=.69
Rearfoot to lower leg	r= -.16 *P*=.39	r=-.07 *P*=.72	r=.29 *P*=.11	r=.29 *P*=.11	r= .23 *P*=.23	r=.26 *P*=.16	r=.23 *P*=.23	r=.26 *P*=.17
Rearfoot to forefoot	r= -.21 *P*=.26	r= -.18 *P*=.34	r=-.09 *P*=.63	r=.09 *P*=.63	r=-.18 *P*=.35	r=-.04 *P*=.85	r=.07 *P*=.73	r=.14 *P*=.47
Femoral anteversion	r= .07 *P*=.73	r=.15 *P*=.42	r=.11 *P*=.58	r=.24 *P*=.19	r= .29 *P*=.11	r= .09 *P*=.63	r=-.09 *P*=.62	r=-.11 *P*=.57
Tibial Torsion	r= .53* *P*=.002	r=.26 *P*=.17	r=-.19 *P*=.29	r=-.31 *P*=.09	r= .43 *P*=.02	r=.35 *P*=.06	r=.18 *P*=.34	r=-.08 *P*=.25

Table 8: Correlations between MARP and DP values and limb characteristics for the descent of the lateral step down in the frontal plane. Asterisk indicates a significant correlation

Limb Characteristics	*MARP:*				*DP:*			
	Foot-shank	*Shank-thigh*	*Thigh-pelvis*	*Pelvis-trunk*	*Foot-shank*	*Shank-thigh*	*Thigh-pelvis*	*Pelvis-trunk*
Navicular Drop	r=.27 *P*=.15	r=.07 *P*=.72	r=.01 *P*=.97	r=-.12 *P*=.55	r= -.23 *P*=.22	r=-.21 *P*=.27	r=-.19 *P*=.30	r=-.15 *P*=.42
Navicular Drift	r=.27 *P*=.16	r=.12 *P*=.52	r=-.09 *P*=.62	r=-.02 *P*=.90	r= .17 *P*=.37	r=.11 *P*=.55	r=.11 *P*=.55	r=.05 *P*=.78
Rearfoot to lower leg	r= .10 *P*=.59	r=-.14 *P*=.46	r=.09 *P*=.65	r=.14 *P*=.46	r= .31 *P*=.09	r=.12 *P*=.53	r=.13 *P*=.49	r=.37 *P*=.05
Rearfoot to forefoot	r= -.03 *P*=.86	r=-.13 *P*=.48	r=.09 *P*=.65	r=-.06 *P*=.76	r= -.03 *P*=.88	r=.01 *P*=.96	r=.13 *P*=.50	r=.24 *P*=.19
Femoral anteversion	r= .07 *P*=.70	r=-.22 *P*=.25	r=-.01 *P*=.96	r=.27 *P*=.14	r= .24 *P*=.20	r= .05 *P*=.81	r=-.07 *P*=.71	r=-.12 *P*=.58
Tibial Torsion	r= .59* *P*=.001	r=.11 *P*=.55	r=-.33 *P*=.07	r=.49* *P*=.006	r= .35 *P*=.06	r=.32 *P*=.09	r=.13 *P*=.51	r=.04 *P*=.82

Table 9: Correlations between MARP and DP values and limb characteristics for the descent of the lateral step down in the transverse plane. Asterisk indicates a significant correlation

Limb Characteristics	*MARP:*				*DP:*			
	Foot-shank	*Shank-thigh*	*Thigh-pelvis*	*Pelvis-trunk*	*Foot-shank*	*Shank-thigh*	*Thigh-pelvis*	*Pelvis-trunk*
Navicular Drop	r= -.07 *P*=.69	r=.09 *P*=.64	r=.14 *P*=.46	r=-.26 *P*=.17	r= -.20 *P*=.28	r=-.15 *P*=.44	r=.02 *P*=.93	r=.05 *P*=.79
Navicular Drift	r= .08 *P*=.70	r=.08 *P*=.70	r=-.31 *P*=.10	r=.15 *P*=.43	r=.30 *P*=.11	r=.07 *P*=.72	r=-.06 *P*=.74	r=-.16 *P*=.39
Rearfoot to lower leg	r= .12 *P*=.55	r=.06 *P*=.74	r=-.29 *P*=.12	r=.28 *P*=.14	r= .14 *P*=.48	r=.15 *P*=.44	r=-.04 *P*=.82	r=-.09 *P*=.65
Rearfoot to forefoot	r= .18 *P*=.36	r=.17 *P*=.37	r=.10 *P*=.62	r=-.19 *P*=.31	r= -.05 *P*=.81	r=.20 *P*=.29	r=.26 *P*=.17	r=.29 *P*=.13
Femoral anteversion	r= -.05 *P*=.77	r=-.2 *P*=.29	r=-.11 *P*=.56	r=.25 *P*=.19	r= .07 *P*=.74	r=-.11 *P*=.57	r=-.32 *P*=.09	r= -.23 *P*=.23
Tibial Torsion	r= .59* *P*=.001	r=-.29 *P*=.12	r=.23 *P*=.22	r=.29 *P*=.12	r= .37 *P*=.05	r=-.19 *P*=.31	r=-.25 *P*=.18	r=-.23 *P*=.21

Table 10: Correlations between MARP and DP values and limb characteristics for the ascent of the single leg squat in the frontal plane. Asterisk indicates a significant correlation

Limb Characteristics	*MARP:*				*DP:*			
	Foot-shank	*Shank-thigh*	*Thigh-pelvis*	*Pelvis-trunk*	*Foot-shank*	*Shank-thigh*	*Thigh-pelvis*	*Pelvis-trunk*
Navicular Drop	r= .34 *P*=.07	r=-.26 *P*=.18	r=.15 *P*=.39	r=-.29 *P*=.11	r= .25 *P*=.19	r=-.12 *P*=.53	r=.22 *P*=.24	r=-.08 *P*=.68
Navicular Drift	r= .12 *P*=.51	r=-.18 *P*=.35	r=.11 *P*=.58	r=-.07 *P*=.72	r= .03 *P*=.89	r=-.06 *P*=.74	r=-.12 *P*=.52	r=-.006 *P*=.98
Rearfoot to lower leg	r=-.09 *P*=.63	r=-.39* *P*=.03	r=-.07 *P*=.73	r=.15 *P*=.42	r=-.07 *P*=.70	r=.08 *P*=.67	r=-.09 *P*=.65	r=.26 *P*=.16
Rearfoot to forefoot	r=-.12 *P*=.53	r=.02 *P*=.91	r=-.11 *P*=.58	r=-.07 *P*=.70	r= -.19 *P*=.31	r=-.11 *P*=.58	r=-.003 *P*=.99	r=-.11 *P*=.56
Femoral anteversion	r= -.41* *P*=.03	r=.41* *P*=.03	r=-.20 *P*=.28	r=.17 *P*=.37	r= -.15 *P*=.43	r=.04 *P*=.85	r=.10 *P*=.59	r=.27 *P*=.14
Tibial Torsion	r= -.03 *P*=.87	r=.18 *P*=.35	r=-.42* *P*=.02	r=.42 * *P*=.02	r= -.21 *P*=.25	r=.12 *P*=.52	r=-.04 *P*=.85	r=.14 *P*=.47

Table 11: Correlations between MARP and DP values and limb characteristics for the ascent of the single leg squat in the transverse plane. Asterisk indicates a significant correlation

Limb Characteristics	*MARP:*				*DP:*			
	Foot-shank	*Shank-thigh*	*Thigh-pelvis*	*Pelvis-trunk*	*Foot-shank*	*Shank-thigh*	*Thigh-pelvis*	*Pelvis-trunk*
Navicular Drop	r= .003 *P*=.99	r=.07 *P*=.70	r=-11 *P*=.57	r=.36* *P*=.05	r= .17 *P*=.38	r=.004 *P*=.99	r=.14 *P*=.47	r=.08 *P*=.67
Navicular Drift	r= .06 *P*=.76	r=.19 *P*=.32	r=-.14 *P*=.46	r=.32 *P*=.09	r=.08 *P*=.67	r=-.03 *P*=.86	r= .14 *P*=.45	r=.03 *P*=.87
Rearfoot to lower leg	r= .07 *P*=.70	r=.48* *P*=.008	r=-.12 *P*=.54	r=-.19 *P*=.31	r=-.12 *P*=.53	r=.11 *P*=.56	r=.19 *P*=.33	r=.13 *P*=.51
Rearfoot to forefoot	r=.11 *P*=.58	r=.11 *P*=.57	r=-.17 *P*=.38	r=.05 *P*=.81	r=-.23 *P*=.22	r=-.01 *P*=.98	r=-.11 *P*=.57	r=-.14 *P*=.46
Femoral anteversion	r= -.11 *P*=.56	r=.17 *P*=.38	r=-.03 *P*=.87	r=-.32 *P*=.09	r=-.15 *P*=.44	r=-.03 *P*=.44	r=-.03 *P*=.87	r=.19 *P*=.31
Tibial Torsion	r= -.39* *P*=.03	r=.11 *P*=.58	r=.15 *P*=.42	r=-.13 *P*=.47	r= -.16 *P*=.41	r=.19 *P*=.32	r=-.11 *P*=.58	r=-.03 *P*=.87

Table 12: Correlations between MARP and DP values and limb characteristics for the descent of the single leg squat in the frontal plane. Asterisk indicates a significant correlation

Limb Characteristics	*MARP:*				*DP:*			
	Foot-shank	*Shank-thigh*	*Thigh-pelvis*	*Pelvis-trunk*	*Foot-shank*	*Shank-thigh*	*Thigh-pelvis*	*Pelvis-trunk*
Navicular Drop	r= -.08 *P*=.67	r=.17 *P*=.38	r=-.11 *P*=.56	r=.28 *P*=.14	r= .25 *P*=.18	r=.03 *P*=.89	r=.15 *P*=.42	r=.10 *P*=.60
Navicular Drift	r= .001 *P*=.99	r=.19 *P*=.33	r=-.16 *P*=.42	r=.16 *P*=.42	r= .14 *P*=.46	r=.08 *P*=.68	r=.06 *P*=.77	r=.05 *P*=.78
Rearfoot to lower leg	r= -.001 *P*=.99	r=.18 *P*=.35	r=.12 *P*=.54	r=-.07 *P*=.70	r=-.12 *P*=.52	r=-.03 *P*=.86	r=-.01 *P*=.98	r=.19 *P*=.30
Rearfoot to forefoot	r= -.09 *P*=.64	r=.02 *P*=.91	r=.14 *P*=.46	r=.03 *P*=.88	r= -.23 *P*=.23	r=-.35 *P*=.06	r=-.32 *P*=.09	r=-.23 *P*=.23
Femoral anteversion	r= .402* *P*=.03	r=-.31 *P*=.09	r=.24 *P*=.20	r=-.13 *P*=.48	r=-.15 *P*=.44	r=-.03 *P*=.86	r=.14 *P*=.47	r=.25 *P*=.18
Tibial Torsion	r= .14 *P*=.48	r=-.24 *P*=.19	r=.412* *P*=.02	r=-.42* *P*=.02	r= -.27 *P*=.15	r=.05 *P*=.82	r=-.001 *P*=.99	r=.25 *P*=.18

Table 13: Correlations between MARP and DP values and limb characteristics for the descent of the single leg squat in the transverse plane. Asterisk indicates a significant correlation

Limb Characteristics	*MARP:*				*DP:*			
	Foot-shank	*Shank-thigh*	*Thigh-pelvis*	*Pelvis-trunk*	*Foot-shank*	*Shank-thigh*	*Thigh-pelvis*	*Pelvis-trunk*
Navicular Drop	r= -.07 *P*=.72	r=.002 *P*=.99	r=.13 *P*=.51	r=-.43* *P*=.02	r= .18 *P*=.34	r=-.02 *P*=.92	r=.22 *P*=.24	r=.15 *P*=.42
Navicular Drift	r= -.09 *P*=.63	r=-.14 *P*=.46	r=.15 *P*=.45	r=-.33 *P*=.08	r= .13 *P*=.50	r=-.03 *P*=.87	r=.10 *P*=.62	r=.08 *P*=.67
Rearfoot to lower leg	r=-.11 *P*=.55	r=-.41* *P*=.03	r=.09 *P*=.65	r=-.03 *P*=.87	r= -.13 *P*=.49	r=.33 *P*=.07	r=.04 *P*=.85	r=.16 *P*=.41
Rearfoot to forefoot	r=.06 *P*=.77	r=-.15 *P*=.44	r=.14 *P*=.47	r=-.13 *P*=.49	r= -.24 *P*=.20	r=-.06 *P*=.77	r=-.19 *P*=.31	r=-.25 *P*=.18
Femoral anteversion	r= .06 *P*=.77	r=-.23 *P*=.22	r=.03 *P*=.86	r=.23 *P*=.21	r= -.04 *P*=.84	r=.25 *P*=.18	r=.04 *P*=.83	r=.21 *P*=.26
Tibial Torsion	r= .21 *P*=.26	r=-.06 *P*=.77	r= -.20 *P*=.28	r=.08 *P*=.67	r= .17 *P*=.35	r=.7 *P*=.60	r=-.13 *P*=.49	r=.04 *P*=.86

Figure 4: Sagittal plane MARP values for the ascent of the lateral step down. Asterisk indicates that shank-thigh MARP value is significantly greater than the thigh-pelvis MARP, the thigh-pelvis MARP, and the foot-shank MARP values. The dagger indicates that the pelvis-trunk MARP value is significantly greater than the foot-shank MARP and the thigh-pelvis MARP values.

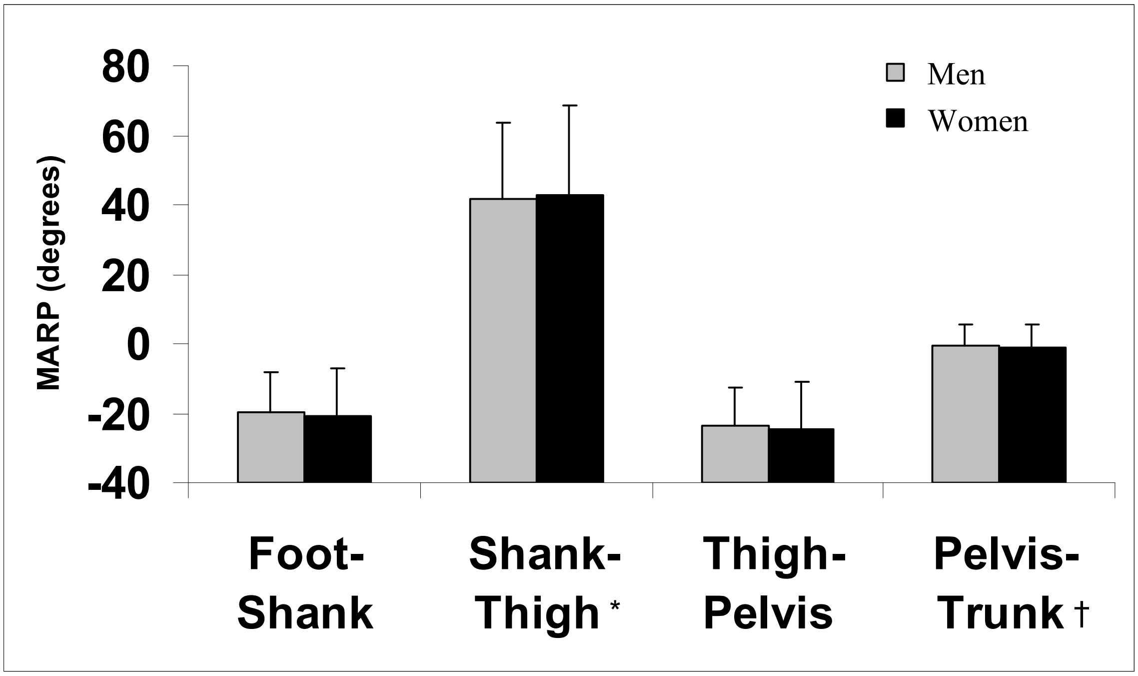


Figure 5: Sagittal plane DP values for the ascent of the lateral step down. Asterisk indicates that shank-thigh DP value is significantly greater than the thigh-pelvis DP, the thigh-pelvis DP, and the foot-shank DP values. Dagger indicates that the thigh-pelvis DP values is significantly great than the foot-shank DP value.

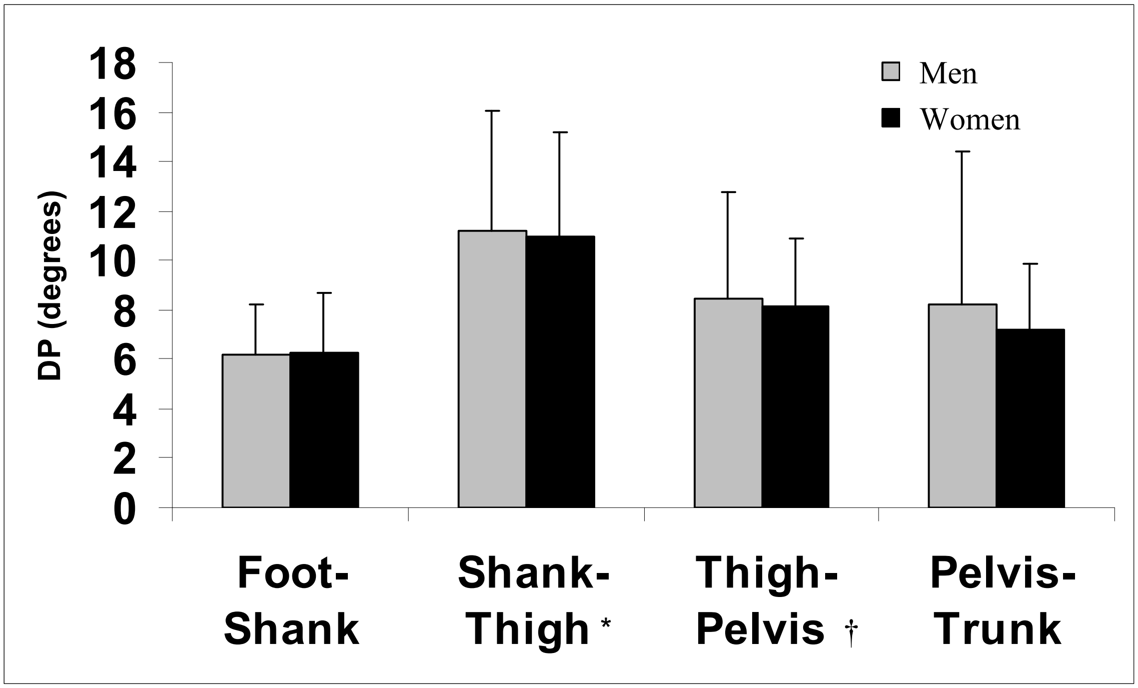


Figure 6: Frontal plane MARP values for the ascent of the lateral step down. There were no significant segment main effects.

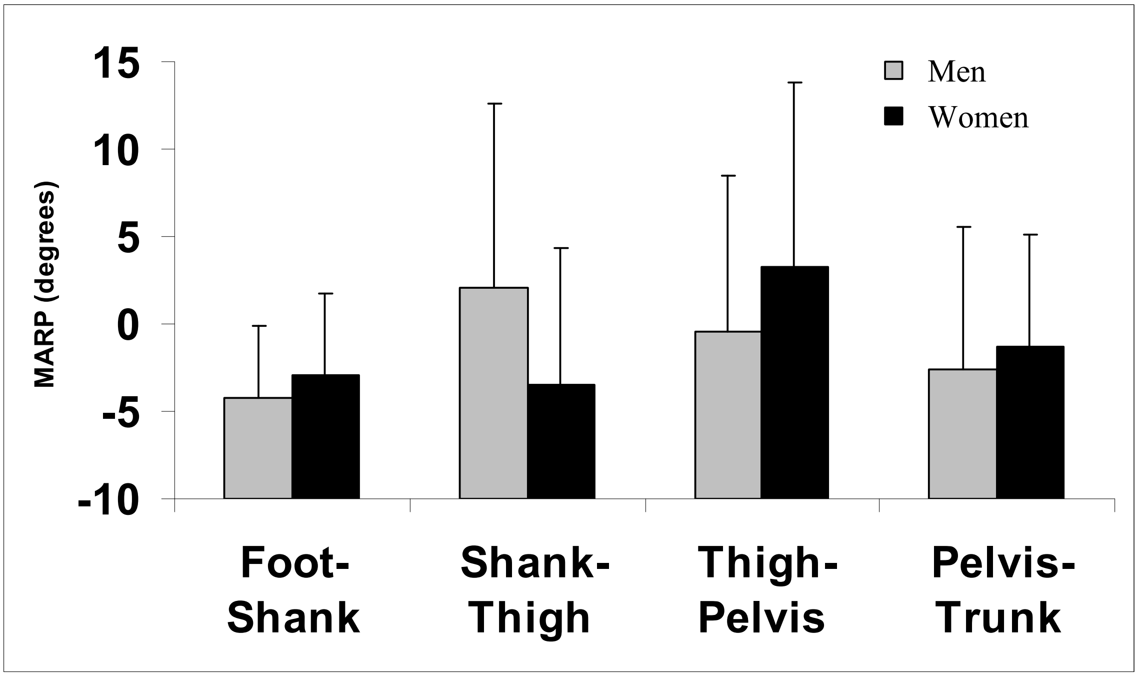


Figure 7: Frontal plane DP values for the ascent of the lateral step down. Asterisk indicates that pelvis-trunk MARP value was significantly less than the foot-shank MARP, shank-thigh MARP, and the thigh-pelvis MARP values.

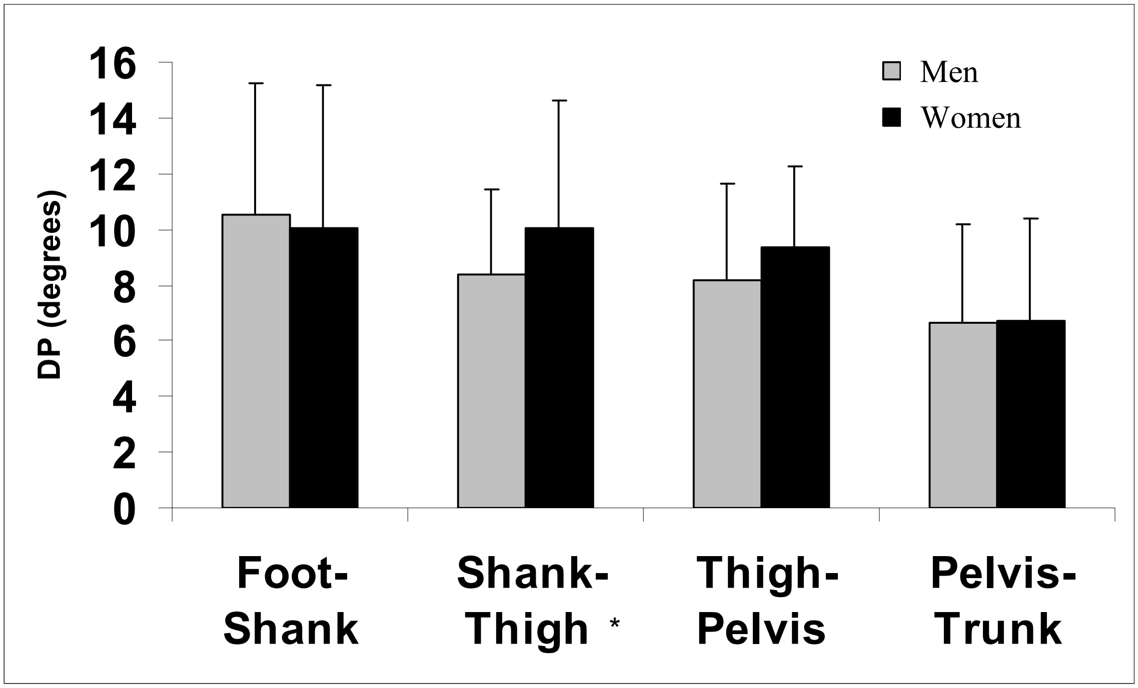


Figure 8: Transverse plane MARP values for the ascent of the lateral step down. Asterisk indicates that the thigh-pelvis MARP value is significantly less than the foot-shank MARP and the pelvis-trunk MARP values.

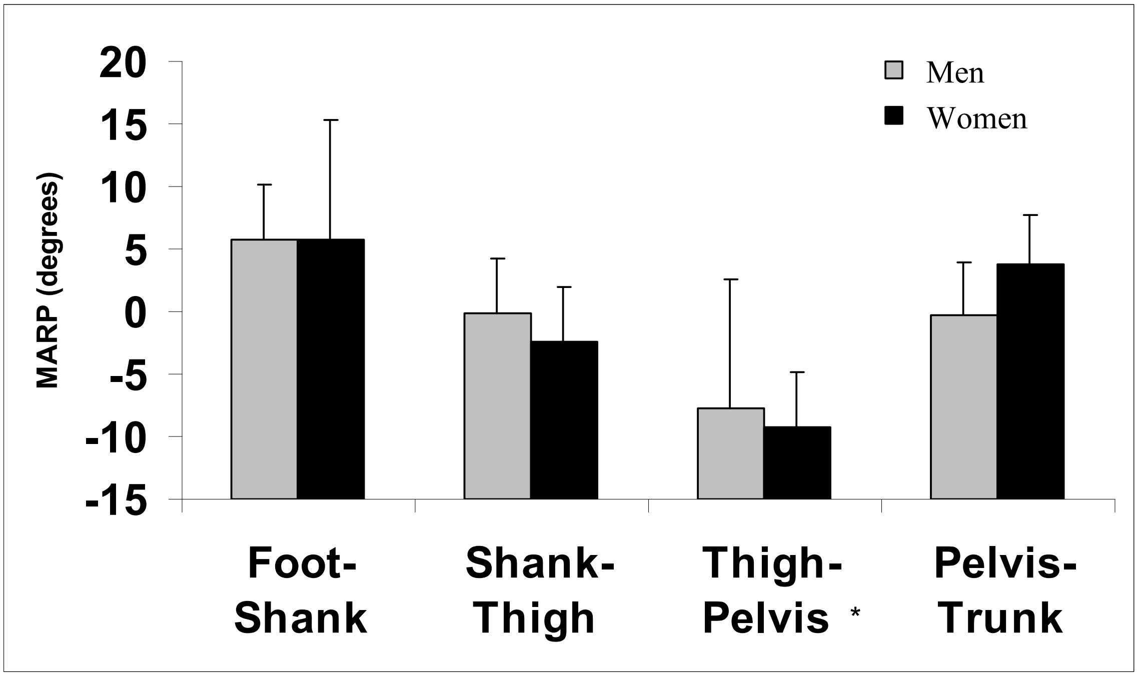


Figure 9: Transverse plane DP values for the ascent of the lateral step down. Asterisk indicates that the thigh-pelvis MARP is significantly greater than the shank-thigh MARP and the pelvis-trunk MARP values.

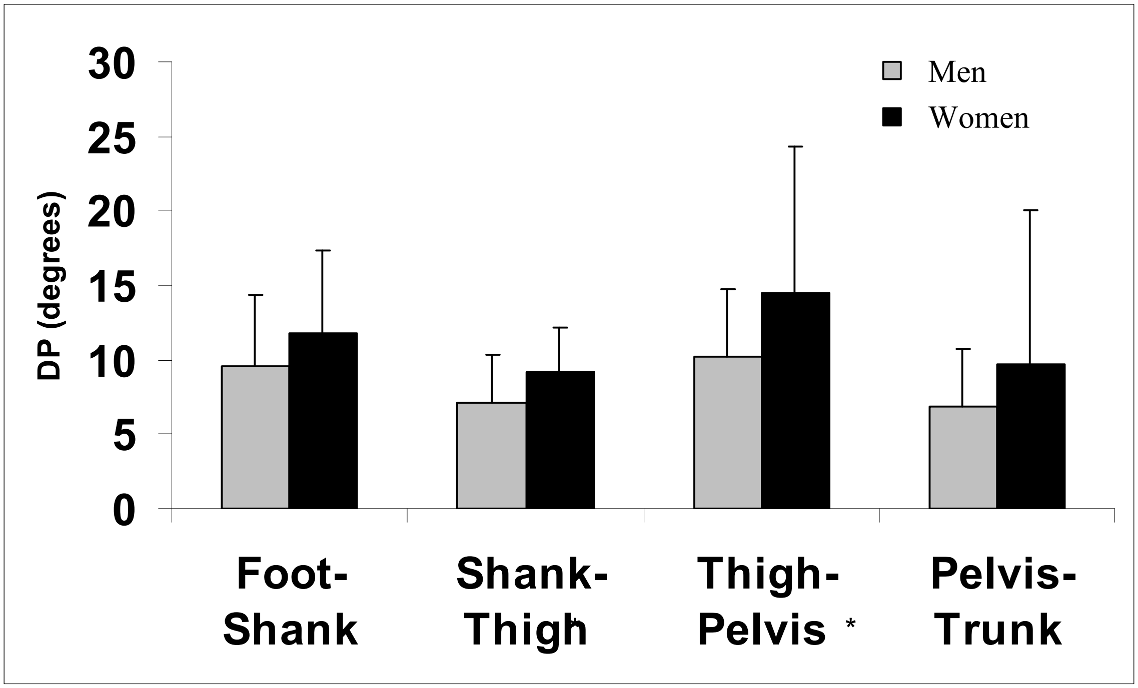


Figure 10: Sagittal plane MARP values for the descent of the lateral step down. Asterisk indicates that the foot-shank MARP and the thigh-pelvis MARP values are both significantly greater than the pelvis-trunk MARP values and shank-thigh MARP. Dagger indicates that the pelvis-trunk MARP value is significantly greater than the shank-thigh MARP value.

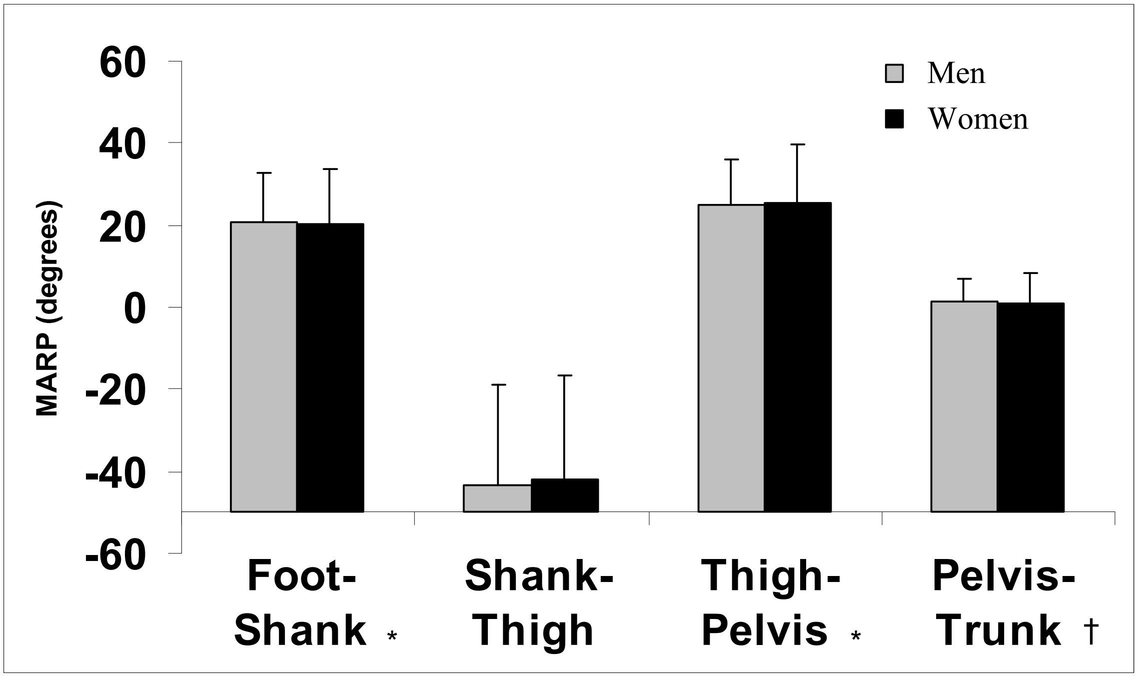


Figure 11: Sagittal plane DP values for the descent of the lateral step down. Asterisk indicates the shank-thigh MARP value is significantly greater than the MARP values of the foot-shank and pelvis-trunk. Dagger indicates that the thigh-pelvis is significantly greater than the foot-shank MARP value.

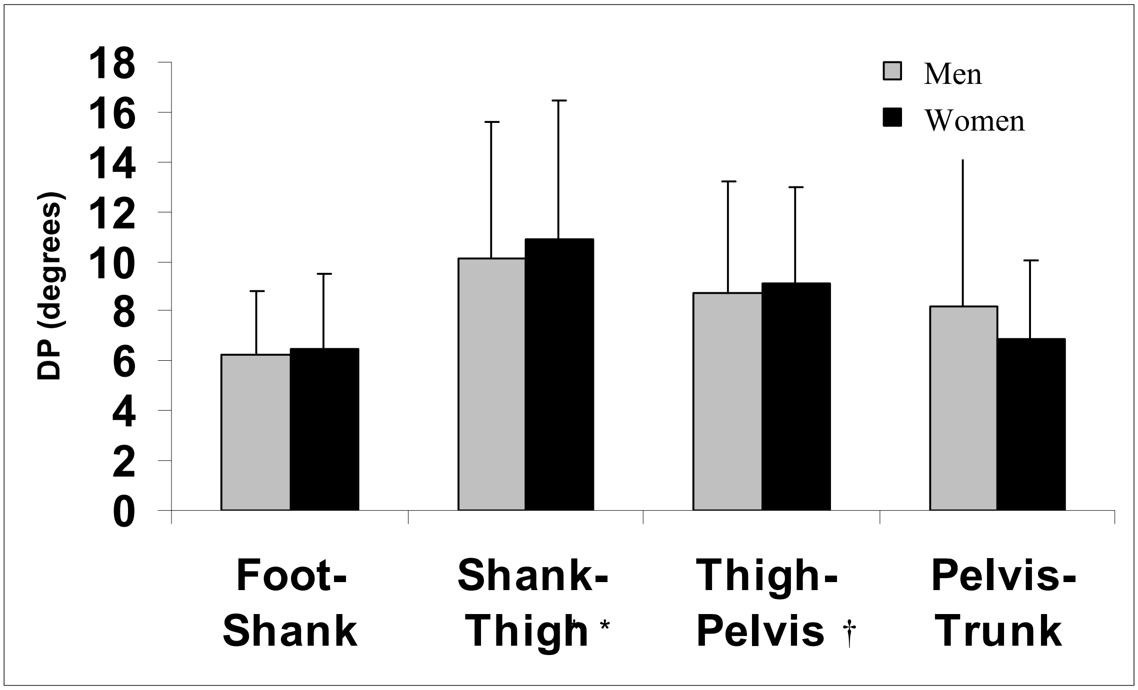


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Figure 12: Frontal plane MARP values for the descent of the lateral step down. There were no significant segment main effects.

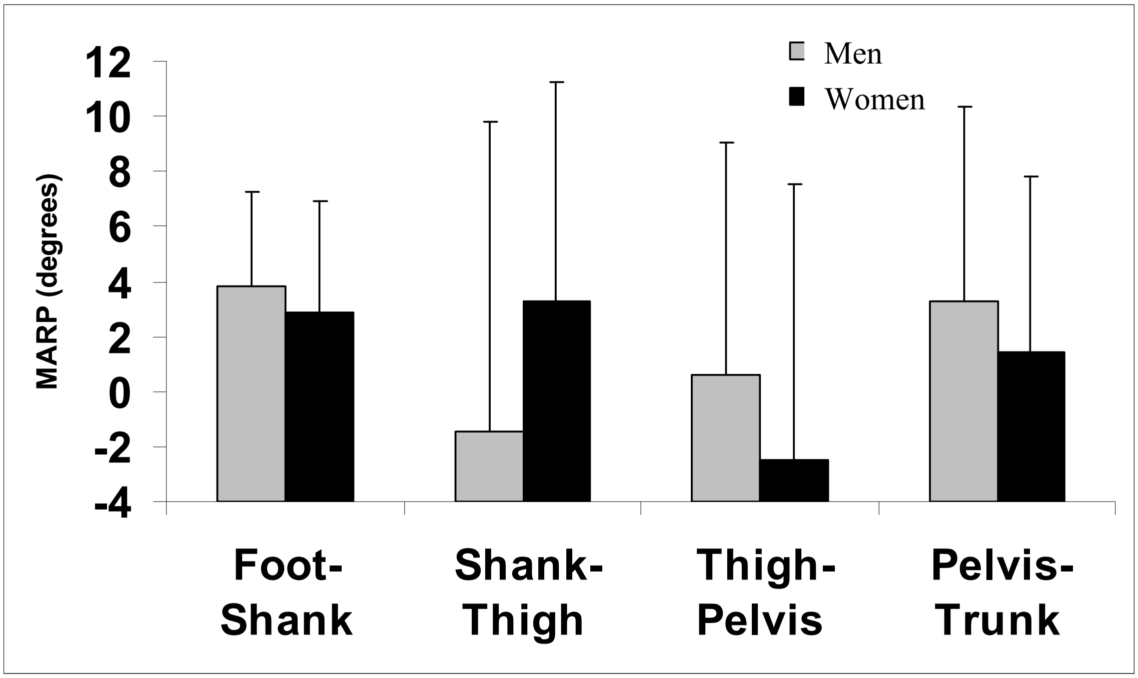


Figure 13: Frontal plane DP values for the descent of the lateral step down. Asterisk indicates that the foot-shank DP value is significantly greater than the pelvis-trunk DP, thigh-pelvis DP, and shank-thigh DP values. Dagger indicates that the thigh-pelvis DP value is significantly greater then the pelvis-trunk DP values. Double-dagger indicates that the shank-thigh DP is significantly greater than the pelvis-trunk DP value.

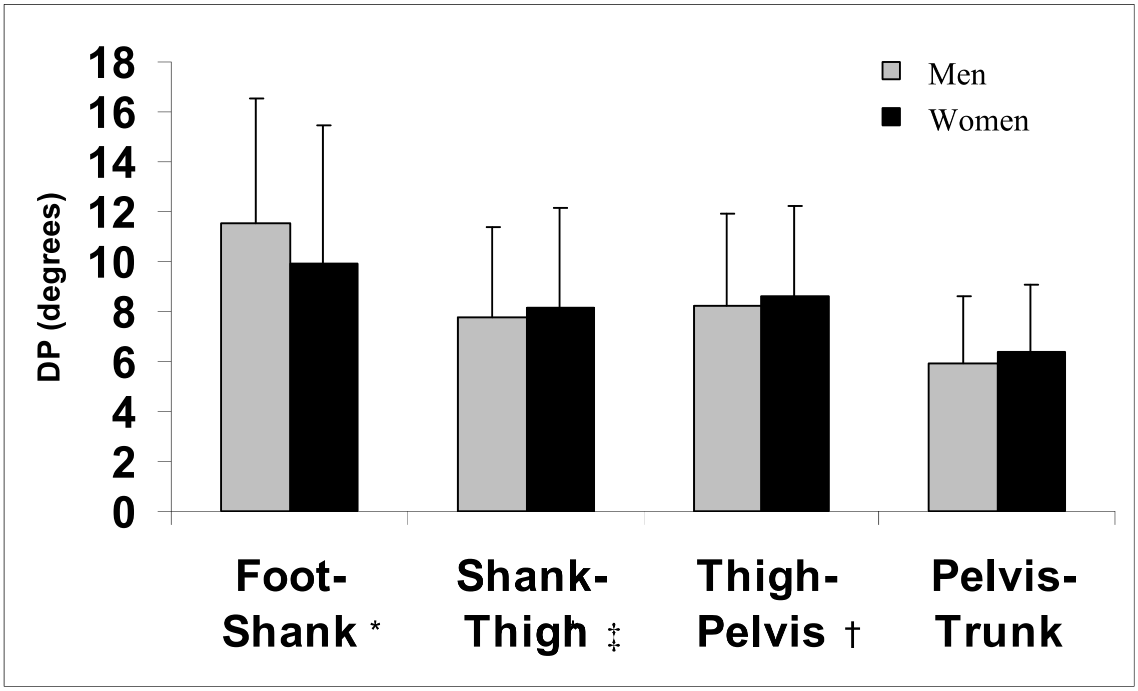


Figure 14: Transverse plane MARP values for the descent of the lateral step down. Asterisk indicates thigh-pelvis is greater than the foot-shank MARP and pelvis-trunk MARP values.

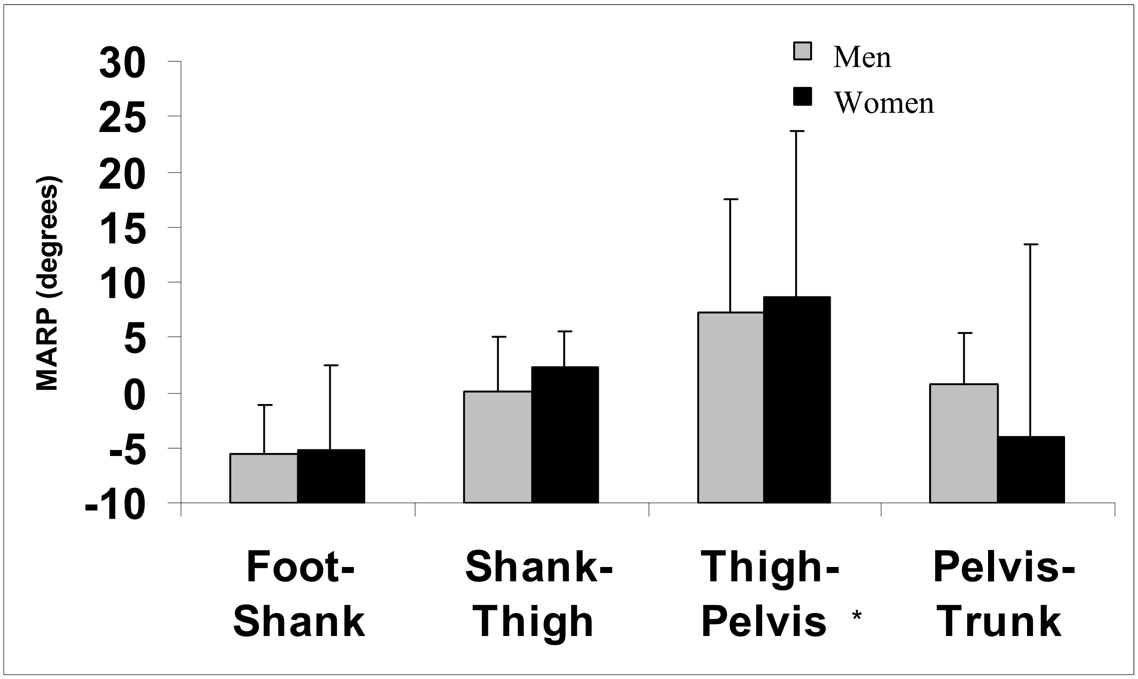


Figure 15: Transverse plane DP values for the descent of the lateral step down. Asterisk indicates that the thigh-pelvis DP value is significantly greater than the shank-thigh DP and pelvis-trunk DP values. Dagger indicates that the foot-shank DP value is significantly greater than the pelvis-trunk DP and shank-thigh DP values.

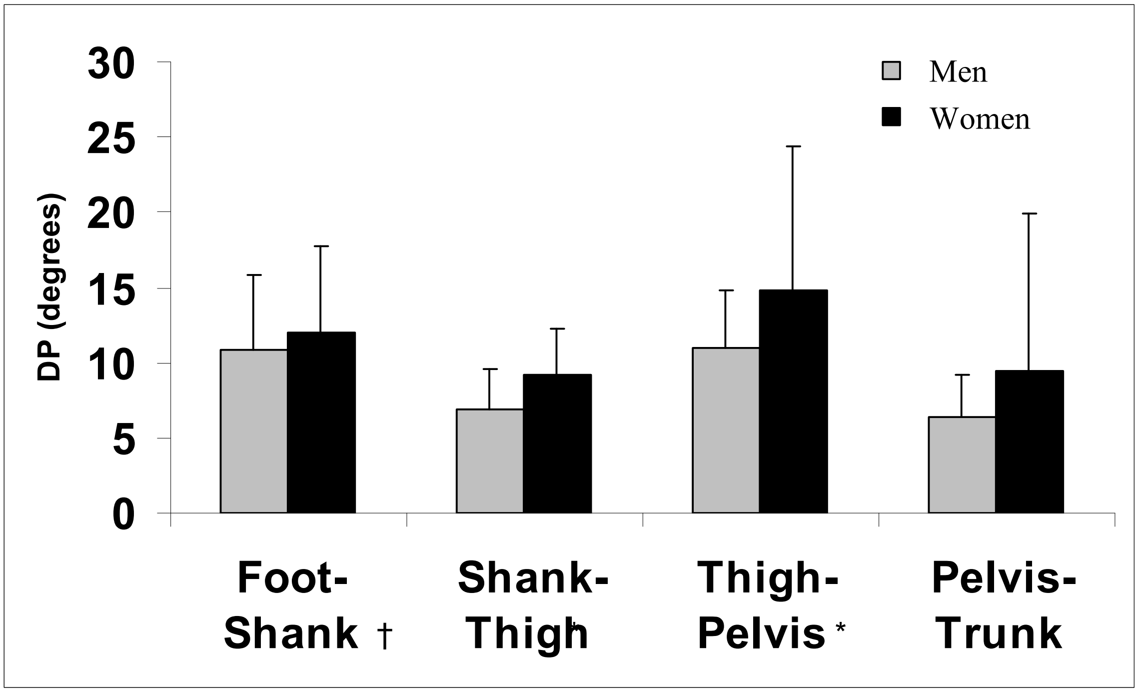


Figure 16: Sagittal plane MARP values for the ascent of the single leg squat. Asterisk indicates that the shank-thigh MARP value is significantly greater than the pelvis-trunk MARP, thigh-pelvis MARP, and the foot-shank MARP. Dagger indicates that the pelvis-trunk MARP is significantly greater than the thigh-pelvis MARP.

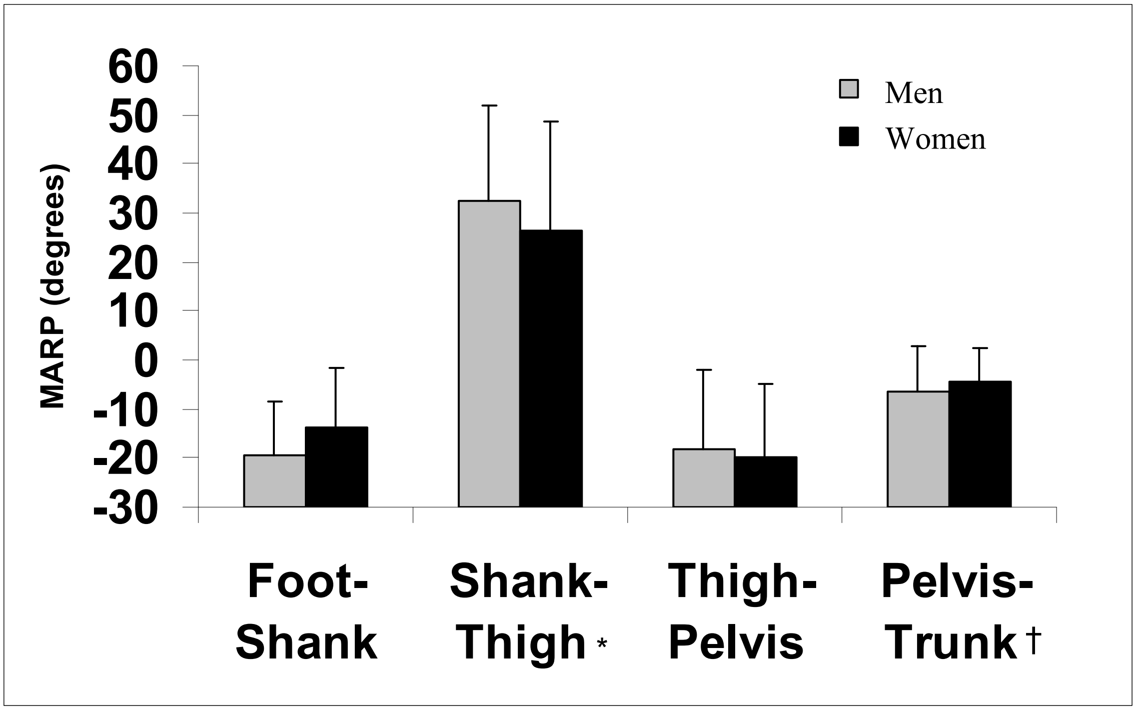


Figure 17: Sagittal plane DP values for the ascent of the single leg squat. Asterisk indicates that the shank-thigh DP value is significantly greater than the thigh-pelvis DP, the foot-shank DP, or the pelvis-trunk DP values. Dagger indicates that the foot-shank DP is significantly greater than the pelvis-trunk DP.

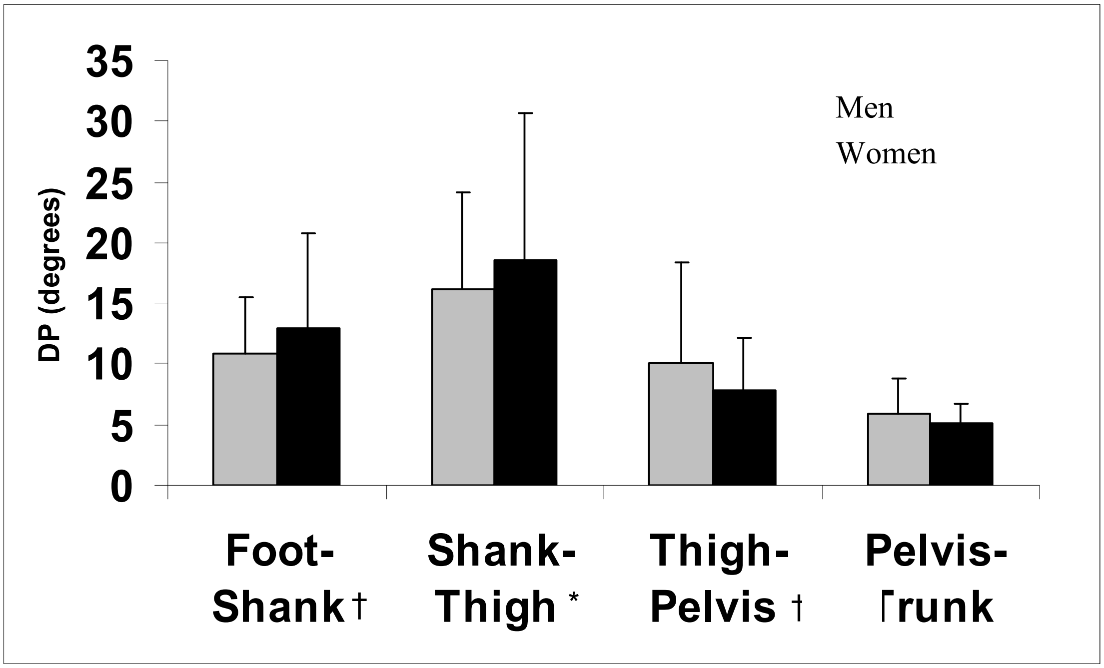


Figure 18: Frontal plane MARP values for the ascent of the single leg squat. Asterisk indicates that the pelvis-trunk MARP is significantly greater than the foot-shank MARP and the thigh-pelvis MARP values.

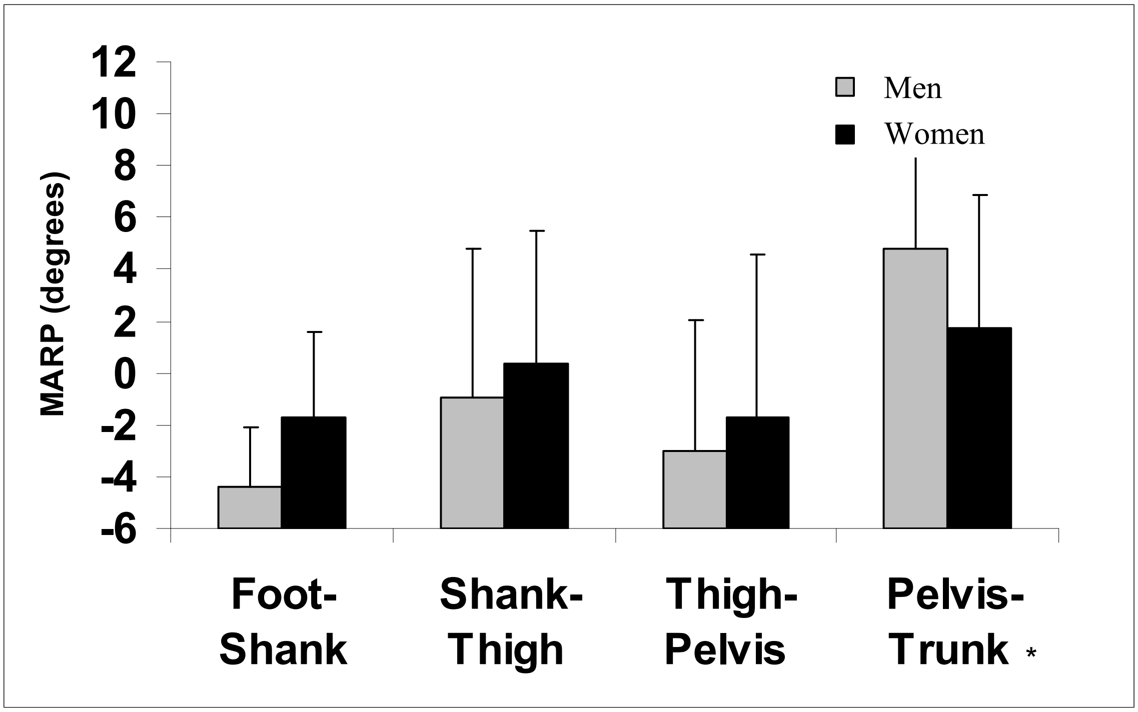


Figure 19: Frontal Plane DP values for the ascent of the single leg squat. Asterisk indicates that the foot-shank DP and the shank-thigh DP are both significantly greater than the pelvis-trunk DP and the thigh-pelvis DP values. The shank-thigh DP values is also significantly greater than the thigh-pelvis DP value.

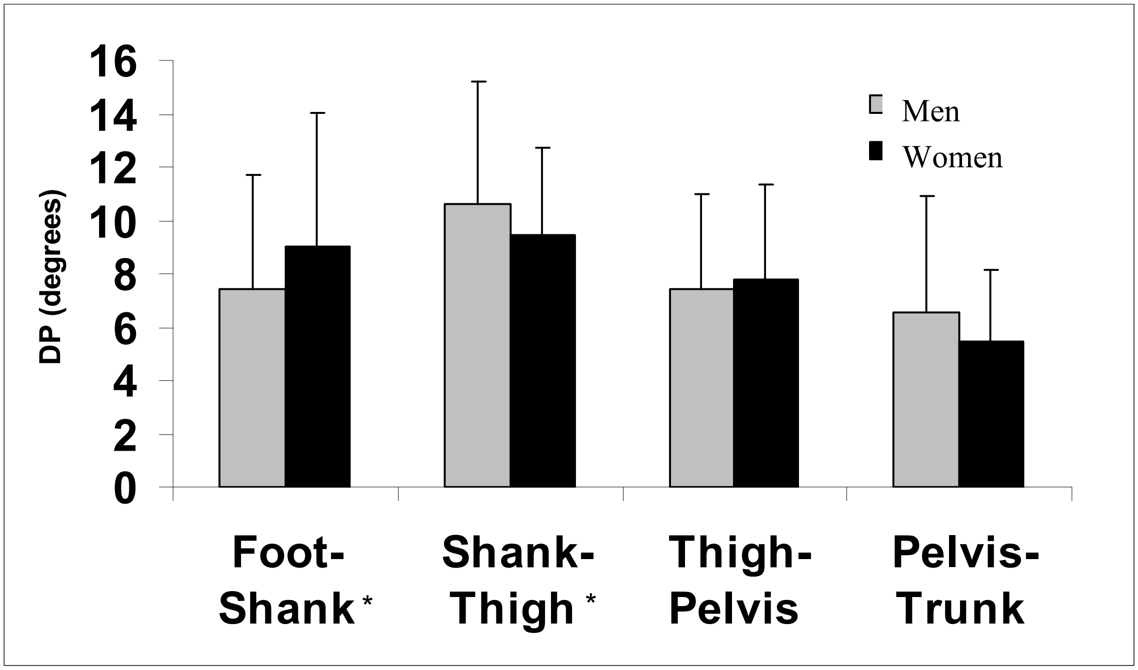


Figure 20: Transverse plane MARP values for the ascent of the single leg squat. Asterick indicates that the foot-shank MARP value is significantly greater than the pelvis-trunk MARP and the shank-thigh MARP values.

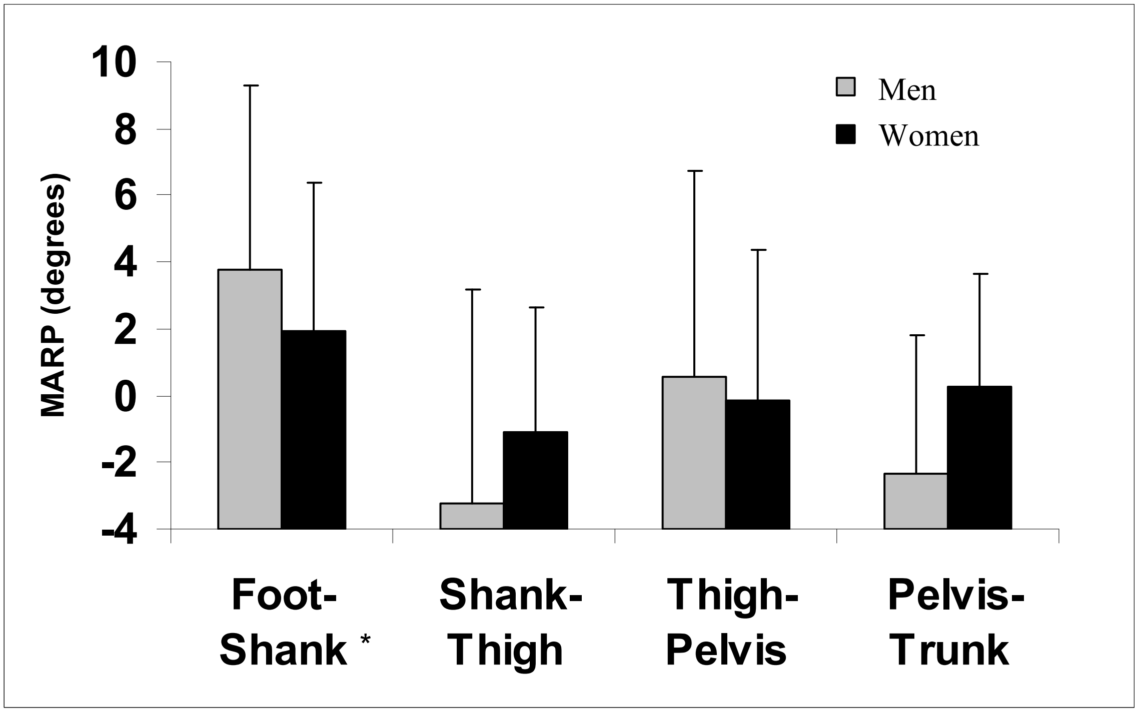


Figure 21: Transverse plane DP values for the ascent of the single leg squat. Asterisk indicates that the pelvis-trunk DP value is significantly less than the DP values for the foot-shank, shank-thigh or thigh-pelvis.

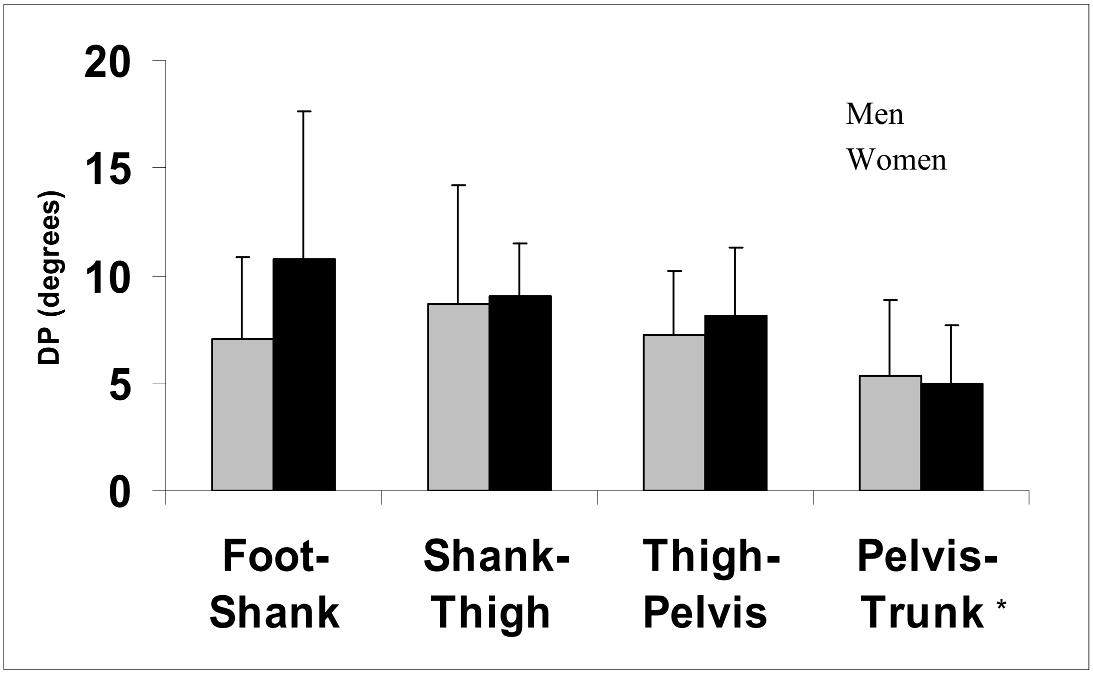


Figure 22: Sagittal plane MARP values for the descent of the singe leg squat. Asterisk indicates that the shank-thigh MARP value is significantly less than the foot-shank MARP, the thigh-pelvis MARP and the pelvis-trunk MARP values. Dagger indicates that the pelvis-trunk MARP value is significantly less than both the foot-shank MARP and the thigh-pelvis MARP values

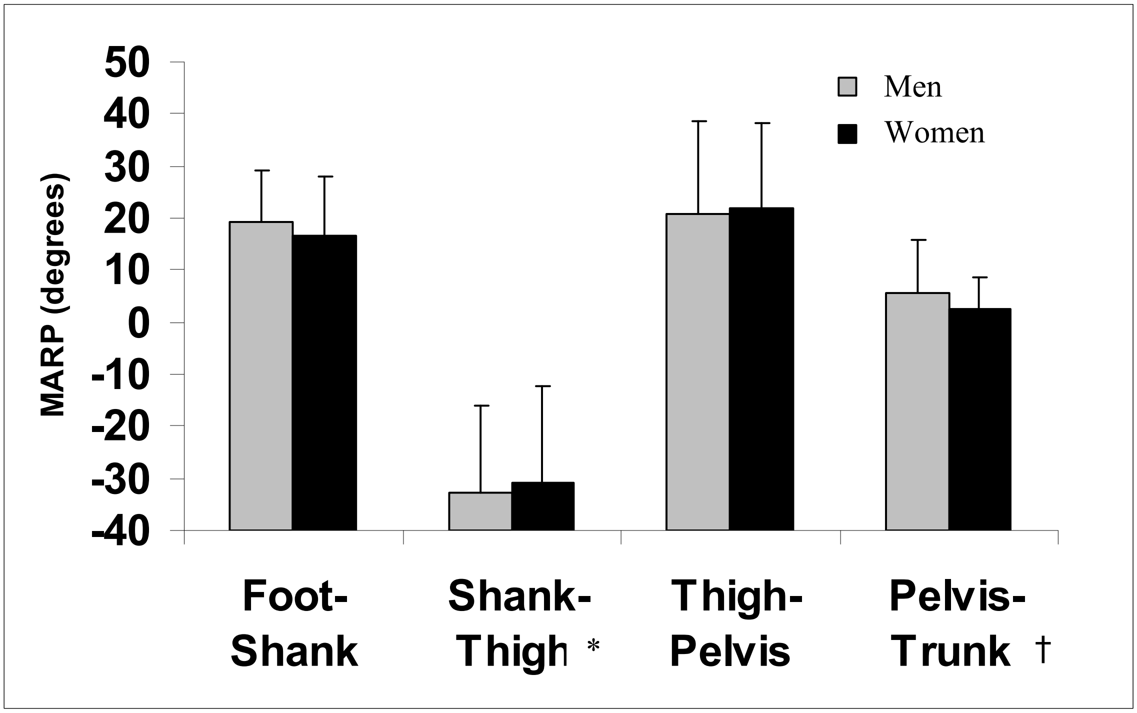


Figure 23: Sagittal plane DP values for the descent of the single leg squat. Asterisk indicates that the shank-thigh DP value is significantly greater than the foot-shank DP, pelvis-trunk DP, and thigh-pelvis DP values. Dagger indicates that the foot-shank DP is significantly greater than the thigh-pelvis DP and the pelvis-trunk DP values.

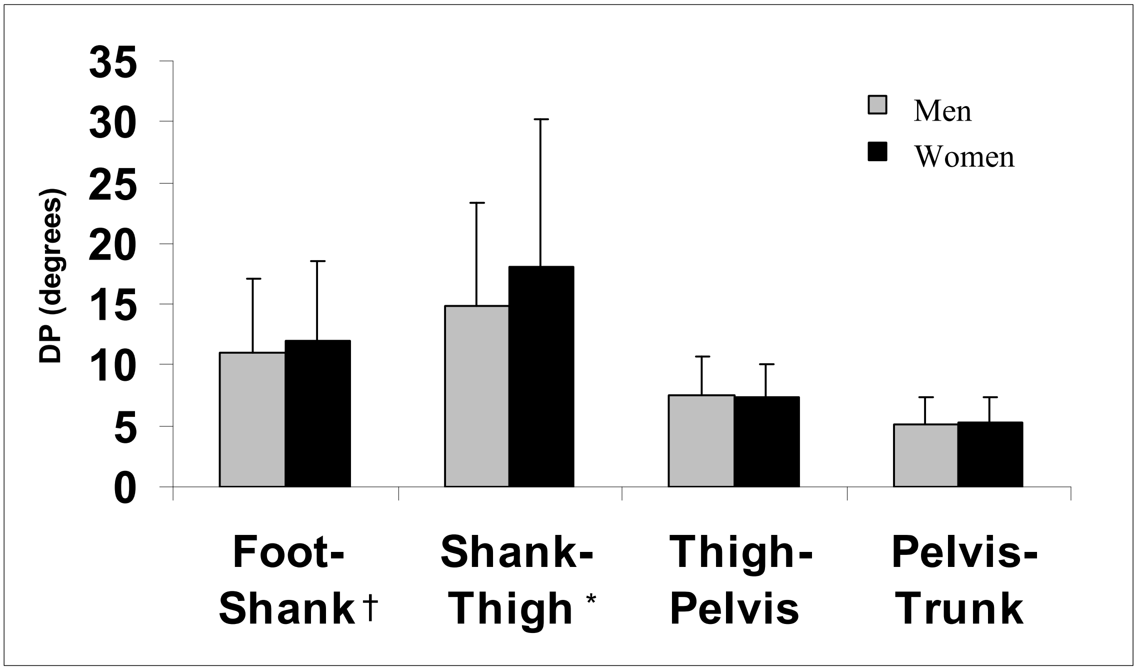


Figure 24: Frontal plane MARP values for the descent of the single leg squat. Asterisk indicates that the foot-shank MARP and the thigh-pelvis MARP values are both significantly greater than the pelvis-trunk MARP or the shank-thigh MARP.

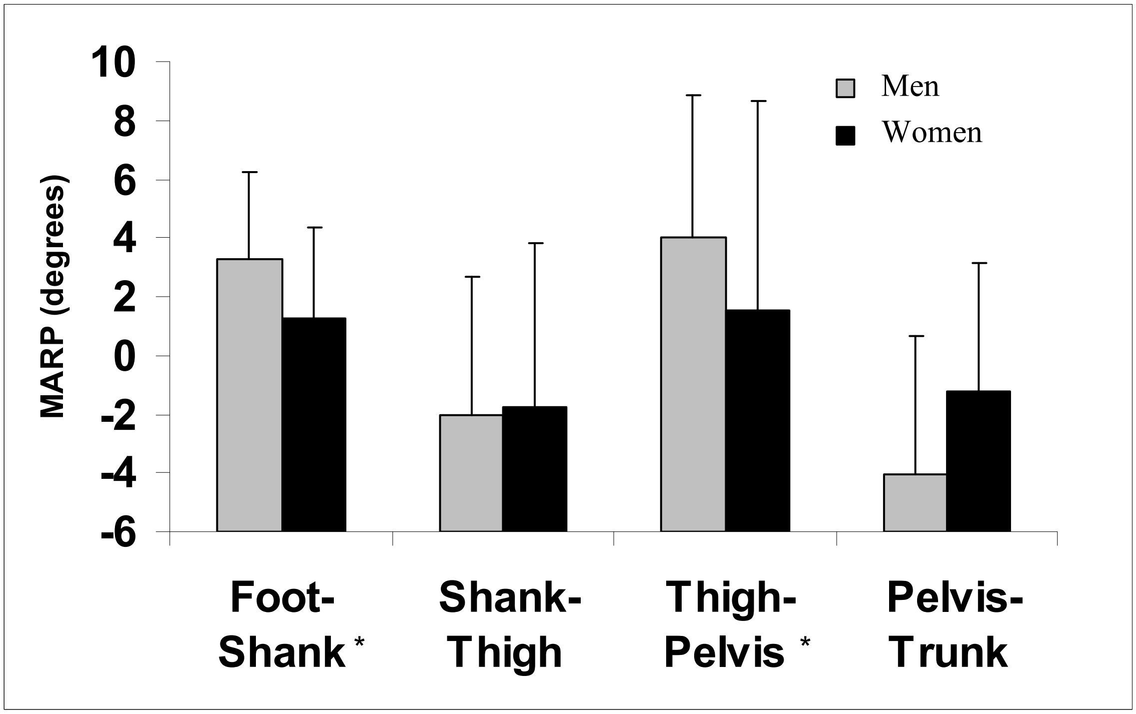


Figure 25: Frontal plane DP values for the descent of the single leg squat. Asterisk indicates that the shank-thigh is significantly greater than the thigh-pelvis DP, the foot-shank DP and the pelvis-trunk DP values. Dagger indicates that the foot-shank DP and thigh-pelvis DP values are both significantly greater than the pelvis-trunk DP value.

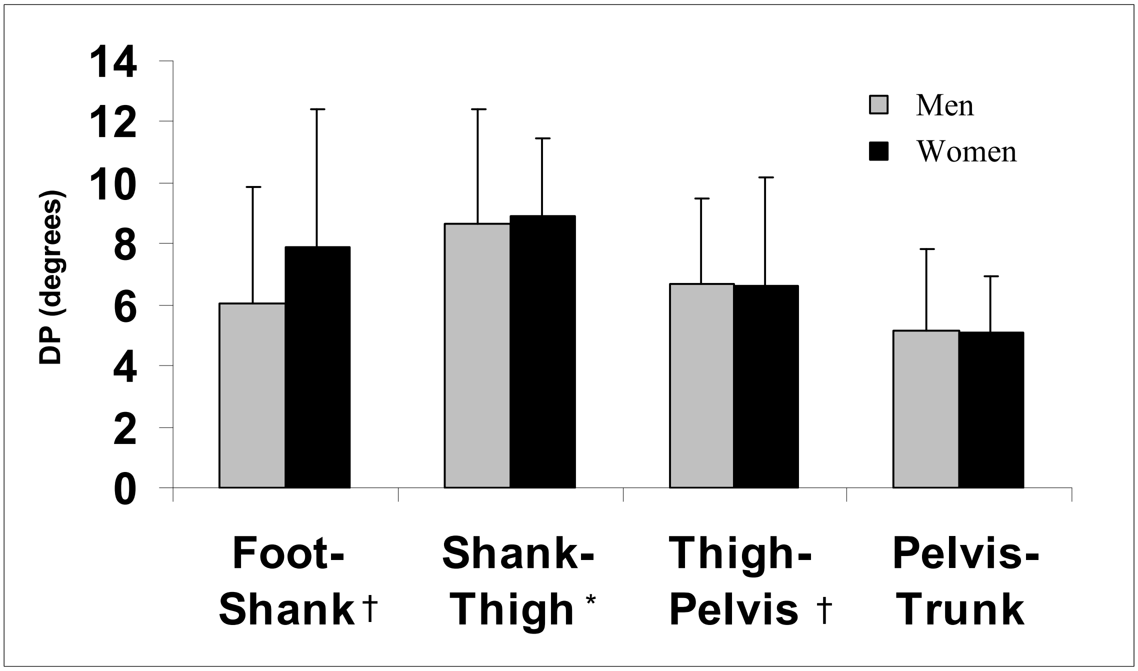


Figure 26: Transverse plane MARP values for the descent of the single leg squat. There were no significant segment main effects.

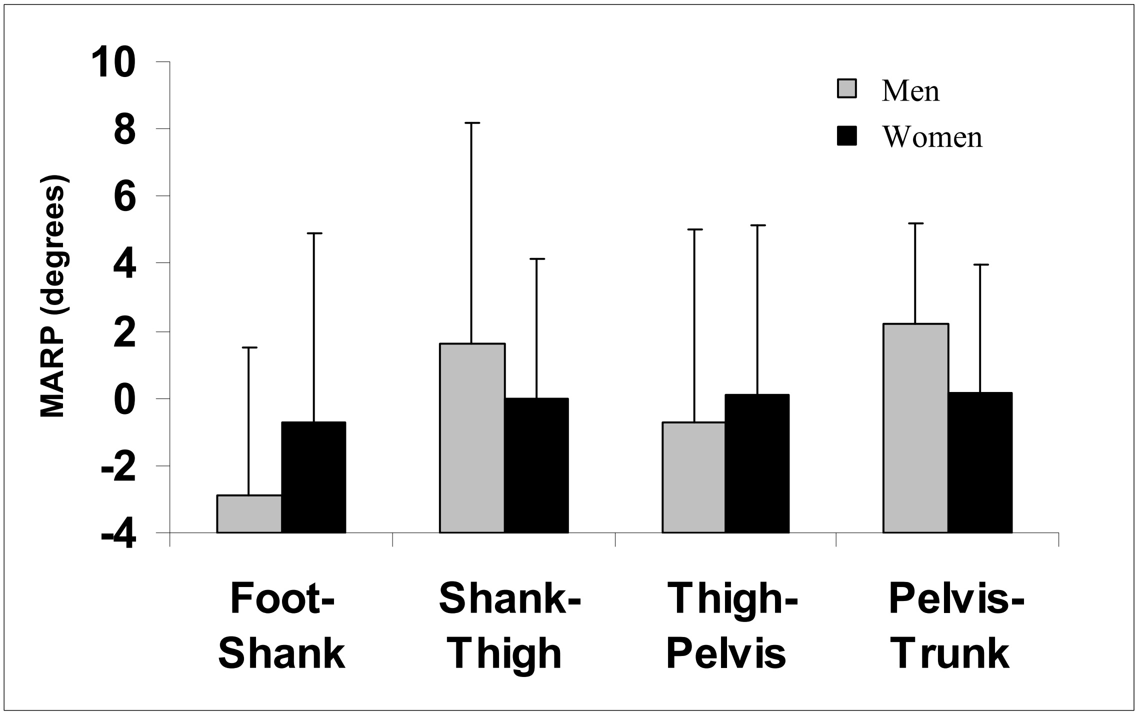
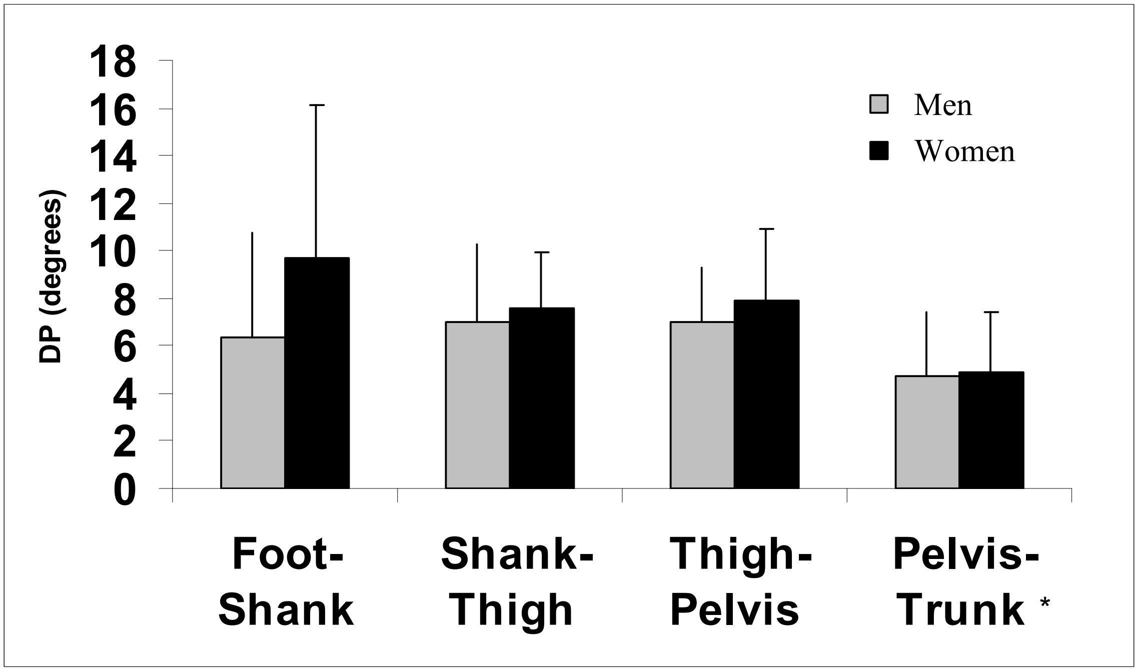


Figure 27: Transverse Plane DP values for the descent of the single leg squat. Asterisk indicates that the pelvis-trunk DP value was significantly less than the foot-shank DP, shank-thigh DP, and thigh-pelvis DP values.



CHAPTER 4: DISCUSSION

The purpose of the current study was to examine the coordination patterns of men and women collegiate Division I athletes using MARP (mean absolute relative phase) and DP (deviation phase) during the single leg squat and the lateral step down and examine if these correlate to static limb characteristics. While previous research has examined the running patterns between the sexes and found differences, including differences in pelvis-thorax coordination, none has considered the lateral step down and single leg squat.[33] Based on the previous research, it was hypothesized that men would display more in-phase patterns, particularly at the pelvis-trunk and thigh-pelvis segments. Contrary to this hypothesis however, we found no significant differences in the MARP and DP values during these tasks between the sexes in pelvis-trunk, thigh-pelvis, shank-thigh and foot-shank segments. Based on the frequency that lateral step downs and single leg squats are incorporated into rehabilitation programs, the most clinically significant result of the investigation was the characterization of the pelvis-trunk, thigh-pelvis, shank-thigh and foot-shank patterns exhibited.

Sex Differences

Lateral Step Downs

Previous research has not examined the lateral step down using a dynamic systems approach. Therefore comparing the current study's findings to previous data is challenging. While the data is limited, research has shown that during a step down, women utilized less knee flexion on their dominant leg when the step height was not adjusted to their height.[27] The current study however, found no statistically significant differences between the sexes during the lateral step down. Interestingly, instead it revealed that women and men statistically performed the step down using similar patterns, with equivalent stability, in the frontal, sagittal and transverse planes. The vertical center of mass displacement (peak ascent minus peak descent) and percent cycle that the transition from descent to ascent occurred were also statistically equal between the sexes. Despite the presences of a metronome, the women completed the step downs ~6% slower than the men. Both the reason for the dissimilarity and effect on the dependent variables is unknown

One likely contributor that might explain the lack of significant sex-related pattern and stability differences may have been task constraints imposed. In addition to the requirement to complete the repetitions to the pace of a metronome, the height of the step downs was adjusted to leg length. Both of these task constraints were imposed to standardize the data and therefore allow sex comparisons. Either of these tasks constraints may explain why men and women performed similarly. Previous studies did not use time or step height as a constraint.[27] This suggests that it is not the specific task that causes men and women to differ, but may be more related to conditions of the task.

Qualitative examination of the data collected did show some trends, although none were statistically significant. The DP values for the lateral step down, during both the ascent and descent indicated that within the transverse plane, men tended to have lower DP values, indicating more stability. Researchers have suggested that with varying degrees of hip flexion, the gluteus medius muscle acts as a hip rotator.[11] Women have been postulated to have weaker gluteus medius strength, thus an increase in transverse plane motion compared to men might point to the strength of this muscle. The trend of men to have lower DP values in the transverse plane may support this theory, although the current study does not statistically support this.[3,33,] Future research should consider the relationship between gluteus medius strength and the stability of transverse femoral motion during lateral step downs.

During actual testing, simple observation revealed that the men and women displayed different execution patterns. The lack of support for this observation may lie in the composition of the MARP and DP values themselves. The MARP and DP values were calculated across each phase of the task (descent and ascent). Perhaps if they had been calculated shorter intervals within each phase, the observed differences may have been statistically significant.

Single Leg Squats

Previous research demonstrates that women tend to have more sagittal and transverse plane ankle motion during the single leg squat, more knee frontal plane motion, and more sagittal plane hip motion than men.[5] The current study examined the coordination within these planes of motion and found no significant differences between the sexes. While past research has focused on joint angles and moments, the current study looked at the pattern and stability of segmental motion and ignored the extent of motion. Motion in each of the three planes was equal statistically during the current study. The reason the current study does not support past research may be multifactorial. Similar to the lateral step downs, this could be a result of the dynamic systems analysis, and its examination of pattern stability as opposed to specific joint motions. In contrast to the lateral step downs in which pace and step height were constrained, the single leg squat only constrained the pace. Thus, this study suggest that men and women may not exhibit different segmental patterns when they are temporally constrained. This element of control may cause individuals to employ similar coordination patterns in order to execute the motion.

Similar to the lateral step downs, qualitative examination of the athletes completing the task suggested kinematic differences, although they were not indicated by statistical comparison of the MARP and DP values. Observations yielded differences in peak joint angles, similar to what has been documented in previous studies.[5] For example, Zeller's study found that women used statistically greater frontal plane ankle range of motion than men did.[5] Although not statistically significant, the current study did demonstrate the trend for women to have more instability in their coordination patterns during the single leg squat than men did at the foot-shank segment. This trend should be further examined by future researchers. Other trends yielded in the data were consistent with previous research. A lack of lateral trunk flexion was another differing kinematic observation seen by Zeller, McCroy, Kibler, and Uhl.[5] The current study found a trend towards an increase in stability for the pelvis-trunk segment in the frontal plane for women. Again it remains statistically insignificant but it again shows that future research with larger study groups is needed to completely rule out coordination pattern differences between the sexes.

Segment Differences

Despite a lack of sex differences, the significant segment main effects help characterize lateral step downs and single leg squats. For example, in the sagittal plane, the MARP values indicate that during the ascent of the lateral step down, the shank-thigh segment was significantly larger than the other three segment pairs, while in the descent, this patterns reverses completely with the shank-thigh being significantly less than the other three segment pairs. The further distance in a positive direction from zero a MARP value becomes, the greater the distal segment is leading the proximal segment. The further distance in a negative direction from zero a MARP value becomes, the greater the proximal segment is leading the distal segment. Thus, for the lateral step down in the sagittal plane, the shank-thigh is statistically moving out of phase to a greater extent than the other three segment. As expected, the DP values reflect these variations, with the shank-thigh experiencing statistically greater pattern variability of the four segments. The shank-thigh pattern is similarly observed in the same order during the single-leg squat, with the similar reversals between the ascent and descent. These differences are likely due to sagittal plane knee motion being the primary plane/joint of motion for both tasks.

With the exception of the MARP values in the sagittal plane, MARP values remained relatively small (close to zero) and varied little (small DP) between segments in the transverse and frontal planes. This may be attributed to the segmental motion in these two planes contributing to total body center of mass stability. Despite small magnitude MARP, there were significant segmental pair differences for the transverse plane.

The DP values in the frontal and transverse planes also provide some interesting characterization of the two tasks. The trunk-trunk for example, is the most stable, as indicated by the consistently low DP values, throughout both the transverse and frontal planes. Ironically, it was the thigh-pelvis segment that displayed the most variability in the transverse and frontal planes. The speculation by Zeller et al support this finding, as they suggested variability in the single leg squat to be attributable to weak gluteus medius strength.[5] Based on the larger DP values, it appears that controlling the thigh-pelvis segment is a challenge for a larger population than just the women, as reported by Zeller, McCroy, Kibler, and Uhl.[5]

Comparing MARP values between planes also offers interesting insight to into these coordination patterns. The trend is for the role each segment plays in the motion to reverse in different planes. For example, during the ascent and descent of the lateral step down, the foot leads the shank in the frontal plane motion however in the transverse plane, the shank is the faster portion of the segment. The biomechanical characteristics of the nature for the shank to rotate during foot eversion and inversion supports this study's findings. As frontal plane motion is initiated by the foot, the shank thus initiates transverse plane motion. Similar findings are seen in the ascent and descent of the single leg squat.

The most obvious trend with the MARP values across planes is the lack of large differences across the frontal and transverse planes. Although patterns have significantly different DP values, indicating larger variability, the overall MARP values, do not different significantly, and in cases where they do differ statistically, the differences are slight. Clinicians can benefit from this knowledge, as instabilities and high degrees of variability may not be as apparent as one thinks, and yet still have potent impacts on the system.

Static Limb Characteristics

The MARP and DP values were also correlated to the results of the static limb characteristics screen. Previous studies have indicated that single leg balance can be affected by lower leg measurements, primarily rearfoot and forefoot alignments.[50] The current study however found few significant correlations between MARP and DP values and lower leg measurements, including rearfoot alignment and navicular drop. One possibility for the differences between the current study and the kinematic data from previous studies maybe attributable to the analyses perspective incorporated.[1,2,3,5] As discussed previously, the dynamic systems analysis may limit the amount of information available beyond the segmental patterns and the stability of the patterns. In addition, none of the present subjects could be classified as abnormal in their static limb characteristics measure according to Gross.[16] Other studies however, support the current study. Trimble et al reported that static lower extremity measurements, including those used in this study, were no indication of dynamic task performance. Further data is needed to determine the true impact of lower extremity measurements and functional outcomes, however, the current study suggests that the stability of the coordination pattern may not correlate to small changes in lower extremity alignment.

Tibial torsion was the only variable that significantly correlated with movement in the frontal and transverse planes during the lateral step down. Approximately 22% of the variance in foot-shank movement in the frontal and transverse planes during the descent can be explained by tibial torsion. Combined with the data discussed above, whereas the shank initiates the movement, the relationship between increases in tibial torsion and increases in the differences in frontal and transverse plane motion seem obvious. Surprisingly however, there was not a corresponding significance in navicular drop, something that would increase the frontal plane motion of the foot. Instead, the impact of alterations to the tibia seems to impact the overall coordination pattern of the lower leg especially more.

CHAPTER 5: CONCLUSIONS

The results of the current study indicated that with temporal constraints, man and woman athletes did not differ significantly in their MARP and DP values during a single leg squat and a lateral step down. These data highlights the need for future research to continue to examine biomechanical data using a dynamic systems approach to compare the sexes. Interesting, the current study also found no or a very weak correlation between static limb characteristics and MARP and DP values, despite previous research which suggests static limb characteristics can alter the function of the overall system. Clinicians striving to prevent knee injures should note the similarities seen when athletes were given a set speed to complete the task. The study did find significant segment main effects, which provide insight into coordination patterns during dynamic activities, and offers clinicians the opportunity to further understand the neuromuscular characteristics of tasks. Future research is needed to identify this as a clear contributor to the similar patterns, but it presents an interesting constraint that clinicians can use during neuromuscular training programs in women.

Appendix A

Purpose:

1. To compare the MARP and DP values of the pelvis-trunk, thigh-pelvis, shank-thigh, and foot-shank segments between man and woman collegiate athletes during the single leg squat and lateral step down in three planes of motion.
2. To determine if MARP and DP values correlate to lower extremity alignment values

Research Hypothesis

1. There will be differences seen in the segmental patterns between man and woman athletes during the single leg squat and lateral step down in the frontal, sagittal, and transverse planes.
2. Man athletes will display more stable pelvis-trunk segmental patterns during the single leg squat and lateral step down in the frontal, sagittal, and transverse planes than women.
3. MARP and DP values will correlate to lower extremity alignment values.

Limitations

1. The athletes were chosen through deliberate sampling. They were recruited based on whether they participate in Division I collegiate sports.

2. The athletes were tested in a lab setting. This was an unfamiliar setting and thus the results may not represent their natural coordination patterns.

3. The study included only 30 athletes (15 man and 15 woman).

4. The athletes were not wearing shoes to allow for sensor placement, which is unnatural to athletic participation and may alter findings.

Delimitations

1. Testing was done on man and woman collegiate athletes at one southeastern United States university.

2. Basketball, soccer, volleyball, baseball, track, softball, tennis and football players were used.

3. The athletes were not classified according to the sport they play but by their sex only.

Assumptions

1. The athletes gave maximal effort on all tests.
2. The athletes gave honest responses on their medical history.
3. The athletes understood all instructions given to them.
4. The physical demands of the study did not exceed the demands commonly experienced by Division I varsity athletes.
5. The athletes maintained similar activities levels, that of in season Division I varsity athletes.
5. Instruments performed optimally.

Definitions

Dynamic activities:

Functional activities that are fast, simple to perform, and stimulate stresses around joints similar to those imposed during athletic performance. They are used to assess and quantify muscle strength and power indirectly.[29, 30]

Coordination:

Creation of appropriate actions by a system so that a goal, specifically motion, is achieved.[31]

Phase Portrait:

Graph of the current state of a system versus the amount of change the system is undergoing. This type of graph allows for a picture of the organization of the neuromuscular system.[32]

Phase Angle:

The angle used to identify the segment body at a certain point in time on a phase portrait. It is the angle between the x-axis and the radius of the graph.[32]

Relative Phase:

The quantative measure of interlimb coordination. Relative phase is the difference between the phase angles of the distal and proximal segments and identifies whether segments are in or out of phase at a certain point in time.[32,33,34]

Mean average relative phase (MARP):

MARP is the average relative phase and also indicates if segments are in or out of phase. Unlike relative phase, MARP is a measure of the overall motion's coordination.[32,35]

Deviation phase (DP):

Deviation phase is the average standard deviation of the MARP value. It examines the stability of the motion's coordination throughout the task, not at one moment.[32,35]

Appendix B

INTRODUCTION

A large body of research exists illustrating the differences in lower extremity injury rates between man and woman athletes. A review by the NCAA tracking injuries found that while incident rates are similar between woman and man athletes competing in the same sports the type of injuries are not, particularly knee injuries.[36] For example, data indicates that woman soccer players are two times more likely and woman basketball players are three times more likely to injure their ACL than man soccer and basketball athletes.[36] A variety of explanations can be offered to explain this imbalance however none are proven. Recent research has focused on identifying kinematic differences between man and woman athletes as an explanation, however it is regularly examined in one-dimensionally, ignoring the complexity of the motion.[1,2,4,3] An alternative approach is to examine activities using a dynamical systems analysis.

Mathematicians, physicists and other scientists have utilized a dynamical systems approach in their examinations for centuries while the motor control community has only recently begun to use this theory. Dynamical systems theory views the body as a series of interacting units that prefer stable, consistent patterns of motion.[37,8] Once established, these patterns are valuable in identifying the function of the neuromuscular system. The purpose of this study was to compare the trunk and pelvis segmental patterns between man and woman collegiate athletes during the single leg squat and lateral step down using a dynamical systems analysis. These patterns will allow clinicians to identify areas of weakness and thus address them properly prior to injury or during rehabilitation.

CURRENT RESEARCH IN SEX DIFFERENCES:

Dynamic activities are the most common method of assessing the functional status of athletes. Table 1 summarizes the common research findings involving dynamic activities. Jumping tasks are the most widely researched dynamic activity with the most common findings being that woman athletes tend to begin jumps in a more valgus knee position, land jumps in a more extended position, and have more ankle plantar flexion throughout their jump than their man counterparts.[5,1,4] Despite these biomechanical differences, women experience the same vertical ground reaction forces, complete the jumps in similar times and with similar velocities as men.[2]

Exactly why these biomechanical differences exist continues to be debated Traditional examinations group the differences into two broad categories: intrinsic and extrinsic factors. Anthropometrics measurements and hormonal differences are the most commonly researched intrinsic factors.[38,39,40] Researchers have identified for women wide pelvises, anteverted hips and narrow intercondylar femoral notches as predisposing factors for lower extremity injuries, compared to men.[34,40] These characteristics however, have also been identified in healthy, uninjured woman and man athletes. Another area receiving attention has been the hormonal changes women experience and its impact on injury rates. While researchers have suggested that certain spikes in estrogen and progesterone levels increase the laxity of the ACL, research has not found evidence.[39,41,42,43,38]

Extrinsically, research has revolved around conditioning, experience, neuromuscular patterns, and muscle strength.[36] While a lack of conditioning or experience is commonly accepted as a precursor to injury, these are not gender specific, and thus may be only a small part of the difference in types of lower extremity injuries.[36] Neuromuscular strategies employed by athletes are another extrinsic factor of great interest. The strategies utilized by women, the order they recruit muscles to complete tasks, and the magnitude of forces generated around joints all relate to these neuromuscular patterns.[39,44] Identifying the precise mechanisms by which the neuromuscular system operates however, challenges researchers. Coordination patterns however, allow researchers to study the final product of the system, which provide small clues at to the overall neuromuscular system.

Coordination Patterns

Coordination patterns are a programmed map of how the neurological system and the musculoskeletal systems work together to accomplish a goal.[31] These relate to the order in which muscles are recruited to execute a task and the position of the body's segments throughout the motion. In addition, coordination patterns can by cyclical, repeating itself over and over again to maintain the body's homeostasis.

DYNAMIC SYSTEMS ANALYSIS:

There are several motor control theories that strive to explain how movement is executed.[37] One approach that is becoming increasingly popular is dynamic systems theory. A dynamic systems analysis allows researchers to qualitatively and quantitatively identify coordination patterns by calculating the relative phase of a motion, rather than velocity or displacement of segments. As opposed to motor program theories which view motion as the execution of patterns stored in the central nervous system, dynamic systems theory views the body as a system that moves based on the constraints imposed upon it.[37,8] The system strives to self-organize into a stable pattern of motion that is efficient and effective under the current constraints.[8]

Traditional Kinematic Analysis

Examination of motor learning and motor control traditionally evolved around identifying what dictates how motion is initiated.[37] Researchers employed linear models to record motions with one or two degrees of freedom to isolate the exact pattern used to complete a task. The final product was seen as a program or pre-determined pathway. By isolating motion in one plane, traditional examinations are able to identify exact positions of joints during activities and determine the torque produced around joints.[37] These linear descriptions however lack the complexity of the actual motions and take for granted the importance of multi-dimensional activities occurring simultaneously.[8] For example, Colby, Francsico, Yu, Kirkendall, Finch and Garrett examined cutting maneuvers in healthy collegiate athletes. They found that the quadriceps muscles activated prior to foot strike and reached their peak during the cutting maneuvers.[45] How this plays into the entire motion is unknown. Rather than examine the entire motion in each plane, the cutting maneuver is examined in isolation, at the knee joint and descriptors thus relate to the action of the knee. The data ignores the interlimb coordination between the thigh and the shank or the thigh and the pelvis.

Dynamic Systems Theory

An alternative to the traditional kinematic analyses utilities the dynamic systems theory. Dynamic systems theory originated in physics and mathematics and is used to describe systems that are always changing.[7] The general principle is to describe the changing system, whereas motion is seeking to find and remain in a stable state.[7] A stable behavior is motion that can resist small perturbation and when larger perturbations are experienced, still return to the original pattern.[8] Identifying the stable pattern allows for the examination of interlimb coordination.[32,5] One result of this examination is a qualitative graph representing the coordination. From this graph, researchers are able to identify if segments are moving "in-phase," or the limbs are coordinated, or if they are moving "out-of-phase." These graphs can also indicate which limb leads the motion or if this changes throughout the motion. Another benefit to dynamic systems analysis is that variability is seen as valuable information, eluding the formation of a stable pattern. In traditional analysis, variability is seen as noise and is thus filtered out. Dynamic systems theory views variability as an indication of where the system swayed from the stable pattern of motion and when it returned.[32] This variability can aid in identifying unique pathological presentations, such as with Parkinson's disease. In patients with Parkinson's disease, a lack of neuromuscular control is the result of the degenerating body. Instead of the stable pattern observed in healthy adults, a chaotic, unorganized graph emerges, as seen in Figure 25.[32]

Statistically, dynamic systems analyses are also unique. Motions involving several joints with multiple degrees of freedom are analyzed by reducing high dimensional motion into a low number of variables that are said to "capture the state" or essence of the motion.[8] The state can then be described in terms of its attractor, or the overall picture of all the system's states. Attractors have three general classifications: point, limit cycle, and chaotic. Limit cycle attractors, such as gait, have closed orbit trajectories, as in Figure 25. The current study looks at limit cycle attractors, if any motion were repeated, the orbit would have this classic oval shape. Chaotic attractors are not easily identified as they all diverge at a given point. Point attractors are motions that share one specific point in the motion.[8]

Components of Dynamic Systems Analysis

Phase Plots (or phase portrait)

Initially, with a dynamical systems analysis of motion, a segment's velocity is plotted as a function of its displacement.[32,9] This produces a picture of how these variables are coupled together and is used to identify patterns.[9] It also provides a description of the state of motion thus identifying the attractor.

One current use of phase portraits in research is gait analysis. Kurz and Steriou used a phase portrait to illustrate the pattern of motion of the thigh and shank during gait. (Figure 26).[32] When the trajectory crosses the x-axis, at which point the angular velocity is actually zero, a change in the movement pattern is indicated. In addition, the cusp in the trajectory path indicates a sudden perturbation which lead to an alteration in the pattern. Clinically, such information offers a biomechanical picture of whether individuals are able to execute a motion with a stable, fluid motion, or whether the task is being executed without stability and chaotically. Such information can be useful for injury prevention, evaluation, and rehabilitation.

Phase Angles

While the phase plot qualifies motion, the phase angle quantifies the motion. Traditional kinematic data consists of several sets of numbers used to describe a point's position in relation to time. With a dynamic systems approach, this position within a pattern at a point in time, can be summarized into one angle, the phase angle.[32] To calculate the phase angle, the Cartesian coordinates from the phase plot are transformed into polar coordinates. From here, the angle between the x-axis and the vector r, or radius to the point on the graph is identified.[32]

Relative Phase

The most important data in a dynamic systems analysis is the relative phase, which accounts for the interlimb coordination.[32,34] The relative phase angle is calculated as follows:

$$\theta_{\text{relative phase}} = \Phi_{\text{distal segment}} - \Phi_{\text{proximal segment}}$$ [32]

where $\Phi_{\text{distal segment}}$ is the phase angle of the distal segment and $\Phi_{\text{proximal segment}}$ is the phase angle of the proximal segment. This value indicates the coordination between two segments. For example, the closer the relative phase is to zero, the more coordinated or in phase the segments are.[32] Relative phase values closer to 180 degrees indicate that the two oscillating segments are out of phase.[33] In addition to indicating the coordination of the segments, the relative phase indicates which segment is leading the motion, as positive relative phase angles indicate the distal segment leading the motion while negative values indicate the proximal segment leads.[32] The slope of the curve can also provide coordination information, specifically which segment is moving with larger velocity at any point. A positive slope indicates that the distal segment is moving quicker than the proximal segment while a negative slope indicates a faster proximal segment.

The relative phase is significant to research because it illustrates the motion of two different segments in the system. It is significant because it enables researchers to illustrate a systemic motion with a minimum amount of data. For example, Lamoth, Beek, and Meijer used relative phase to examine the difference in pelvis and thoracic rotation during walking when the velocity of the stride was increased.[33] As shown in figure 3, when velocity was low, the relative phase values remained tight around 0. When the velocity increased, the relative phase values became more variable, ranging between 50 and 150 degrees.[33] This high relative phase indicates that at higher velocities, the pelvis and thorax move out-of-phase. The positive relative phase indicates that the pelvis is leading and at 50% of the stride cycle, the positive slope indicates that the pelvis is faster than the thorax.

A traditional kinematic analysis would have required considerably more data points to only show a fraction of this information. The velocity of the pelvis and thorax along with each segment's displacement would be compared along with joint angles. The relative phase angle incorporates all this information.[32,35]

Mean Absolute Relative Phase:

To determine if relative phase curves are significantly different, the mean absolute relative phase (MARP) must be calculated. MARP is calculated as follows:

$$\text{MARP} = \sum \frac{|\phi \text{ relative phase}|}{N}$$ [32]

where ϕ relative phase is the relative phase angle of a portion of the segment and N is the number of values present during that time. Like the relative phase, the MARP value indicates if interacting segments are in or out of phase with one another. As opposed to the relative phase which focuses on one moment during the trajectory, the MARP value is an average of all the relative phase values, thus giving an idea of the stability of the entire motion.[32,35] Higher values indicate out-of-phase or unstable motions, while lower values indicate an in-phase or stable motion.

Deviation Phase*:*

The final calculation necessary during data analysis is the deviation phase (DP). DP is calculated as follows:

$$DP = \frac{\Sigma\,|SD|}{N} \quad {}^{32}$$

where N is the number of points in MARP and SD is the standard deviation of the MARP. A low deviation phase indicates a stable MARP while higher deviation phases indicate more instability in MARP.[32,35]

METHODS:

Static Limb Characteristics

The current study will include a static limb characteristic measurements, a means to identify skeletal malalignments and joint deformities that may alter coordination patterns.[16] The static limb characteristic measurements will be limited to a static analysis of the lower extremity, as documented in previous research.[16]

Navicular Drop Test: Most static limb characteristic measurementss include a navicular drop test to assess the degree the talus plantarflexes on the calcaneus during gait.[18] To begin, the ankle is placed in subtalar joint neutral position, as previously described in literature. Next the distance from the inferior border of the navicular tuberosity to the horizontal is measured and compared it to the position of the navicular tuberosity in a weight bearing position.[16,17] Excessive sagittal displacement of the navicular tuberosity may be exhibited indicating the presence of subtalar joint pronation or ligamentus laxity.[17]

The navicular drop test is reliable at predicting excessive subtalar joint pronation and a valid indicator of arch height.[46,16,47] Studies have also utilized the navicular drop test to determine if foot pronation could predispose individuals to lower extremity pathologies. In 2001, Bennett et al found that collegiate athletes with medial tibial stress syndrome had significantly greater navicular drop measurements than athletes without medial tibial stress syndrome.[48] With this in mind, the inclusion of the navicular drop test in static limb characteristic measurements prior to data collection aids in identifying possible problems prior to actual collection process. For the current study, an athlete with excessive foot pronation may exhibit different coordination patterns than those without. Bennett, et al. study's documented that with excessive foot pronation comes altered gait mechanics, primarily placing addition stress on the medial lower leg, translating into altered shear forces across the knee.[48] The result could be abnormal perturbations in the phase portrait of the limb as the system compensates for these stresses. While athletes will not be excluded based on excessive navicular drop measurements, this data will be collected as a means of explaining possible abnormal data sets.

Leg Length Inequality: A quantitative examination of the length of the lower extremity is also included in the current study. Leg length inequalities are classified as true, a result of tibia or femur length differences, or as apparent, a result of a rotated pelvis. The inequality results in altered and unbalanced limb loading, whereas the shorter limb accepts a greater proportion of the load.[49]

Coordination patterns are significantly impacted by any length inequality. If the body is unable to evenly distribute stress placed upon it, the system will be forced to compensate in unnatural coordination patterns. A phase portrait for an athlete with a leg length inequality might show multiple cusps, where even slight perturbations are able to affect the gait patterns. If the cause of the leg length inequality is pathological, the portrait is likely to be more chaotic and sporadic. For athletes with congenital leg length inequality, phase portraits and coordination patterns must change to compensate for the added stress of unequal force distribution. For example, O'Toole et al. looked at the effect leg length discrepancies had on one-dimensional foot loading patterns.[50] They found that when leg length differences are significant, the total foot loading on the longer limb can increase by up to seven percent.[50] An increase of seven percent will greatly change the way a task is executed, as the body attempts to complete the task awkwardly.[50] By limiting the population to Division I varsity athletes, there were no individuals with significant leg length inequalities. Due to these increases in stresses, individuals are often unable to compete at elite levels with these altered mechanics. This is still tested in the current study to ensure no coordination data is skewed by abnormalities.

Patella orientation: The position of the patella can also significantly impact the biomechanics of the lower extremity. Clinicians have identified two abnormal patella positions: patella alta and patella infera.[51] The change in the position of the patella immediately alters the contact forces between the patella and the femur.

DYNAMIC BATTERY OF TESTS:

To accurately see the coordination patterns of athletes during competition testing would have to occur during events. Currently no equipment is sophisticated enough or widely available that allows this.[57] Instead researchers rely on dynamic testing, functional activities that attempt to assess and quantify muscle strength and power indirectly.[29] Dynamic activities are fast, simple to perform, and simulate stresses around joints similar to those imposed during athletic performance, all within the confines of a laboratory.[30]

Single Leg Squat

The single leg squat requires that the athlete maintain control over their dominant leg, something common in sports performance.[5] It is often utilized to screen for hip weaknesses in the athletic population following injury. Previous one-dimensional research found that during the single leg squat, women displayed more ankle dorsiflexion, ankle pronation, hip adduction and hip flexion compared with their man peers.[5] Like other studies, movement was examined in isolation, eliminating the element of interaction. Procedures will be performed as previously documented by Zeller, McCroy, Kibler, and Uhl, where athletes stand on their leg and with hands on their hips. They then squat down as far as possible and stand back up, all in time with a metronome set to 60 beats per second.[5]

Lateral Step Downs

The final task in the current study is the lateral step down. This task if often used in rehabilitation protocols to strengthen the gluteus medius muscle in particular. It is especially relevant in coordination research, as it allows for the examination of pattern changes as the gluteus medius becomes fatigued.[27]

KINEMATIC DATA COLLECTION:

Kinematic data is collected by an electromagnetic tracking system with the MotionMonitor, a commercially available acquisition and analysis software. At the core of the system is a transmitter with 3 coils that are used to create an electromagnetic field. Sensors attached to the subject create a magnetic flux within the magnetic field and this is relayed to the base computer through cables. The MotionMonitor software calculates sensor position and orientation from data conveyed by the sensors. The hardware consists of an extended range direct-current transmitter and eight receivers. By digitizing particular points on a segment, segmental axes can be created to describe segmental orientation within the world.

CLINICAL RELEVANCE

Coordination is particularly significant in the prevention and rehabilitation of athletic injuries. The current study aims to identify the average coordination patterns of Division I collegiate athletes for three selected movements. This information may assist clinicians in identifying compensatory patterns. Often functional tasks administered within the sports medicine field, assess outcomes, whether tasks are completed accurately and pain free. Even strength testing focuses on achieving a set level of torque. These tasks can overlook neuromuscular compensations that have developed.

A dynamical systems evaluation, as in the current study, would allow clinicians to identify and address unstable or inefficient coordination patterns. Such analysis can be used to chart rehabilitation's progresses or be used to identify areas of weakness to improve upon as a preventative measure.

The current research study aimed to identify what the typical patterns are and thus give clinicians an overall picture of the patterns. This knowledge equips clinicians with information to use in evaluating athletes for inefficient behavior without having the elaborate equipment.

This study strove to arm clinicians with the knowledge of overall movement patterns during dynamic activities. Clinicians should see the segment main effects as insight into how athletes' neuromuscular system executes tasks. By observing the segments leading and directly motions, clinicians can then address "knee friendly" patterns and incorporate these into injury prevention programs.

APPENDIX C

CONSENT TO ACT AS A SUBJECT IN AN EXPERIMENTAL STUDY

Title: Effects of sex on core strength and coordination patterns during dynamic activity

Primary Investigator:

Corrie Barnett, ATC
Graduate Student, Athletic Training
Georgia Southern University
912-871-1920

Co-Investigators:

Bryan Riemann, PhD, ATC
Graduate Athletic Training Program Coordinator
Co-Director, Biomechanics Laboratory
Georgia Southern University

Description:

We are attempting to study the relationship between the pelvis, thigh, and lower leg during certain activities and to see if these can be explained by core strength. Thirty men and thirty women will participate in this study. The results of this study will help us to better understand the effects of core strength exercises on lower extremity control and possibly injury prevention.

You are being asked to participate in this study because you are a Division I varsity intercollegiate athlete. In addition, you have no current injury to the legs or your trunk.

If you agree to participate in this study, you will be asked to complete a medical history form. This study asks that you attend two testing sessions, each lasting approximately 1 hour long. The activities you will be asked to perform during the testing session are described below.

Single Leg Squat: You will be asked to complete 8 squats while standing on one leg. To prevent injury from falling, a spotter will be in close proximity. During each test, you will be asked to stand with your head facing forward, hands on your hips, and attempt to perform a single leg squat. The technique requires you to maintain your knees inline with your toes, or behind them, while you flex your knees to 90^0, and then return to starting position. The squats will be performed to the beat of a metronome, which will be set at 60 beats per minute. You will go down on a click and then come back up on a click. We will ask you to complete two squats for practice and then perform the eight squats consecutively for recording.

Lateral Step-Down: During the lateral step-off procedures, we will ask you to stand on one leg, with your other foot to the lateral edge of a step with a height that is 20% of your leg length and facing forward with hands on your hips. When you are ready, you will be asked to step off the step to the side, so the heel of the non-dominant leg touches the ground. The lateral step-off will be performed to the beat of a metronome set at 60 beats per minute. You will go down on a click and then come back up on a click. You will be given two practice trials before completing the test trials. This will be performed for 90 seconds or until you cannot continue.

During each of the test trials, we will make several types of measurements concerning the position of your hip, thigh, and lower leg. These positions will be made using a special computer system that uses magnetic based sensors to track your body's motion. Eight sensors will be attached using neoprene and Velcro sleeves to both your feet, lower legs, upper legs, lower back, and upper back. Cables will be attached from each of these sensors to a personal computer.

RISKS AND BENEFITS:

The risk assumed during the testing is mild. The abdominal and low back exercises, as well as the trial tasks are commonly used exercises throughout our athletic training room and laboratory, as well as other athletic training rooms and laboratories, with normal and injured groups (i.e. low back problems). To minimize any risk of injury, you will be instructed on the proper test procedures during an introductory session. Only trained laboratory personnel will conduct the testing procedures. These personnel will be undergraduates, selected by the Laboratory Directory, Bryan Riemann, who will undergo sufficient training specific to the procedures involved with the investigation, as well as the sensitivity associated with human subject research. It is possible that any experiment may have harmful effects that are not known. The electromagnetic field is low level and has been approved for medical research because it does not present any health risks. There are no known risks to a fetus or pregnant mother from participation in this study.

The benefits to the athletes may be an increase in core strength, which if our hypthotheses are supported may enhance performance. The benefits to society include providing some data to support, or not support, the usage of core strengthening in performance training and/or injury prevention.

COMPENSATION FOR ILLNESS OR INJURY:

Georgia Southern University investigators and their associates recognize the importance of your voluntary participation to their research studies. These individuals and their staffs will make reasonable efforts to minimize, contrail, and treat any injuries that may arise as a result of this research.

If you believe that you are injured as the result of the research procedures being performed, please contact Corrie Barnett, ATC (912-871-1920) immediately or the Georgia Southern University Institutional Review Board IRB Coordinator at the Office of Research Services and Sponsored Programs at (912) 681-5465. You will not receive monetary payment for, or associated, with any injury that you suffer in relation to this research.

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

CONFIDENTIALITY:

I understand that any information about my records or me will be handled in a confidential (private) manner consistent with the privacy that medical records are handled. A case number will indicate my identity on all records. I will not be specifically mentioned in any publication of research results. However, in unusual case my research records may be inspected by appropriate government agencies or released to an order from a court of law. All information and research methods will be kept for a period of five years after the termination of this investigation.

RIGHT TO WITHDRAWL:

I understand that I am not required to take part in this research study and, if I change my mind, I can withdraw at any time. My decision whether or not to participate in this study, or to withdraw from participation will have no affect on my status as a student, an athlete with Georgia Southern University, or any other benefit to which I am entitled. I also understand that I may be removed from the research study by the investigators in the event of an inability to complete the testing procedures.

VOLUNTARY CONSENT:

I certify that I have read the preceding information, or it has been read to me, and understand its contents. Any questions I have pertaining to the research have been, and will continue to be answered by Corrie Barnett 912-871-1920. Any questions I have concerning my rights are answered by the Georgia Southern University IRB Office (912-681-5465). A copy of this consent form will be given to me. My signature below means that I have freely agreed to participate in this project.

______________________________	____________________
Subject's Signature	Date
______________________________	____________________
Witness Signature	Date

INVESTIGATORS' CERTIFICATION:

I certify that the nature and purpose, the potential benefits, and possible risks associated with participation in this research study have been explained to the above individual and that any questions about this information have been answered.

______________________________	____________________
Investigators' Signature	Date

Medical History Survey

Subject #: ______________ Date: ____________

Age: ____________ Height: _______________ Weight: ___________

Lower Dominant Limb: R L Leg Length: _____________

Sex: M F

1. Have you ever sustained an injury to either leg (thigh, knee, ankle, etc.) or back? Yes NO
   If so, explain:

____

____

2. Have you ever sustained a head injury that caused you to loose consciousness or have problems with balance? Yes No
   If so explain:

____

____

3. Are you currently taking any prescription or over the counter (OTC) drugs? Yes No
   If so explain:

____

____

4. Do you wear orthotics or specialized shoe inserts? Yes No
   If so, are you wearing them now? Yes No

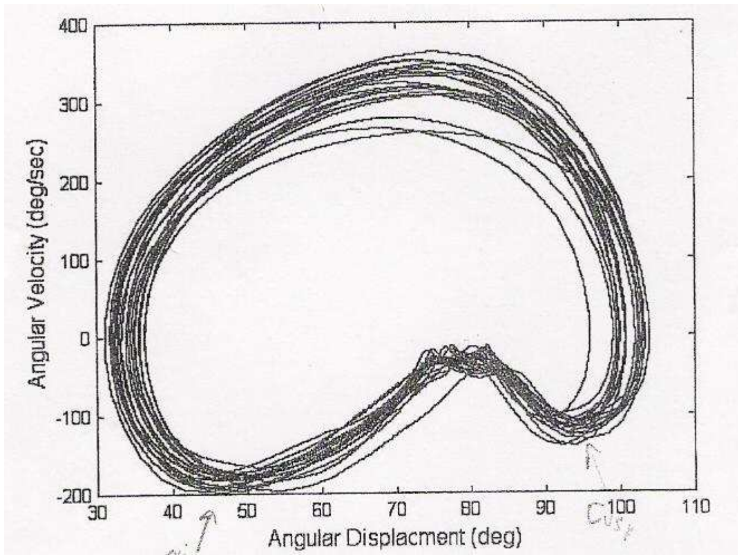
Appendix C

Table 14: Current Research in Woman Kinematics during Dynamic Activities compared to men:

Ankle
Greater overall ankle ROM during jumps [1]
Significantly more ankle dorsiflexion and ankle pronation during single-legged squat [5]
Knee
Greater overall knee ROM during jumps [1]
Longer to reach peak knee extensor joint moment during jumps[1]
Significantly less knee flexion occurring earlier in activities[2 58]
More proximal tibia anterior shear force during jumping tasks [14]
Started and ended in a more valgus position during single-legged squat [5]
Hip and Trunk
Land in more erect position for jumps [1]
Significantly more hip internal rotation during single-leg landings [2]
Significantly more hip rotation time with hop tests [2]
More hip adduction and hip flexion during single-legged squat [5]
Less lateral trunk flexion during single-legged squat [5]
Other Findings
Same vertical ground reaction forces with jumps [2]
Similar times, with similar velocities during jumps [2]

Figure 28: Phase Portrait of pelvis to thigh for gait in a) healthy adult versus phase portrait of pelvis to thigh for gait in b) an adult with Parkinson's disease [32]

a)



b)

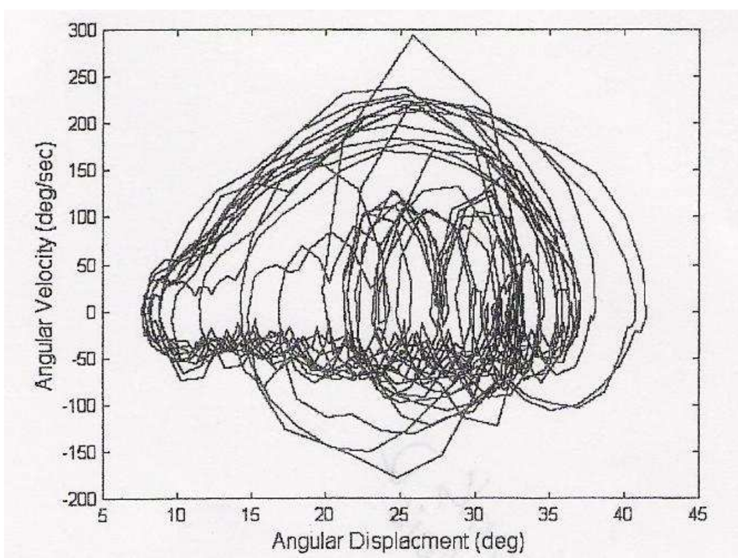
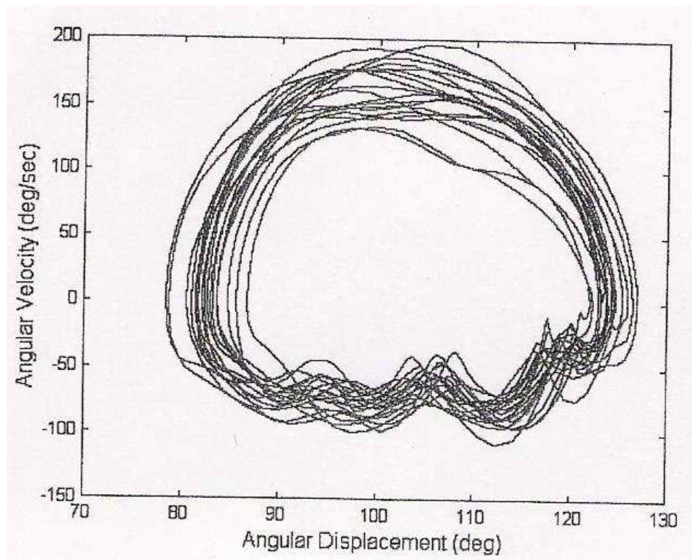
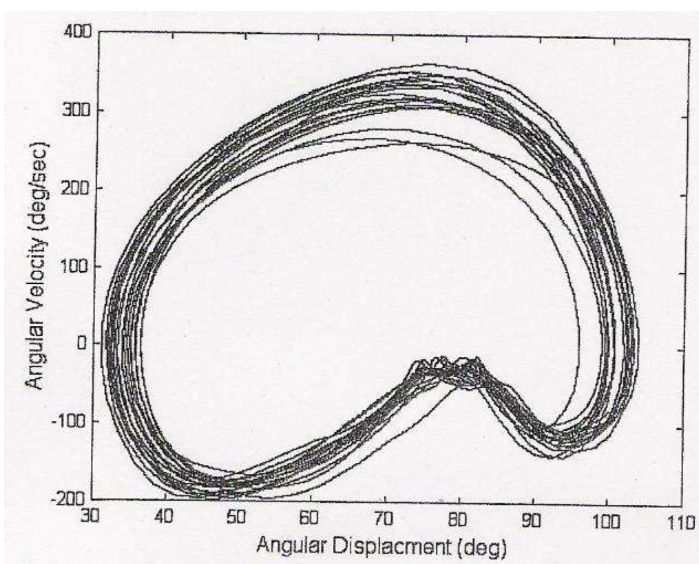


Figure 26: Walking: a) in phase coordination pattern versus b) out of phase walking pattern [32]

a)



b)



Bibliography

1. Decker M, Torry M, Wyland D, Sterett W, Steadman J. Gender differences in lower extremity kinematics, kinetics and energy absorption during landing. *Clin Biomech.* 2003;18:662-669.

2. Lephart S, Ferris C, Riemann B, Myers J, Fu F. Gender differences in strength and lower extremity kinematics during landin. *Clinc Ortho Related Res.* 2002;1:162-169.

3. Malinzak R, Colby S, Kirkendall D, Yu B, Garrett W. A comparsion of knee joint motion patterns between men and women in selected athletic tasks. *Clin Biomech.* 2001;16:438-445.

4. Wojcik L, Thelen D, Schultz A, Ashton-Miller J, Alexander N. Age and gender differences in peak lower extremity joint torques and ranges of motion used during single-step balance recovery from a forward fall. *J Biomech.* 2001;34:67-73.

5. Zeller B, McCroy J, Kibler B, Uhl T. Differences in kinematics and electromyographic activity between men and women during the single-legged squat. *Am J Sports Med.* 2003;31:449-456.

6. Hamill J, van Emmerik R, Heiderscheit B, Li L. A dynamical systems approach to lower extremity running injuries. *Clin Biomech.* 1999;12:297-308.

7. Davids K, Glazier P, Araujo D, Bartlett R. Movement systems as dynamic systems: The functional role of variability and its implications for sports medicine. *Sports Medicine.* 2003;23:245-260.

8. Clark J. Dynamical systems perspective on gait. In: Craik R, Oatis R, eds. *Gait Application and Theory*: Mosby; 1995.

9. Li L, van den Bogert E, Caldwell C, van Emmerik R, Hamill J. Coordination patterns of walking and running at similar speed and stride frequency. *Hum Mov Sci.* 1999;18:67-85.

10. Buzzi U, Ulrich B. Dynamic stability of gait cycles as a function of speed and system constraints. *Motor Control.* 2004;8:241-253.

11. Schache A, Blanch P, Rath D, Wrigley T, Bennell K. Differences between the sexes in the three-diminsonal angular rotations of the lumbo-pelvic-hip complex during treadmill running. *J Sports Sci.* 2003;21:105-118.

12. Van Uden C, Bloo J, Kooloos J, Van Kampen A, de Witte J, Wagenaar R. Coordination and stability of one-legged hopping patterns in patients with anterior cruciate ligament reconstruction: preliminary results. *Clin Biomech.* 2003;18:84-87.

13. Wojtys E, Ashton-Miller J, Huston L. A gender-related difference in the contribution of knee musculature to sagittal plane shear stiffness in subjects with similar knee laxity. *J Bone Joint Surg.* 2002;84-A:10-16.

14. Chappell J, Yu B, Kirkendall D, Garrett W. A comparison of knee kinetics between man and woman recreational athletes in stop-jump tasks. *Am J Sports Med.* 2002;30:261-267.

15. Schmuitz R, Riemann B, Thompson T. Gluteus medius activity during isometric closed-chain hip rotation. *J Sports Rehab.* 2002;11:179-188.

16. Gross M. Lower quarter screening for skeletal malalignment- suggestions for orthotics and shoewear. *J Orthop Sports Phys Ther.* 1995;21:389-405.

17. Razeghi M, Batt M. Foot type classifications: a critical review of current methods. *Gait Posture.* 2002;15:282-291.

18. Magee D. *Orthopedic Physical Assessment*. 3 ed. Philadelphia: W.B. Saunders; 1997.

19. Drouin J, Valovich-mcLeod T, Shultz S, Gansneder B, Perrin D. Reliability and validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque, and position measurement. *Eur J Appl Physiol.* 2004;91:22-29.

20. Wilk K, Romaniello W, Soscia S, Arrigo C, Andrews J. The relationship between subjective knee scores, isokinetic testing, and functional testing in the ACL-reconstructed knee. *JOSPT.* 1994;20:60-73.

21. Wedekind S. The relationship between core strength and pelvic position of woman athletes during dynamic activity. *Unpublished master's thesis, Georgia Southern University, Statesboro, Georgia.* 2004.

22. Bertocci G, Munin M, Frost K, Burdett R, Wassinger C, Fitzgerald S. Isokinetic performance after total hip replacement. *Am J Phys Med Rehab.* 2004;83:1-9.

23. Leetun D, Ireland J, Wilson J, Ballantyne B, Davis M. Core stability as risk factors for lower extremity injury in athletes. *Med Sci Sports Exerc.* 2004;26:926-934.

24. Le Clair K, Riach C. Postural stability measures: what to measure and for how long. *Clin Biomech.* 1996;11:176-178.

25. Brosky J, Nitz A, Malone T, Caborn D, Rayens M. Intrarater reliability of selected clinical outcome measures following anterior cruciate ligament construction. *J Orthop Sports Phys Ther.* 1999;29:39-48.

26. Salem, Salinas, Harding. Bilateral kinematic and kinetic analysis of the squat exercise after anterior cruciate ligament reconstruction. *Arch Phys Med Rehabil.* 2003;84:1211-1216.

27. Selfe J. Motion analysis of eccentric step test performed by 100 healthy subjects. *Physiotherapy.* 2000;85:241-247.

28. Leardini A, Catani F, al e. Validationof a functional method for estimation of hip joint centre location. *J Biomech.* 1999;32:99-103.

29. Bandy W, Rusche K, Tekulve F. Reliability and limb symmetry for five unilateral functional tests of the lower extremities. *Isokinet Exerc Sci.* 1994;4:108-111.

30. Bolgla L, Keskula D. Reliability of lower extremity functional performance tests. *J Orthop Sports Phys Ther.* 1997;26.

31. Walter C. An alternative view of dynamical systems concepts of motor control and learning. *Res Quarterly Exerc Sport.* 1998;69:326-333.

32. Kurz M, Stergiou N. Applied dynamic systems theory for the analysis of movement. In: Stergiou N, ed. *Innovative Analysis of Human Movement*: Human Kinetics; 2004.

33. Lamoth C, Beek P, Meijer O. Pelvis-thorax coordination in the transverse plane during gait. *Gait Posture.* 2002;16:101-114.

34. Heiderscheit B, Hamill J, van Emmerik R. Q-angle influences on the variability of lower extremity coordination during running. *Med Sci Sports Exerc.* 1999;31:1313-1319.

35. Kurz M, Stergiou N. Effect of normalization and phase angle calculations on continuous relative phase. *J Biomech.* 2002;35:369-374.

36. Arendt E, Dick R. Knee injury patterns among men and women in collegiate basketball and soccer: NCAA data and review of literature. *Am J Sports Med.* 1995;23:694-701.

37. Davids K, Handford C, Williams M. The natural physical alternative to cognitive theories of motor behavior:An invitation for interdisciplinary research in sports science. 1994.

38. Slauterbeck J, Fuzie S, Smith M, et al. The menstrual cycle, sex hormones, and anterior cruciate ligament injury. *JAT.* 2002;37:275-280.

39. Hewett T. Neuromuscular and hormonal factors associated with knee injuries in woman athletes: strategies for intervention. *Sports Medicine.* 2000;29:313-327.

40. Dienst M, Burks R, Greis P. Anatomy and biomechanics of the anterior cruciate ligament. *Ortho Clinics North America.* 2002;22.

41. Harmon K, Ireland M. Gender differences in noncontact anterior cruciate ligament injuries. *Clinics in Sports Medicine.* 2000;12.

42. Karageanes S, Blackburn K, Vangelos Z. The association of the menstrual cycle with laxity of the anterior cruciate ligament in adolescent woman athletes. *Clinical J Sports Med.* 2000;10:162-168.

43. Ireland M. The woman ACL: why is it more prone to injury. *Ortho Clinics North America.* 2002;33.

44. Lephart S, Abt J, Ferris C. Neuromuscular contributions to anterior cruciate ligament injuries in women. *Curr Opinion Rheumatology.* 2002;14:168-173.

45. Colby S, Francisco A, Yu B, Kirkendall D, Finch M, Garrett W. Electromyographic and kinematic analysis of cutting maneuvers: implications for anterior cruciate ligament injury. *Am J Sports Med.* 2000;26:234-240.

46. Sell K, Verity T, Worrell T, Pease B, Wigglesworth J. Two measurement techniques for assessing subtalar joint position: a reliability study. *J Orthop Sports Phys Ther.* 1994;19:162-167.

47. Neely F. Methods of measurement of biomechanical abnormalities of the lower limbs: a review of their reliability. *Sport Exercise and Injury.* 1997;4:168-171.

48. Bennett J, Reinking M, Pleumer B, Pentel A, Seaton M, Killian C. Factors contributing to the development of medial tibial stress syndrome in high school runners. *J Orthop Sports Phys Ther.* 2001;31:504-510.

49. White S, Gilchrist L, Wilk B. Asymmetric limb loading with true or simulated leg-length differences. *Clin Orthop.* 2004;421:287-292.

50. O'Toole G, Makwana N, Lunn J, Harty J, Stephens M. The effect of leg length discrepancy on foot loading patterns and contact times. *Foot Ankle Int.* 2003;24:256-259.

51. Singerman R, Davy D, Goldberg V. Effects of patella alta and patella infera on patellofemoral contact forces. *J Biomech.* 1994;27:1059-1065.

52. Bickham D, Young W, Blanch P. Relationship between a lumbopelvis stabilization strength test and pelvic motion in running. *Journal of Sport Rehabiliation.* 2000;9:219-228.

53. Nadler S, Malanga G, Bartolia L, Feinberg J, Prybicien M, Deprince M. Hip muscle imbalance and low back pain in athletes: influence of core strength. *Med Sci Sports Exerc.* 2002;34:9-16.

54. Greenberger H, Paterno M. Relationship of knee extensor strength and hopping test performance in assessment of lower extremity. *J Orthop Sports Phys Ther.* 1995;22:202-206.

55. Jaric S. Muscle Strength testing: use of normalization for body size. *Sports Medicine.* 2002;32:615-631.

56. Cahalan T, Johnson M, Lui S, Chao E. Quantitative measurements of hip strength in different age groups. *Clin Orthop Relat Res.* 1989(246):136-145.

57. Clark N. Functional performance testing following knee ligament injury. *Physical Therapy in Sports.* 2001;2:91-105.

58. McLean S, Neal R, Myers P, Walters M. Knee joint kinematics during the sidestep cutting maneuver: potential for injury in women. *Med Sci Sports Exerc.* 1999;31:959-968.

59. Buchanan P, Vardaxis V. Sex-related and age-related differences in knee strength in basketball players ages 11-1 years. *J Athl Train.* 2003;38:231-237.

60. Huston L, Wojtys E. Neuromuscular performance characteristics in elite woman athletes. *Am J Sports Med.* 1996;24:427-436.

61. Neumann D, Soderberg G, Cook T. Comparsison of maximal isometric hip abductor muscle torques between hip sides. *Phys Ther.* 1988;68:496-452.

62. Johnson M, Mille M, Martinez K, Crombi G, Rogers M. Age-related changes in hip abductor and adductor joint torques. *Arch Phys Med Rehabil.* 2004;85:593-597.