LOADING RATE IN SELF-INITIATED VERTICAL JUMP LANDINGS: DEVELOPMENTAL AND GENDER COMPARISONS

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The study compared gender and developmental differences in vertical loading rate upon a two-footed landing from a self-initiated VJ. Fifty-seven subjects grouped by age (pre-pubescent (8-11 yrs); post-pubescent (19-29 yrs)) and gender consented to participate. Subjects jumped for a ball set at 50% of their maximum VJ height, and landed on two feet, facing forward, with only their dominant foot on the force plate. Motion analysis (3-D) and ground reaction force (GRF) data were collected. Statistical analyses indicated significant developmental differences in vertical loading rate normalized to kinetic energy, but no gender differences. Children may have higher loading rates because they lack the experience, strength, and associated neuromuscular patterns that prepare them to modulate force as adults do.

KEY WORDS: landings, loading rate, development, gender.

INTRODUCTION: Research surrounding the disproportionately higher incidence of non-contact anterior cruciate ligament (ACL) injuries in females has led to numerous investigations of the biomechanics and neuromuscular aspects of landing (e.g., McClay & Ireland, 2003). Initial findings indicated that females had less knee flexion upon landing, but current findings are mixed regarding gender differences in landing mechanics (e.g., knee flexion angle) (Ford, Myer, Devine, & Hewitt, 2004) and indicate that both landing type (e.g., single leg, double leg) and landing task (e.g., drop jump, vertical jump, stride jump, etc.) (McClay & Ireland, 2003) are influential. Age or developmental level also impacts landing mechanics (Hass, Schick, Chow, Tillman, Brunt, & Cauraugh, 2003; Yu, McClure, Onate, & Guskiewicz, 2004). To grasp an understanding of the gender disparity in ACL injury rates almost seems further from us than it was previously, as echoed by participants at the most recent ACL research retreat (McClay & Ireland, 2003). Yet, there is clearly a need for further insight into ACL injury mechanisms as this injury remains 2.4 to 9.7 times greater in females (Beynnon, 2003) than males and occurs without contact in 70% of the cases (Fleming, 2003). Although no direct causal relationship between magnitude of external load and ACL injury has been documented, the rate at which vertical load is modulated may influence injury risk (Dufek & Bates, 1990). Information regarding loading rates experienced during landing tasks could contribute to the ACL injury puzzle solution (McClay & Ireland, 2001). In addition, developm ental level appears to interact with gender to influence landing kinetics and kinematics (e.g., Yu, et al., 2004). Thus, this study examined landing from a self-initiated vertical jump (VJ) across gender and developmental level (i.e., pre- and post-pubescent). The purpose was to compare gender and developmental differences in vertical loading rate upon a two-footed landing from a self-initiated VJ.

METHODS:

Subjects: Fifty-seven subjects with no back or lower extremity injuries volunteered to participate. Subjects were grouped by gender and age, that is, 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 in the age range of 7-10 years and boys in the age range of 8-11 years. 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 experienced recreational participants in jumping and landing activities and demonstrated a mature VJ.

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). Each subject completed three maximal effort self-initiated VJs using a VERTEC (Sports Imports, Inc. Columbus, OH). Leg dominance was determined by asking the subject to jump up and land on one leg. Subjects then practiced the jumping and landing task. Jumping involved completion of a standing VJ to grab a target (64 cm circumference inflatable ball) suspended on a retractable cord at 50% of the subject's maximum VJ height. Landings were on two feet in a balanced and face forward position with only the dominant foot on the force plate. Each subject selected a take-off position during the practice trials. This position was marked on the floor for subsequent data collection. Following the 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). Ground reaction force 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 were simultaneously triggered, thus synchronized. Data capture started just before the self-initiated VJ 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. Ground reaction force data were processed with the Motion Analysis, Inc. System using the Kintrak 6.02 software program. Trials were imported in to the Motion Analysis Inc., Kintrak 6.02 software program for processing kinematics, kinetics, and temporal variables. Data exported to spreadsheets for statistical analysis included; maximum vertical ground reaction force (MGRFz), time from initial contact (IC) to MGRFz, and vertical velocity of total body center of mass just prior to IC. Vertical loading rate was determined as the MGRFz normalized to total body kinetic energy at IC (i.e., normalized maximal load), divided by the time from IC to MGRFz. This normalization process was necessary to account for differences in mass among adult and children subjects and differences in jump height, thus velocity at impact. With data collection from functional landing tasks as opposed to landings from standardized heights, these normalization procedures allow comparison across subjects that jump to different heights (e.g., James, Bates, & Dufek, 2003). Data were averaged across 3-4 trials/ subject before group means were calculated. A 2 x 2 (gender x development) ANOVA was used to determine significant differences in loading rate. A second 2 x 2 x 2 (gender x development x loading factors) was used to locate the source of differences in loading rate. Significance was set at $p < .05$.

RESULTS: Subject characteristics are displayed in Table 1. Loading rate and loading rate factors are displayed in Table 2. Results showed significant differences in loading rate ($F(1,53) = 10.877$; $p = .002$) between adults and children, but no significant gender differences. Children also demonstrated significantly greater maximum normalized vertical load ($F(1,53) = 33.838$; $p = .0000$) and significantly less time to reach maximum vertical load ($F(1,53) = 4.179$; $p = .046$).

Table 1 Subject characteristics (Mean ± SD).

Group	Age (years)	Height (cm)	Weight (kg)	VJ (cm)
Children (n=29)	9.41 ± 0.99	136.63 ± 9.51	33.85 ± 7.90	29.85 ± 5.58
Girls (n=14)	9.19 ± 1.00	136.67 ± 6.15	32.91 ± 8.10	27.94 ± 4.97
Boys (n=15)	9.63 ± 0.95	136.60 ±12.23	34.79 ± 7.86	31.75 ± 5.66
Adults (n = 28)	23.90 ± 2.76	170.91 ± 9.49	72.83 ± 14.75	48.85 ± 10.85
Women (n=14)	24.22 ± 2.27	163.54 ± 6.22	62.37 ± 9.11	41.91 ± 4.62
Men (n=14)	23.57 ± 3.23	178.29 ± 5.59	83.29 ± 11.53	55.79 ±10.93

Table 2 Developmental and Gender Loading Rate Characteristics (Mean ± SD).

Group	Loading Rate ((N/KE)/sec)	Maximal Normalized Vertical Load (N/KE)	Time to Maximal Vertical Load (sec)
Children (n=30)	263.91 ± 187.09	8.25 ± 2.62	.0393 ± .0149
Adults (n=28)	131.88 ± 95.04	4.93 ± 1.44	.0561 ± .0410

DISCUSSION: The intention of this research was to examine gender and developmental differences in vertical loading rate when landing from a self-initiated VJ. Loading rate data may facilitate an understanding of the gender disparity in non-contact ACL injuries. A higher loading rate may be associated with a greater risk of injury (Dufek & Bates, 1990). If females exhibit greater loading rates than males in landing tasks, it may be a factor that increases the females' risk of ACL injury. However, no gender differences were evident for this sample of recreational athletes. Instead developmental differences were apparent. Children exemplified almost twice the loading rate of adults, given their body mass and velocity just prior to plate-contact.

The higher loading rates demonstrated by the children were due to significantly faster times to MGRFv (i.e., on average 16.8 ms faster) and significantly greater MGRFv normalized to KE just prior to impact. Children also reached MGRFv quicker in a study by Hass et al. (2003) who's prepubescent girls (age 8-11) reached MGRFv an average of 14 ms faster than post-pubescent girls (age 18-25) when performing a series of stride jump tasks with one-foot landings. Hass et al. did not find developmental differences in the magnitude of the MGRFv as normalized to bodyweight. Normalization to body weight does not address any potential differences in velocity just prior to impact, making it difficult for direct comparison to the MGRFv normalized to KE in this study. However, if a mean loading rate is calculated for the stride jumps in Hass's Table 2 using the mean MGRFv and the time to reach MGRFv, loading rates range from 72 to 99 body weights/second (BW/sec) for children and 50 to 65 BW/sec for adults. Expression of our data in BW/sec yields average loading rates of 47.4 for children and 37.4 for adults. Given unknown differences in jump heights across the two studies and one versus two footed landings, these loading rates are most likely comparable. Children seem to generate larger loading rates than adults. This difference may exist because children are less prepared for the landing simply because they are children, that is, they have yet to accrue the experience, strength, and associated neuromuscular patterns that prepare them to modulate force as adults do.

If a high loading rate is a major factor in ACL injury risk, these results appear counterintuitive as 8-11 year old children are not experiencing a majority of ACL injuries, that is, as compared to older aged children and adults. However, the ability to effectively modulate force may interact with the degree of muscle co-contraction at entry into the task (Chmielewski, Hurd, Synder-Mackler, 2004). Too much co-contraction may create a stiff system, less capable of adaptation. A previous investigation of this same sample (Croce, Russell, Swartz, & DeCoster, in press) indicated that adults had a greater level of hamstrings/quadriceps co-contraction 100 msec prior to landing. Adults appeared to pre-tune the hamstrings prior to landing, perhaps in anticipation of impact forces. On the other hand, children exhibited significantly smaller co-contraction ratios prior to landing and significantly greater hamstrings' co-activation just after landing. This difference in hamstrings to quadriceps co-contraction prior to landing may be a factor allowing children to cope with greater loading rates without injury.

CONCLUSION: In this developmental and gender comparison of vertical loading rates upon landing from a self-initiated VJ, there were no gender differences, but children demonstrated significantly greater loading rates than adults. Children reached MGRFz significantly faster and had significantly larger normalized maximal loads. This developmental difference may be related to the fact that children are children, that is, they have yet to accrue the experience, strength, and associated neuromuscular patterns that prepare them to modulate force as adults do. Less muscle stiffness about the knee joint prior to landing may be a factor that permits children to deal with loading rates higher than those of adults. Future study should examine the loading rates of just adults to scrutinize the gender difference. Developmental issues surrounding the ACL injury puzzle need to continue to be addressed to determine when effective neuromuscular training programs need to be implemented to decrease the ACL injury risk for sport participants.

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