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# The Effects of Gender on the Ground Reaction Forces During an Unanticipated Jump, Land, and Cut Maneuver

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***Abstract*-** Females have a high risk for anterior cruciate ligament (ACL) injury. The most common mechanism of injury involves landing from a jump, unanticipated change of direction, and/or deceleration activities. PURPOSE: To examine the ground reaction forces of adolescent basketball athletes occurring at the knee during unplanned jump, land, and cut maneuvers. METHODS: Ten healthy adolescent basketball athletes (5 female, 5 male) participated in this study (female: age= 14.6±1.3 years; height= 177.8±8.0 cm; mass= 65.9±7.1 kg, max vertical jump= 41.9±4.3 cm; male: age= 15.2±1.9 years; height= 181.6±3.6 cm; mass= 72.7±6.0 kg, max vertical jump= 54.0±8.2 cm). Each participant was instructed to jump over a barrier, land with each foot on a floor-mounted force plate, and cut in a specific direction. Participants made a side cut either to the right or left, or stepped forward into a straight run. Each subject performed fifteen (15) randomized jump, land, and unanticipated cutting maneuvers. Independent samples t-tests examined differences between the genders for dependent variables. RESULTS: Males experience greater anterior forces during the peak knee flexion ($p = 0.022$) and push off ($p = 0.040$) during the left cut. In the center cut, males had lateral forces while females had medial forces ($p = 0.010$) in the right leg at the point of peak ground reaction forces. In the right cut, females had increased anterior forces ($p = 0.041$) in the right leg during initial contact. During peak knee flexion, males had posterior forces while females had anterior forces ($p = 0.033$) in the right leg during the right cut. During peak ground reaction forces, males experienced greater lateral forces ($p = 0.031$) in the left leg and greater posterior forces ($p = 0.009$) in the right leg during the right cut. CONCLUSION: Gender has an important impact on jump, land and cut maneuvers regardless of cutting direction. The ground reaction forces in the anterior and posterior direction were most affected between the genders which is significant as the ACL primarily restrains the tibia moving anteriorly on the femur during movement.

***Keywords*-** *anterior cruciate ligament, gender, kinetics, knee*

## I. INTRODUCTION

Research has previously attempted to examine the impact gender has on an athlete's ability to perform athletic maneuvers with some promising results. An injury to the anterior cruciate ligament (ACL) is severely debilitating (1). ACL injuries are common in athletes as it is estimated over 100,000 ACL injuries occur annually in the United States alone (2,3,4,5). The annual incidence rate for the general population (non-athletic population) is 1 in 3,000, which is relatively low (6). The ACL injury rates for athletic populations, however, are much higher.

Male and females have an overall comparable risk of sustaining an injury; however, in examining lower extremity injuries alone, females are at a much higher risk for anterior cruciate ligament (ACL) rupture. Females have a 2 to 8 times greater risk of injuring the ACL than their male counterpart (5,7,8,9,10,11,12,13,14,15,16,17,18,19,20). Sports requiring athletes to engage in frequent acceleration, deceleration, jumping, landing, and rapid changes of direction increase the risk for non-contact ACL injuries (5,8,12,13,18). An ACL injury can be described as a result from two common mechanisms, either contact or noncontact events. It has been estimated that approximately 70% of all ACL injuries are a result of a noncontact mechanism, indicating the injury occurred while the athlete was alone and was not being influenced by the impact of another athlete (4,6,21).

Previous research has indicated that many risk factors including environmental, anatomical, neuromuscular, and hormonal elements could predispose female athletes to non-contact ACL injuries (7,14). Gender differences have been a primary focus for many researchers, but other authors postulate the increased risk of injury is more dependent on sport specific activities rather than gender (22).

Sports participation has increased dramatically over the last four decades. Both male and female athletes are entering formalized athletic participation at very young age, and new opportunities for sports participation are increasing rapidly. Across the United States of America, over 25 million high school students participate in athletic activities annually and participation rates are continuing to increase (23,24).

Adolescent and prepubescent athletes most commonly injure the lower extremity (ankle and knee) followed by the hand, wrist, elbow, shin, calf, and head and neck (25). According to sources, children and adults could have physical and physiological differences which could leave younger athletes exposed to injury including: larger surface area to mass ratios than adults; disproportionately larger heads; improperly fitting protective equipment; growing cartilage vulnerable to stress; and decreased ability to perform complex motor skills required for successful participation in many sports (23). According to Junge and colleagues, many children do not have the ability to master complex motor skills until later in childhood development, typically around 10-12 years of age (11,26). In addition, a temporary decline in coordination and balance occurs to a majority of pubescent athletes. It has been postulated that pre-pubescent athletes generate lower speeds, have less mass, and declined strength capability and are thus less likely to sustain injury due to acute blunt trauma (27).

Given the current extensive body of knowledge, researchers have failed to determine the exact mechanism of injury to predict when or how injuries occur and we have yet to develop specific training protocols to prevent these injuries from occurring. The high rate of injury, especially to the female athlete, has been an area of concern for many allied health professions, athletes, and parents.

The purpose of this study was to determine the effects of gender on the vertical and shear ground reaction forces in adolescent basketball athletes to better understand the ACL injury phenomenon.

## II. METHODS

### A. Participants

Ten adolescent basketball athletes (males: n = 5; females: n = 5) between the ages of 13-17 were recruited for participation. Participants were required to have a minimum of 1 year experience playing basketball at the club level. Subject height, mass, age, maximum vertical jump, years playing basketball, years playing club are listed in Table 1.

All participants reported being free of ligamentous, bony, or cartilaginous injury in either knee for at least 6 months prior to participation. Athletes with previous anterior cruciate ligament injuries were excluded from participation. The subjects were in good physical condition and accustomed to participating in running, jumping, and changing direction during basketball practice and games. Prior to the execution of the study, all participants and their legal guardians were verbally informed of the details of the study and required to read and sign an informed ascent and consent documents approved by an Institutional Review Board for the use of Human Subjects.

### B. Instrumentation

The ground reaction forces were collected with two in-ground force plates. The force plates (Kistler, Type 9821C) were sampled at 1250 Hz. Variables obtained from the force plates included peak X (medial/lateral), Y (anterior/posterior), and Z (vertical) landing and push-off forces for each leg. All force values were normalized for participant bodyweight in order account for the effects of mass when comparing between subjects. The global coordinate orientations for each force plate are depicted in Figure 1.

TABLE 1. MALE AND FEMALE DEMOGRAPHIC DATA

Participant Demographics

| | Females | Males |
|---|---|---|
| Subjects | N = 5 | N = 5 |
| Age (years) | 14.6 ± 1.3 | 15.2 ± 1.9 |
| Height (cm) | 177.8 ± 8.0 | 181.6 ± 3.6 |
| Mass (kg) | 65.9 ± 7.1 | 72.7 ± 6.0 |
| BMI | 20.8 ± 2.1 | 20.5 ± 1.2 |
| Maximum Vertical Jump (cm) | 41.9 ± 4.3 | 54.0 ± 8.2 |
| Years Playing Basketball | 7.0 ± 1.9 | 5.3 ± 2.9 |
| Years Playing Club | 2.0 ± 0.8 | 2.0 ± 1.3 |

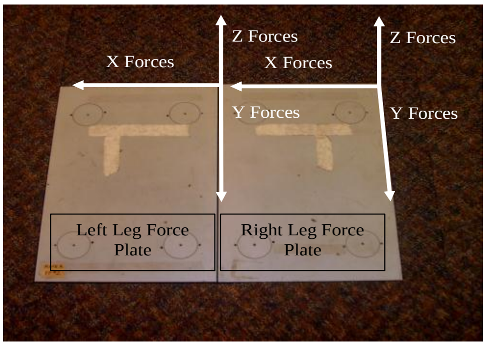


Figure 1. Ground Force Plate Global Coordinate System. X Forces are medial-lateral; Y Forces are anterior-posterior; and Z Forces are vertical (body weight normalized) for both the left and right force plates.

### C. Procedures

Each of the participants reported to the research laboratory and completed a one-time data collection. All subjects participating in the study performed a similar warm-up protocol within the biomechanics laboratory. Participants were asked to start by standing on a pressure sensor. Upon a verbal cue from the researcher, the participant jumped over a barrier, landed with one foot on each of the in-ground force plates, and performed a side cut in an unanticipated specific direction. The force plate jump distance was approximately 120-150 cm and was marked with taped lines on the floor so consistency was maintained for all subjects during testing. As the participant jumped over the barrier, the pressure sensor would signal a light for one of the three cutting directions to appear on a board while the participant was still in flight. Upon landing, the participants were instructed to make a side step (right light indicated the participant should cut to the right leading with the right leg and using the left leg as a plant leg) and immediately run towards cones approximately 4.6 m (15 feet) away. When cutting to the center, participants were allowed to choose the lead leg. The three cutting directions were: 30° degrees to the right, straight ahead, or 30° degrees to the left (*Figure 2*). A minimum of fifteen (15) randomized jump, land, and unanticipated cuts were performed so each subject had 5 good trials in each of the three directions. Landing force was defined for each leg as the moment when the force plate detected any vertical component (Fz greater than 20 N) of a ground reaction.

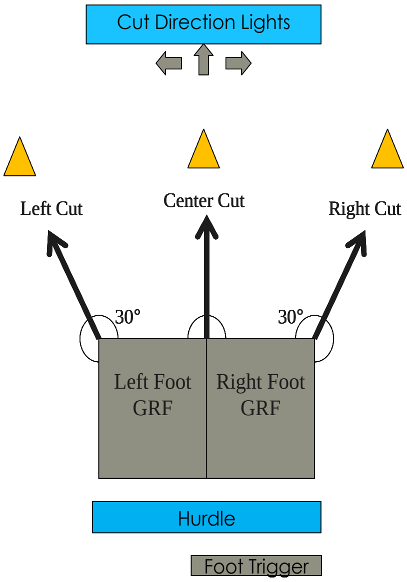


Figure 2. Laboratory schematics for the Jump, Land, and Cut Task.

Peak GRF was calculated using MATLAB. Peak vertical GRF was defined as the maximum value of the VGRF (Vertical Ground Reaction Force). Body weight was used to normalize peak VGRF data. Peak sagittal (anterior/poster) and frontal (medial/lateral) was defined as the maximum value of each measure, for each the right and left leg as determined by the data collected from the force plate during contact.

### *D. Statistical Analysis*

Statistical analyses were performed using an independent samples t-test to examine the effect of gender on the joint kinematics during the initial contact, peak knee flexion angles, peak ground reaction forces (GRF), and push off. An a-priori α level of 0.05 was set for determining statistical significance. Effect size was reported by taking the mean of the male's scores and subtracting the mean of the female's scores then dividing by the pooled standard deviations. All statistical analyses were completed using SPSS, version 15.0.

## III. Results

An independent samples t-test was run on the demographic data to determine if significant differences were noted between the genders. Height ($p = 0.013$), weight ($p = 0.005$), and vertical jump ($p = 0.006$) were all statistically significant demographic values. The male participants weighted more, were taller, and jumped higher than the female participants in this study. None of the other demographics were significant.

### *A. Left Cut*

#### *1) Initial Contact*

No statistical differences were noted for the left cut between the genders for either foot ground reaction forces during the initial contact.

#### *2) Peak Knee Flexion Angle*

Statistical differences ($p = 0.022$, $d = 0.93$) were noted between the genders for the left foot ground reaction forces with the male participants incurring anterior forces (0.64 N/kg ± 0.58 N/kg) and female participants sustaining posterior forces (-0.89 N/kg ± 1.06 N/kg) during peak knee flexion angles (Figure 3). No statistical differences were noted between the genders for the right foot ground reaction forces during peak knee flexion angles.

#### *3) Peak GRF*

No statistical differences were noted for the left cut between the genders for either foot during the moment of peak ground reaction forces.

#### *4) Push Off*

Statistical differences ($p = 0.040$, $d = 0.81$) were noted between the genders for the left foot ground reaction forces with the male participants incurring anterior forces (0.53 N/kg ± 0.58 N/kg) and female participants sustaining posterior forces (-0.84 N/kg ± 1.11 N/kg) during the push off (Figure 3). No statistical differences were noted between the genders for the right foot ground reaction forces during the push off.

### *B. Center Cut*

#### *1) Initial Contact*

No statistical differences were noted for the center cut between the genders for either foot ground reaction forces during initial contact.

#### *2) Peak Knee Flexion Angle*

No statistical differences were noted for the center cut between the genders for either foot ground reaction forces during at the point of peak knee flexion.

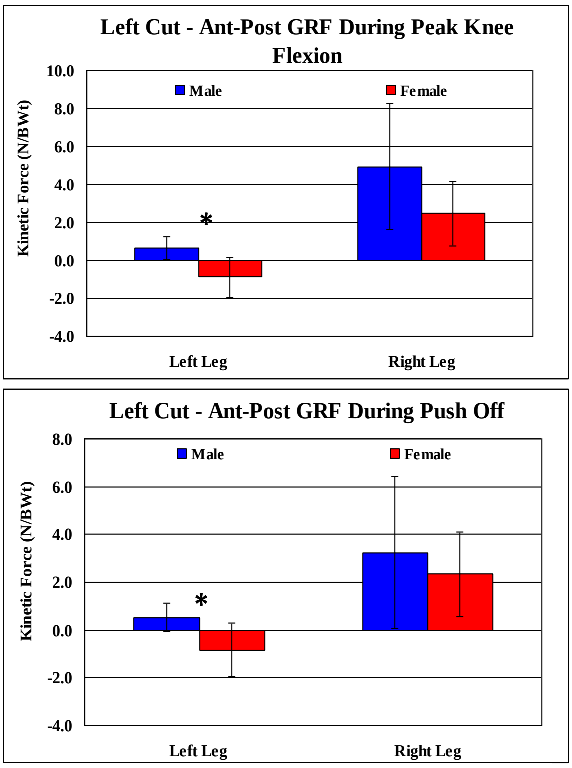


Figure 3. Means and standard error for left cut peak knee flexion and push off.

*3) Peak GRF*

Statistical differences (p = 0.010, d = -1.06) were noted between the genders for the right foot ground reaction forces with the male participants incurring lateral forces (-2.19 N/Kg ± 1.19 N/Kg) and female participants sustaining medial forces (0.62 N ± 1.45 N/Kg) during peak GRF in the right leg (Figure 4). No statistical differences were noted between the genders for the left foot ground reaction forces during peak GRF.

*4) Push Off*

No statistical differences were noted for the center cut between the genders for either foot ground reaction forces during push off.

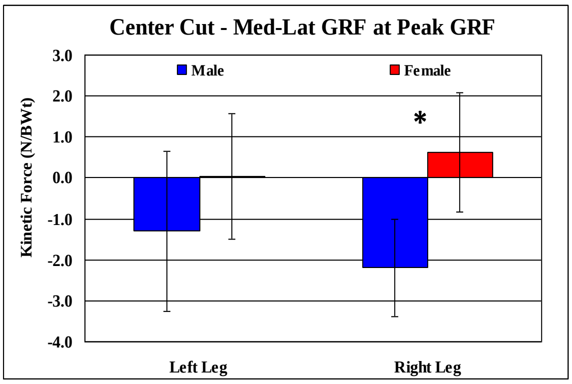


Figure 4. Means and standard error for center cut peak ground reaction force.

*C. Right Cut*

*1) Initial Contact*

Statistical differences (p = 0.041, d = -0.80) were noted between the genders for the right foot ground reaction forces with the female participants sustaining greater anterior forces (0.23 N/kg ± 0.17 N/kg) than the male participants (0.02 N/kg ± 0.10 N/kg) during the initial contact (Figure 5). No statistical differences were noted between the genders for the left foot ground reaction forces during initial contact.

*2) Peak Knee Flexion Angle*

Statistical differences (p = 0.033, d = -0.84) were noted between the genders for the right foot ground reaction forces with the male subjects sustaining posterior forces (0.17 N/kg ± 0.61 N/kg) and female subjects sustaining anterior forces (1.19 N/kg ± 1.01 N/kg) during peak knee flexion angles (Figure 5). No statistical differences were noted between the genders for the left foot ground reaction forces during peak knee flexion angles.

Statistical differences (p = 0.031, d = -0.89) were noted between the genders for the left foot ground reaction forces in the medial-lateral direction with male participants sustaining greater medial forces (3.22 N/kg ± 1.93 N/kg) than the female participants (0.76 N/kg ± 0.83 N/kg) during peak knee flexion angles (Figure 5). No statistical differences were noted between the genders for the right foot ground reaction forces during peak knee flexion angles.

*3) Peak GRF*

Statistical differences (p = 0.009, d = -1.12) were noted between the genders for the right foot ground reaction forces with the male participants incurring posterior forces (0.36 N/kg ± 0.54 N/kg) and the female participants incurring anterior forces (1.30 N/kg ± 0.93 N/kg) during the peak GRF (Figure 5). No statistical differences were noted between the genders for the left foot ground reaction forces during peak GRF

*4) Push Off*

No statistical differences were noted for the right cut between the genders for either foot ground reaction forces during push off.

## IV. Discussion

The purpose of this study was to determine the effects of gender on ground reaction forces of adolescent basketball athletes during jump, land, and cut maneuvers. The non-contact ACL injury mechanism is commonly described as deceleration, changes in direction, landing from a jump, or knee hyperextension. The primary restraint of the anterior cruciate ligament is to prevent anterior tibial translation. If participants are subjected to large anterior forces during landing and cutting, the ACL could be at risk for injury.

The primary kinetic findings of this investigation were that: 1) male participants' sustained greater anterior forces in

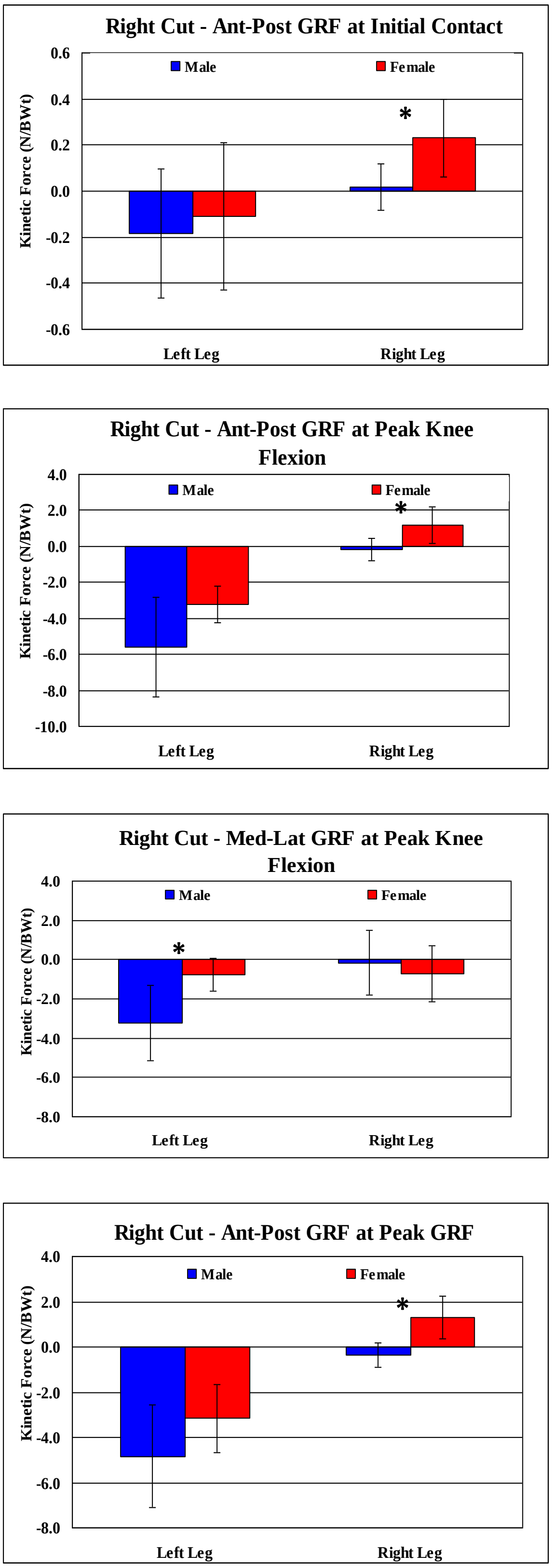


Figure 5. Means and standard error for right cut initial contact, peak knee flexion and peak ground reaction force.

the left leg during peak knee flexion angles and push off during the left cut; 2) male participants sustained medial forces and female participants sustained lateral forces in the right leg during the center cut; 3) female participants sustained greater anterior forces in the right leg than males during the peak flexion angles in the right cut; 4) the females sustained anterior forces, while males sustained posterior forces in the right leg during the peak ground reaction forces (GRF) in the right cut; and 5) the male participants sustained greater medial forces in the left foot during the peak knee flexion angles while cutting to the right.

Quatman et al. examined the effect of maturation on the gender differences in landing forces and performance of vertical jumps (28). The study indicated as male participants matured, the height of vertical jump increased; however the same was not the case for female participants. In addition, male participants decreased landing ground reaction forces, but girls did not. While our study did not examine large variations in maturation (all of our participants were between the ages of 13-17 years old) we did observe a similar trend of larger ground reaction forces in the female athletes.

Significant differences were previously reported between genders during peak ground reaction forces in the center run and side cut in adolescent youth soccer players (29). The side cut in the study by Sabick et al. required the athlete to land with each foot on a force plate and then lead with the right foot when performing a side-step cut after a drop landing. Our study attempted to mimic sports activity by having athletes jump over a barrier rather than utilizing a drop landing, however, the data from the Sabick et al. study demonstrates similar results with significant forces in the center run and right cut during peak ground reaction forces (29). The center run was statistically significant in the medial-lateral direction, while the right cut was statistically significant in the anterior-posterior direction.

The landing forces in the anterior direction were similar to a previous study undertaken in the laboratory. Boham et al. examined the effects of fatigue on the ground reaction forces for female collegiate soccer athletes during unanticipated cutting and discovered induced fatigue increased in anterior and medial-lateral forces (30,31,32). While this study does not include a fatiguing protocol, it appears that the differences in force directions (noted as significant) are consistent. The primary function of the ACL is to restrain anterior tibial translation on the femur. The secondary function of the ACL is to resist valgus/varus (medial-lateral) loading during locomotion. With significant ground reaction forces occurring in these directions, further research is need to examine the effects of these forces on the injury mechanism (30,31,32).

Sell et al. focused on landing tasks during planned and unplanned jumps in various directions (left, right, or vertical jumping) and determined the jumps to the left had greater vertical and posterior ground reaction forces compared with right and vertical jumps (33). The vertical jumps also demonstrated significantly greater vertical and posterior ground reaction forces than the right cut. Our data collection did not follow these trends and did not find any statistical significance for the vertical or posterior ground reaction forces during any of the cutting directions. Sell et al. only examined the right leg during testing; therefore, this study could offer an alternative explanation for the force productions occurring in the dominant and non-dominant lower extremities in adolescent athletes during athletic maneuvers (33).

The female athletes in this study appeared to have significantly different landing force accommodation than did the adolescent male athletes. Cuts to the right appeared to have the greatest significance for all participants. Females sustained greater anterior forces in the right leg and males sustained greater medial forces in the left leg. In the left cut, males appeared to have greater anterior forces in the left leg. The center cut males experience medial forces while females experienced lateral forces in the right leg. The center cut is the only cut in which the forces were highest in the plant leg (trail leg). The medial forces seen in the center cut for the males could have indicated the males were landing and taking off with more precision than were the females who appeared to distribute their weight to the lateral portion of the foot prior to initiating the cut.

## V. CONCLUSIONS

This study takes a novel approach to research, as it is one of very few studies to examine both the left and right lower extremity during dynamic athletic maneuvers and to examine the effects of gender on an adolescent athletic population. Gender had a significant effect on landing forces during unplanned cutting maneuvers in adolescent basketball athletes. The differences in kinetic forces could indicate alterations in landing strategies employed by male and female adolescent athletes during unanticipated cutting tasks. Differences in forces could indicate risk for ACL injury. The anterior forces are of particular concern as the primary restrain of the ACL is to resist anterior forces during athletic maneuvers, particular deceleration type activities such as landing.

Future research should examine the effects of ACL prevention training protocols and attempt to further examine the effects of the significant force differences seen between the genders. In addition, athletes from other sports should be examined using similar protocols to examine for sport specific differences between and among adolescent athletes. Fatigue is also a very important factor in the neuromuscular strategies of athletes and as such should be examined to determine if differences occur between the genders.

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