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Age and Gender Effects on Lower Extremity Kinematics of Youth Soccer Players in a Stop-Jump Task

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Background: Gender differences in lower extremity motion patterns were previously identified as a possible risk factor for noncontact anterior cruciate ligament injuries in sports.

Hypothesis: Gender differences in lower extremity kinematics in the stop-jump task are functions of age for youth soccer players between 11 and 16 years of age.

Study Design: Descriptive laboratory study.

Methods: Three-dimensional videographic data were collected for 30 male and 30 female adolescent soccer players between 11 and 16 years of age performing a stop-jump task. The age effects on hip and knee joint angular motions were compared between genders using multiple regression analyses with dummy variables.

Results: Gender and age have significant interaction effects on standing height ($P = .00$), body mass ($P = .00$), knee flexion angle at initial foot contact with the ground ($P = .00$), maximum knee flexion angle ($P = .00$), knee valgus-varus angle ($P = .00$), knee valgus-varus motion ($P = .00$), and hip flexion angle at initial foot contact with the ground ($P = .00$).

Conclusion: Youth female recreational soccer players have decreased knee and hip flexion angles at initial ground contact and decreased knee and hip flexion motions during the landing of the stop-jump task compared to those of their male counterparts. These gender differences in knee and hip flexion motion patterns of youth recreational soccer players occur after 12 years of age and increase with age before 16 years.

Clinical Relevance: The results of this study provide significant information for research on the prevention of noncontact anterior cruciate ligament injuries.

Keywords: anterior cruciate ligament (ACL); injury prevention; adolescents; landing; biomechanics

Anterior cruciate ligament injuries are among the most common knee injuries in sports.9,13,36 Rupture of the ACL has been estimated to occur in the general population at a frequency of approximately 1 in 3000 people in the United States per year.13,36 Of these injuries, approximately 70% occur in recreational and sporting activities, with the highest frequency in athletes participating in sports involving pivoting and sudden stopping tasks,24 including basketball,3,9 volleyball,14 and soccer.3,9 The majority of ACL injuries in sports occur in the absence of physical contact with other players at the time of injury and are categorized as noncontact ACL injuries.5,17 It has been repeatedly shown that females have a higher incidence of noncontact ACL injuries than do their male counterparts.3,9,14,30,33,42 In particular, female athletes at both the collegiate1 and high school levels7,30,58 have demonstrated an increased susceptibility to ACL injuries compared to their male counterparts.

A variety of intrinsic and extrinsic factors have been explored to account for the gender difference in susceptibility to ACL injuries. Many previous studies have focused on exploring intrinsic factors, including narrow intercondylar notch38,45,48,51, ACL size38,45, knee joint laxity46,51, standing posture, including subtalar joint pronation, misalignment of the lower extremity, and pelvic position31; and hormonal variations.24,27,55 Many of these studies regarding intrinsic factors tacitly assume that females and
females have similar knee motion patterns corresponding to similar forces on the ACL.

Extrinsic factors for noncontact ACL injuries that have also been examined include shoe-surface interaction, playing surface, skill level, level of conditioning, muscle strength, and altered neuromuscular controls. Malinzak et al. recently found that college-aged women may have smaller knee flexion angles and greater knee valgus angles during the stance phases of selected athletic tasks. Chappell et al. not only confirmed the gender differences in knee kinematics in stop-jump tasks but also showed that female recreational athletes had increased peak proximal tibial anterior shear force and knee extension moment during landings of stop-jump tasks. These gender differences in lower extremity kinematics and kinetics in athletic tasks may be associated with the elevated risk for noncontact ACL injuries in female recreational athletes. Hewett et al. and Myklebust et al. showed decreased knee injuries after lower extremity neuromuscular training programs. These studies combined together, to a certain extent, support the opinion that altered neuromuscular controls are risk factors for noncontact ACL injuries.

The purpose of this study, as a continuation of the work by Malinzak et al. and Chappell et al., was to investigate the possible age effects on the gender differences in lower extremity motion patterns of youth soccer players in a stop-jump task. An understanding of age and gender effects on the lower extremity motion patterns in athletic tasks may provide significant information for the development of prevention programs for noncontact ACL injuries. We hypothesized that gender differences in selected lower extremity kinematics in the stop-jump task were functions of age for youth soccer players between the ages of 11 and 16 years.

Methods

Subjects

A total of 60 youth recreational soccer players between 11 and 16 years of age without a known history of lower extremity injuries were recruited from youth soccer clubs in the Chapel Hill, Durham, and Raleigh areas of North Carolina. A youth recreational soccer player was defined as a child younger than 18 years who regularly played organized recreational soccer 2 to 3 times per week (2 training sessions during weekdays and a game during the weekend) within the past 2 years. Subjects were divided into 6 age groups from 11 to 16 years of age. Each age group had 5 male and 5 female subjects. The use of human subjects in this study was approved by the institutional internal review board. Written consent was obtained from each participant as well as from parents or guardians.

Testing Protocol

Subjects were asked to wear spandex shorts and comfortable running shoes. Male subjects were asked to be topless, and female subjects were asked to wear sports bras for the test. After a subject and one of his or her parents or guardians signed the consent form, his or her body mass and standing height, as well as knee and ankle joint widths, were measured. The knee width was defined as the distance between the lateral and medial femoral condyles, and the ankle joint width was defined as the distance between the lateral and medial malleoli. Body mass index was also calculated for the subject as the body mass divided by the square of standing height.

Twelve reflective markers were placed bilaterally at the acromion process, anterior superior iliac spine (ASIS), midlateral thigh, lateral condyle, midlateral shank, and lateral malleolus. Another reflective marker was placed at the joint between lumbar vertebrae 4 and 5 (L4-L5). Each reflective marker on the midthigh was placed in alignment with the reflective markers on the lateral knee and greater trochanter on the same leg in the side view. Each reflective marker on the midshank was placed in alignment with the reflective markers on the lateral knee and lateral malleolus on the same leg in the side view.

The stop-jump task consisted of an approach run with up to 4 steps followed by a 2-foot landing and an immediate 2-foot vertical jump for maximum height. After the stop-jump task was described to each subject, the subject was allowed to have as many practice and warm-up trials as desired. Demonstration of the stop-jump task was minimized to avoid coaching effects on the subject’s natural performance. After the warm-up, the subject was asked to perform 5 successful trials of the stop-jump task with maximum vertical jump effort at the highest approach run speed that he or she felt comfortable to perform the maximum-effort vertical jump. A successful trial was defined as a trial in which the subject performed the stop-jump task as instructed and the videographic and analog data were successfully collected.

Data Collection

Three-dimensional (3D) coordinate data of the reflective markers during each trial of the stop-jump task were collected using 6 infrared video cameras at a sample rate of 120 frames/s. The video cameras were calibrated for a space of 2 m long × 1.5 m wide × 2 m high. Two type 4060A Bertec force plates (Bertec Corp, Worthington, Ohio) were placed at the center of the ground level of the calibrated space to collect ground-reaction force data at 1200 samples/channel/s, so the beginning and end of the stance phase of each trial of the stop-jump task could be accurately identified in data reduction. Subjects were asked to land and jump on the force plates when performing the stop-jump task. The video cameras and force plates were controlled and time synchronized by the Peak Performance Motus videographic and analog real-time data acquisition system (Peak Performance Inc, Englewood, Colo).

Data Reduction

Raw 3D coordinates of reflective markers were filtered through a second-order Butterworth digital filter at the estimated optimal cutoff frequencies. The 3D coordinates of hip joint centers were estimated from the 3D coordi-
nates of the reflective markers on the ASIS and L4-L5, as well as cadaveric data from the literature.\(^4\) The 3D coordinates of knee joint centers were estimated from the 3D coordinates of hip joint centers, reflective markers on the midthighs, and reflective markers on the lateral knees and the knee widths. The 3D coordinates of ankle joint centers were estimated from the 3D coordinates of the reflective markers on the lateral knees, midshanks, and lateral malleoli, as well as the ankle joint widths.

Trunk, thigh, and shank segment reference frames were defined using the filtered 3D coordinates of reflective markers and joint centers. Hip joint angles were calculated as Euler angles of the thigh segment reference frame relative to the trunk segment reference frame, with flexion-extension (z-axis) as the first rotation, valgus-varus (y-axis) as the second rotation, and internal-external rotation (x-axis) as the third rotation. Knee joint angles were calculated as Euler angles of the shank segment reference frame relative to the thigh segment reference frame, with flexion-extension (z-axis) as the first rotation, valgus-varus (y-axis) as the second rotation, and internal-external rotation (x-axis) as the third rotation.

The instants of initial foot contact with the ground and maximum knee flexion were identified for each successful trial. The duration between the initial foot contact with the ground and maximum knee flexion was referred to as the landing phase of the stop-jump task. The right knee flexion and varus angles and the right hip flexion and internal rotation angles at the initial foot contact and maximum knee flexion were identified for each trial. The knee flexion-extension and valgus-varus motions and the hip flexion-extension and internal-external rotation motions were defined as the corresponding joint angles at the maximum knee flexion minus the corresponding joint angles at initial foot contact with the ground.

Data Analysis

The right hip joint flexion-extension, abduction-adduction, and internal-external rotation motions and the knee joint flexion-extension, valgus-varus, and internal-external rotation motions during the landing phases of the 5 successful trials were averaged for each subject. Regression analyses with dummy variables were performed to determine the age and gender effects on body mass, standing height, body mass index, hip and knee joint angles at initial foot contact with the ground and maximum knee flexion, and hip and knee joint motions during the landing phase of the stop-jump task. The full regression model for each dependent variable (y) was

\[
y = a_0 + b_0g + a_1(x - 10) + b_1g(x - 10) + a_2(x - 10)^2 + b_2g(x - 10)^2 + e (g = 0 \text{ for males;} \quad g = 1 \text{ for females}),
\]

where \(a_0, a_1, a_2, b_0, b_1, \) and \(b_2\) were regression coefficients; \(x\) was age; \(g\) was the dummy variable representing gender; and \(e\) was the regression residual. The 2 second-order terms of age were included in the full regression model with an expectation that the age effects on motion patterns were not linear. A stepwise procedure was used to determine the best regression equation for each dependent variable as a function of age and gender. An adjusted type I error rate of 0.01 and a partial regression determination of 0.05 were used to indicate statistical significance in determining the best regression equation for each dependent variable. This means that an independent variable in the regression model needed to have a contribution to the explanation of the total variation of the dependent variable that was no less than 5% with a type I error rate and no less than 0.01 to remain in the best regression equation.

RESULTS

Age and gender significantly affected the body mass (\(r = 0.81, P = .00\)) and standing height (\(r = 0.85, P = .00\)) for youth recreational soccer players (Figures 1 and 2). The body mass and standing height of male youth recreational soccer players had an increasing trend between 11 and 16 years of age, whereas the increase in body mass and stand-
Age and gender effects on kinematics

Height of female youth recreational soccer players tended to slow down after 12 years of age. The body mass index increased with age ($r = 0.74, P = .00$) without significant gender differences for youth recreational soccer players (Figure 3).

Age and gender significantly affected the knee flexion angle at initial foot contact with the ground ($r = 0.49, P = .00$) and the maximum knee flexion angle ($r = 0.40, P = .00$) of youth recreational soccer players during the stance phase of the stop-jump task (Figures 4 and 5). The knee flexion angle at initial foot contact with the ground and the maximum knee flexion angle of male youth recreational soccer players in the stop-jump task remained the same as age increased, whereas these angles for female youth recreational soccer players decreased as age increased, especially after 14 years of age.

Age and gender significantly affected the knee valgus-varus angle at initial foot contact with the ground ($r = 0.32, P = .00$) (Figure 6). Both male and female youth recreational soccer players had valgus knee angles at initial foot contact with the ground in the stop-jump task before 12 years of age. The knee valgus-varus angle of both male and female youth recreational soccer players at initial foot contact with the ground changed from the valgus to the varus direction. Male youth recreational soccer players, on average, had a varus knee angle at initial foot contact with the ground in the stop-jump task after 12 years of age, whereas this knee angle of their female counterparts remained in valgus.

Gender significantly affected the knee valgus-varus angle at the maximum knee flexion in the stop-jump task ($r = 0.37, P = .01$) (Figure 7). Male youth recreational soccer players, on average, had a varus knee angle at maximum knee flexion.
mum knee flexion in the stop-jump task, whereas their female counterparts, on average, had a valgus knee angle.

Age and gender significantly affected the knee valgus-varus motion during landing ($r = 0.58$, $P = .00$) (Figure 8). Female youth recreational soccer players tended to increase their knee valgus motion during the landing as age increased, whereas their male counterparts’ knee varus motion remained the same during the landing as age increased.

Age and gender significantly affected the hip flexion angle at initial foot contact with the ground ($r = 0.72$, $P = .00$) and the hip flexion angle at the maximum knee flexion ($r = 0.420$, $P = .001$) of youth soccer players in the stop-jump task (Figures 9 and 10). Male youth recreational soccer players, on average, had little hip internal rotation at initial foot contact with the ground in the stop-jump task, whereas their female counterparts, on average, externally rotated their hips approximately 13° at the same time. Male youth recreational soccer players, on average, had a 14° hip internal rotation at the maximum knee flexion in the stop-jump task, whereas their female counterparts, on average, had little hip internal rotation during the same time.

Figure 7. Gender effect on knee valgus-varus angle at the maximum knee flexion in the stop-jump task. Gender (g) significantly affects the knee valgus-varus angle at the maximum knee flexion (y) in the stop-jump task: $y = 4.428 - 12.798g$, where g = 0 for males and g = 1 for females ($r = 0.372$, $P = .005$).

Figure 8. Age and gender effects on knee valgus-varus motion during the landing of the stop-jump task. Age (x) and gender (g) significantly affect the knee valgus-varus motion of youth soccer players between 11 and 16 years of age in the stop-jump task: $y = 4.428 - 2.106g(x - 10)$, where g = 0 for males and g = 1 for females ($r = 0.420$, $P = .001$).

Figure 9. Age and gender effects on hip flexion angle at initial contact. Age (x) and gender (g) significantly affect the hip flexion angle of youth soccer players at initial foot contact with the ground (y) in the stop-jump task: $y = 53.867 - 25.216g + 8.617g(x - 10) - 1.441g(x - 10)^2$, where g = 0 for males and g = 1 for females ($r = 0.717$, $P = .000$).

Figure 10. Age and gender effects on hip flexion angle at maximum knee flexion. Age (x) and gender (g) significantly affect the hip flexion angle of youth soccer players at the maximum knee flexion (y) in the stop-jump task: $y = 53.867 - 25.216g + 8.617g(x - 10) - 1.441g(x - 10)^2$, where g = 0 for males and g = 1 for females ($r = 0.717$, $P = .000$).
Female Regression

Female Regression

Female

Male

Female

Male

comparison to prepubescent subjects. Zeller et al.59 showed an increasing trend of the rate of ACL reconstructions in adolescents after 12 years of age. A recent study by Hass et al.23 showed a significant decrease in knee flexion angles during the landings of postpubescent subjects. That study also showed significant gender differences in the entire lower extremity position in a single-legged squat. They suggested that women may tend to position their entire lower extremity and activate muscles in a manner that could increase strain on the ACL in athletic tasks. Studies on knee anatomy and biomechanics have shown that the anterior shear force applied on the tibia by the quadriceps muscles increases as the knee flexion angle decreases. Nunley et al.40 reported that the patellar tendon–tibial shaft angle increases linearly as the knee flexion angle increases with weightbearing and that, on average, female subjects’ patellar tendon–tibial shaft angle was 3.7° greater than that of male subjects. That means that female subjects had a knee anterior shear force 13% greater than that for male subjects at the same knee flexion angle. The results of the present study combined with the literature, to a certain degree, support the view that lower extremity motion patterns may be motor control–related risk factors for non-contact ACL injuries.

The gender differences in knee and hip flexion motion patterns of youth recreational soccer players after 12 years of age may be the consequences of gender differences in physical development. The results of this study showed a similar age and gender interaction effect on youth recreational soccer players’ standing height, body mass, and relative body mass as that on their knee and hip flexion motions. The age and gender interaction effects on the development of standing height, body mass, and relative body mass of youth recreational soccer players found in this study were consistent with literature on the physical development of adolescents. The Centers for Disease Control and Prevention (CDC) 2000 growth charts have shown that boys become heavier and taller than girls at the same age after 13 years of age. The general trends of the body mass and standing height curves as functions of age obtained in this study were very similar to the growth curves of weight and height for boys and girls between 11 and 16 years of age in the CDC 2000 growth charts.41

DISCUSSION

The purpose of this study was to investigate the age and gender effects on the lower extremity motion patterns of youth recreational soccer players in the stop-jump task, particularly the age and gender interaction effects. The results of this study partially supported our hypothesis that the gender differences in lower extremity motion patterns in the stop-jump task are a function of age for adolescents. The results of this study showed that female youth recreational soccer players after 12 years of age had decreased knee and hip flexion angles in comparison to their male counterparts during the landing of the stop-jump task. These results suggested that female youth recreational soccer players after 12 years of age tend to land with the lower extremities more extended than did their male counterparts when performing the stop-jump task and that this gender difference in the lower extremity movement pattern increases as age increases after 12 years of age.

Landing with small knee flexion angles in the stop-jump task may increase the load on the ACL. Powell and Barber-Foss.43 reported that high school girls had significantly greater rates of knee injuries, knee surgeries, and ACL injuries than did boys in basketball and soccer. Yu et al.58 showed an increasing trend of the rate of ACL reconstruction surgeries in adolescents after 12 years of age. A recent study by Hass et al.23 showed a significant decrease in knee flexion angles during the landings of postpubescent subjects in selected athletic tasks in comparison to prepubescent subjects. That study also showed significant increases in ground-reaction forces and lower extremity joint resultant forces and joint power of postpubescent subjects in comparison to prepubescent subjects. Zeller et al.59 recently showed significant gender differences in the entire lower extremity position in a single-legged squat. They suggested that women may tend to position their entire lower extremity and activate muscles in a manner that could increase strain on the ACL in athletic tasks. Studies on knee anatomy and biomechanics have shown that the anterior shear force applied on the tibia by the quadriceps muscles increases as the knee flexion angle decreases. Nunley et al.40 reported that the patellar tendon–tibial shaft angle increases linearly as the knee flexion angle increases with weightbearing and that, on average, female subjects’ patellar tendon–tibial shaft angle was 3.7° greater than that of male subjects. That means that female subjects had a knee anterior shear force 13% greater than that for male subjects at the same knee flexion angle. The results of the present study combined with the literature, to a certain degree, support the view that lower extremity motion patterns may be motor control–related risk factors for non-contact ACL injuries.

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The age and gender interaction effects on the standing height, body mass, and body mass index of youth recreational soccer players may indicate an age and gender interaction effect on their strength. Investigators repeatedly have reported the correlations of strength with standing height and body mass. Gross et al.\textsuperscript{15-20} have reported positive correlations of lifting capacity with standing height and body mass for subjects between 10 and 80 years of age. Hager-Ross and Rosblad\textsuperscript{21} studied the grip strength in children from 4 to 16 years of age. They reported strong correlations of grip strength with standing height and body weight. They also reported that the increase in grip strength with age was approximately parallel for boys and girls until 10 years of age, after which boys were significantly stronger than were girls. The combination of the results of this study and the results in the literature, to a certain extent, indicates that the gender difference in relative strength may occur and tend to increase among youth after 12 years of age and that the gender differences in knee and hip flexion motions of youth recreational soccer players may be associated with their gender difference in strength. This means that the risk for noncontact ACL injuries may be associated with strength if lower extremity motion patterns are indeed risk factors for noncontact ACL injuries. This notion, to a certain extent, is supported by the study by Hewett et al.\textsuperscript{25} Future studies are needed to investigate the possible strength effects on lower extremity motion patterns with actual strength measures.

Prevention of ACL injuries in adolescents is an important task in sports medicine practice. The literature indicates that the ACL injury rate in adolescents increases linearly after 12 years of age and that adolescents at 17 and 18 years of age have the highest ACL injury rate.\textsuperscript{58} The literature also shows that ACL injury reconstruction surgeries are complicated for adolescents and often have poor results. Surgical treatments of ACL injuries in immature adolescents are often delayed because of the concern of secondary complications such as leg-length discrepancy and distal femoral deformity.\textsuperscript{1,11,28,29,35,47,49,53} On the other hand, the natural history of untreated ACL injuries in adolescents is not acceptable. Studies show that delaying surgical treatment of ACL injuries often results in chronic knee instability, recurrent injuries in other knee structures such as menisci, early knee osteoarthritis, and the giving up of sports.\textsuperscript{2,19,34} Because of these concerns in surgical and nonsurgical treatments of ACL injuries in adolescents, ACL injuries are more devastating for adolescents than for adults, and the early training for the prevention of noncontact ACL injuries in adolescents is important.

The results of some recent studies may need to be considered in the future development of training programs for the prevention of noncontact ACL injuries. Hewett et al.\textsuperscript{25} and Myklebust et al.\textsuperscript{60} showed reduced injury rates after neuromuscular control training. These studies provided some evidence that altered neuromuscular controls are risk factors for noncontact ACL injuries and that noncontact ACL injuries may be preventable through neuromuscular control training. However, it is not yet clear if the training effects on the injury rate were due to technical training, strength training, or both. It is not clear what the neuromuscular control training changed in regard to motion patterns in athletic tasks. Future studies may need to investigate the effects of technical training and strength training on lower extremity motion patterns in athletic tasks. Also, the athletic tasks in neuromuscular control training for female athletes should be carefully selected. Recent studies\textsuperscript{12,56} showed significant gender differences in lower extremity motion patterns in those landing tasks preceded by horizontal movements and followed by other tasks but not in a simple vertical landing task. These studies indicated that certain athletic tasks may be more relevant than other athletic tasks in neuromuscular training programs for the prevention of noncontact ACL injuries in female athletes.

This study was limited by its sample size. A relatively small sample size was used in this study, which may have prevented us from detecting gender and age effects on some other lower extremity motion patterns in this study. Future studies with a large sample size are needed to confirm the results of this study. Also, only selected lower extremity kinematic variables were analyzed in this study. Future studies are needed to investigate the age and gender differences in lower extremity kinematics, as well as kinetics, in landing tasks and estimate probability for ACL injuries. Furthermore, skill level was not controlled and used as an independent variable in this study. Future studies should control the skill level of the subjects or include the skill level as an independent variable in data analysis. Furthermore, the type I error rate used in this study as the indication of statistical significance was not adjusted for a total of 21 regression analyses because the main objective of this study was to explore if there were any age and gender differences in lower extremity motion patterns instead of determining age and gender differences in specific lower extremity motion patterns. Although the actual type I error rate of the 12 significant regression equations presented in this study was no greater than 0.04, the type I error rate may need to be adjusted for more than one regression analysis or analysis of variance to guarantee the overall type I error rate in future studies when specific lower extremity motion patterns are compared between genders and among age groups. In addition, future studies using skeletal maturity as an independent variable may be needed to establish the relationship between actual skeletal maturity and changes in neuromuscular controls. Despite these limitations, the results of this study provided significant information for future studies on the prevention of noncontact ACL injuries and the development of training programs for the prevention of noncontact ACL injuries.

CONCLUSION

Youth female recreational soccer players have decreased knee and hip flexion angles at initial ground contact and decreased knee and hip flexion motions during the landing of the stop-jump task compared to those of their male counterparts. These gender differences in knee and hip
flexion motion patterns of youth recreational soccer players appear to occur after 12 years of age and increase with age before 16 years of age. The age and gender interaction effects on the lower extremity motion patterns of youth recreational soccer players are similar to those on their body mass and standing height.

REFERENCES


