

KNEE VALGUS IN SELF-INITIATED VERTICAL JUMP LANDINGS: DEVELOPMENTAL AND GENDER COMPARISONS

Pamela J. Russell¹, Erik E. Swartz², Laura C. Decoster³, Ron V. Croce²

¹Bridgewater State College, Bridgewater, MA, USA; ²University of New Hampshire, Durham, NH, USA; ³NH Musculoskeletal Institute, Manchester, NH, USA

The study examined gender and developmental differences in knee valgus angle and external knee valgus moment at the time of maximal vertical ground reaction force (MGRFz) in self-initiated vertical jump (VJ) landings. Fifty-six subjects grouped by age (pre-pubescent (8-11 yrs); post-pubescent (19-29 yrs)) and gender jumped for a ball set at 50% of their maximum VJ height then landed on two feet with only their dominant foot on the force plate. Statistical analyses of motion analysis (3-D) and GRF data showed that children had greater valgus angles ($p = .003$) and moments ($p = .026$) at MGRFz compared to adults. Females had greater ($p = .016$) valgus moments than males, but similar valgus angles at MGRFz. It will be important to ensure that as both boys and girls progress through puberty they develop an ability to offset high valgus moments and land with good lower extremity alignment

KEY WORDS: landing, knee valgus, gender, development.

INTRODUCTION: Recent findings continue to support the gender disparity in non-contact anterior cruciate ligament (ACL) injuries (Agel, *et al.*, 2005). Females injure the ACL at rates 2.4 to 9.7 times greater than males. The multifactorial nature of these non-contact ACL injuries has made it difficult to specify contributory factors, but current research is linking sagittal and frontal plane mechanics in an effort to understand their coupled influence on the ACL (Kernozek, *et al.*, 2005). Gender differences may be more evident in frontal, not sagittal, plane mechanics. In a recent prospective study of 205 female athletes (15-16 years-old), knee external valgus moments and angles were significant predictors of ACL injury (Hewett, *et al.*, 2005). The ACL-injured group displayed 8° more knee valgus than the uninjured group and the greater valgus positions of the ACL-injured group correlated with their maximal vertical ground reaction force (MGRFz). Combined sagittal and frontal plane loading may contribute to ACL injury (Freedman *et al.*, 1998) yet not many studies have coupled sagittal and frontal plane mechanics (e.g., Hewett *et al.*, 2005; Kernozek, *et al.*, 2005). Few have explored when, during development, gender differences in these coupled mechanics may become apparent. This study examines knee valgus position and knee abduction/adduction moments at the time of MGRFz across gender and developmental levels (i.e., pre- and post-pubescent) during self-initiated vertical jump (VJ) landings. Information about the multidirectional impact of forces at the knee during jump-landings could contribute to the ACL injury puzzle solution.

METHODS:

Subjects: Fifty-six subjects without back or lower extremity injuries volunteered to participate. Subjects were grouped by gender and age as either prepubescent or post-pubescent according to guidelines established by Tanner (1986). Since the onset of puberty is correlated with a rapid gain in height at an average age of 10.5 for girls and 12.5 for boys (Tanner, 1986), prepubescent subjects (i.e., children) included girls 7-10 years of age and boys 8-11 years of age. Puberty is complete at approximately 17 years for females and 20 years for males, thus post-pubescent subjects (i.e., adults) included 19-29 year old women and men. All subjects were recreational participants in jumping and landing activities and demonstrated a mature vertical jump pattern.

Subject Preparation: Upon reporting to the laboratory, adult subjects and parents of each child signed a University-approved consent form. Subjects dressed in form-fitting clothing and were fitted with standardized footwear in appropriate sizes (New Balance Athletic Shoe

Company, Lawrence, MA). Maximum VJ height was selected from three maximal effort VJs, completed using a VERTEC® (Sports Imports, Inc. Columbus, OH). Leg dominance was established by asking the subject to jump up and land on one leg. Subjects then practiced the jump-landing task. Jumps were vertical, made from a standing position, and included grabbing a target (64 cm circumference inflatable ball) suspended from the ceiling on a retractable cord at 50% of the subject's maximum VJ height. Landings were on two feet in a balanced face forward position, with only the dominant foot on the force plate. Each subject took off from a self-selected position, established during the practice. Following practice, one inch retro-reflective markers were placed on the right and left sides of the subject at the: acromioclavicular joint, anterior-superior iliac spine, greater trochanter, anterior thigh, lateral femoral condyle, tibial tuberosity, middle tibia, distal tibia, superior navicular, lateral calcaneus, and base of the fifth metatarsal. These markers defined a 3-segment model for each leg. A single marker was placed on the sacrum to define a pelvis segment.

Data Collection: Following application of reflective markers, each subject started from their marked position; jumped to grab the target, positioned at their midline and at 50% of their maximum VJ height; and landed on two feet, balanced and facing forward. Subjects completed four trials that met the above criteria. Three-dimensional position-time data were collected at 120 Hz using a 6-camera motion capture system (Motion Analysis, Inc. Santa Rosa, CA). GRF data were sampled at 960 Hz using an AMTI force plate (Advanced Medical Technologies Inc., Watertown, MA) interfaced with a 6-channel signal amplifier. All data collection was simultaneously triggered, thus synchronized. Data capture started just before the jump and ended when the subject assumed a balanced position after landing.

Data Reduction: The three-dimensional position-time data were stored by the Motion Analysis Inc., MIDAS system then tracked and smoothed (4th order recursive Butterworth filter (10 Hz)) using EVa 6.01 software. GRF data were processed with the Motion Analysis, Inc. System using the Kintrak version#6.02 software. Position-time data were imported into the Motion Analysis Inc., Kintrak software program to process kinematics, kinetics, and temporal variables. Knee angle in the frontal plane (varus/valgus) was determined using standard Euler angle calculations. Knee abduction/adduction moments were calculated using an inverse dynamics approach. Data exported to spreadsheets for statistical analyses included; knee varus/valgus angles at the time of MGRFz, external knee varus/valgus moments at the time of MGRFz, and total body kinetic energy at initial contact with the force plate. Knee varus/valgus moments were normalized to total body kinetic energy at initial contact to account for differences in mass among adults and children and differences in jump height, thus velocity at impact. Data collection from functional landing tasks as opposed to landings from standardized heights requires normalization procedures that allow comparison across subjects that jump to different heights (e.g., James, *et al.*, 2003). Data were averaged across 3-4 trials/subject before group means were calculated. Two 2 x 2 (gender x development) ANOVAs were used to determine significant ($p < .05$) differences in knee varus/valgus angle at MGRFz and external varus/valgus moment at the knee at MGRFz.

RESULTS: Subject characteristics are in Table 1. Developmental comparisons indicated that children, as compared to adults, had significantly greater knee valgus angles ($F(1,52) = 10.08$; $p = .003$) and external knee valgus moments ($F(1,52) = 6.16$; $p = .016$) at MGRFz (Table 2). Gender comparisons showed that at MGRFz females had significantly ($F(1,52) = 5.25$; $p = .026$) greater external knee valgus moments than males (Table 2).

Table 1. Subject Characteristics (Mean \pm SD).

Group	Age (years)	Height (cm)	Mass (kg)	VJ (cm)
Children (n=27)	9.40 \pm 1.01	136.00 \pm 9.46	33.29 \pm 7.75	30.21 \pm 5.58
Adults (n = 28)	23.90 \pm 2.76	170.91 \pm 9.49	72.83 \pm 14.75	48.85 \pm 10.85

Table 2. Knee Valgus Angle and External Moment: Developmental and Gender Comparison (Mean \pm SD)

Group	Knee Valgus at MGRFz (degrees)	External Knee Valgus Moment at MGRFz (Nm/KE)
Children (n=27)	10.34 \pm 5.35 ^a	-.41 \pm .31 ^b
Adults (n=28)	5.64 \pm 5.91 ^a	-.24 \pm .22 ^b
Females (n=27)	8.85 \pm 4.43	-.40 \pm .28 ^c
Males (n=28)	7.14 \pm 7.34	-.25 \pm .26 ^c

^{a,b,c} $p < .05$

DISCUSSION: The intent of this study was to examine frontal plane knee angles and moments at maximal sagittal plane loading during a jump-landing task. Developmental comparisons showed that children had significantly more knee valgus (10.34°) than adults (5.64°) did at MGRFz. Although there are no known knee valgus comparisons between prepubescent children and adults during jump-landing, Barber-Westin, *et al.*, (2005) examined frontal plane lower limb alignment during a drop vertical jump task. Of 52 subjects 9 to 10 years-old, 19 boys (76%) and 25 girls (93%) showed distinct knee valgus at landing. Valgus angles were not quantified, but valgus position was indicated by lack of knee separation in reference to hip width (i.e., the frontal plane distance between the knees was 60% or less of the frontal plane distance between the hips). In a second study of 536 children 9 to 17 years-old, the majority had distinct knee valgus alignment upon landing, (i.e., the deepest point of the phase, viewed from the front) (Barber-Westin, *et al.*, 2006). Data from the current study support the work of Barber-Westin and colleagues and indicate that young children display knee valgus when landing from jump.

At MGRFz, children also had significantly greater normalized external knee valgus moments compared to adults. An external valgus moment would be resisted by an internal varus moment to keep the lower extremity aligned and prevent excess valgus positioning. Internal varus moments were not determined in this study, but, unlike adults, children appeared less successful in offsetting the external valgus moment. That is, children displayed more knee valgus at MGRFz than adults did. These prepubescent children may not currently possess the necessary strength or skill to control knee valgus during landing. Yet, as these children become physically mature through puberty, their muscle strength will increase and their mastery of motor skills will improve. These growth-related changes should give them better control over the external valgus moment that occurs at MGRFz during jump landing. Since increased knee valgus at landing (Hewett, *et al.*, 2005) may predispose female athletes to ACL injury, it will be very important to ensure increases in muscle strength and motor control parallel the physical changes initiated by puberty so that pubertal children gain control over valgus loading during jump-landing.

Gender comparisons showed that at MGRFz: females had significantly greater normalized external knee valgus moments than males, without a concomitant difference in knee valgus position. Although no gender comparisons were made during a drop vertical jump task with a two-footed landing, Hewett *et al.*, (2005) found a 2.5% greater external knee valgus moment and 8° more knee valgus at MGRFz in 15-16 year-old females that later incurred an ACL injury compared to 15-16 year-old females that did not incur ACL injury. In a gender comparison of internal varus moments during a drop jump task with a two-footed landing, 24 year-old females had significantly smaller peak varus moments than 24 year-old males and a

significantly greater range of knee varus/valgus motion during landing (Kernozek, *et al.*, 2005). However, examination of valgus position at peak internal varus moment showed no gender differences (Kernozek, *et al.*, 2005). Chappell *et al.*, (2002) reported no gender differences in knee varus/valgus moments in 19 to 25 year-olds when landing on two-feet in three different stop-jump tasks. Valgus position data were not collected. Gender differences in knee valgus position and moments may vary with the landing task (land-stop, land-go, drop-land, jump-land, planned, reactive, number of legs, etc.), time of observation during landing, and the performer's physical characteristics, particularly those that change with maturation.

Although there were no significant statistical interactions in this study, use of a gender category with a broad age range (i.e., 9-10 and 23-24 year-olds) may confound gender comparisons regarding knee valgus. Future research should group according to small age ranges or physical maturation and link multidirectional joint kinetics and kinematics to investigate portions of landing that are most stressful to the ACL ligament.

CONCLUSION: This study examined gender and developmental differences in knee valgus angle and the external knee valgus moment at the time of MGRFz during landing from a self-initiated VJ. Children had more knee valgus and a greater external valgus moment than adults did at the time of MGRFz. There were no gender differences in knee valgus at MGRFz, but females had a greater external valgus moment at the time of MGRFz. It will be important to ensure that as children progress through puberty they develop the ability to offset potentially higher external valgus moments and land with good lower extremity alignment.

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