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# Biomechanical Deficit Profiles Associated with ACL Injury Risk in Female Athletes

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## Abstract

**Purpose—**To quantify the prevalence of biomechanical deficit patterns associated with ACL injury risk and their inter-connections in a large cohort of female athletes during an unanticipated cutting task.

**Methods—**High school female athletes (N=721) performed an unanticipated cutting task in the biomechanics laboratory. Trunk and lower extremity 3D kinetics and kinematics were measured and entered into a latent profile analysis model.

**Results—**Approximately 40% of female athletes demonstrated no biomechanical deficits and were categorized into the *low risk* group. The second most prevalent profile (24%) demonstrated a combination of high quadriceps and leg dominance deficits and was labeled as *quadriceps-leg*. The third most prevalent profile (22%) demonstrated a combination of trunk and leg dominance deficits and to lesser extent ligament dominance deficits, and was labeled as *trunk-leg-ligament*.

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CONFLICT OF INTEREST
The authors declare no conflict of interest

Finally, the fourth profile (14%) demonstrated very high ligament dominance deficits only and it was labeled as *ligament dominance* profile.

**Conclusions—**This is the first study to identify the most common biomechanical profiles associated with ACL injury during a cutting task in a large cohort of female athletes. Approximately 60% of female athletes belong to one of the high-risk profiles. With the exception of the *ligament dominance* profile, the current analysis indicates that risk profiles consist of a combination of biomechanical deficits. The findings provide important insight into the prevalence of biomechanical deficits and future directions for the development of injury prevention programs. The findings can be used to guide the development of quick and easy tests that accurately categorize athletes into one of the profiles and subsequently prescribe tailored injury prevention programs that will be more effective and efficient than the current generic ones.

### Keywords

Latent Profile Analysis; Biomechanics; Cutting; Knee Injury

## INTRODUCTION

It is estimated that approximately 250,000 anterior cruciate ligament (ACL) injuries occur every year in the US(13) while the incidence of ACL reconstruction has steadily increased to approximately 130,000 in 2006.(27) ACL injuries lead to substantial cost for the health care system, decrease in physical activity, loss of athletic scholarships, and decrease in academic performance.(12) The cost of ACL reconstructions in the US that require inpatient hospitalization (representing only 3.4% of all ACL reconstructions) exceeds $110M annually.(4) More importantly, knee osteoarthritis develops within 10–20 years after injury in the majority of patients even after surgical reconstruction.(24, 32) Thus, hundreds of thousands of previously active people develop symptomatic post-traumatic knee osteoarthritis at a young age as a result of previous ACL injury which has substantial negative impact on individual’s quality of life and associated costs of our healthcare system.

ACL injuries occur when the athlete decelerates suddenly such as during cutting and landing maneuvers. Cutting tasks are the most common activities responsible for ACL tear, accounting for 57% of injuries in collegiate basketball and soccer.(3) Four theories have been developed for the explanation of ACL injury risk. The ligament dominance theory suggests that female athletes at high risk perform athletic maneuvers with excessive knee valgus, hip adduction and hip internal rotation. Trunk dominance theory suggests that poor trunk control during athletic maneuvers leads to increased risk for ACL injury. Quadriceps dominance theory suggests that excessive relative quadriceps forces or reduced hamstring recruitment place the ACL at high risk for injury. Finally leg dominance theory suggests that large leg-to-leg asymmetries predispose athletes to injury.(15) Support for these theories has been provided by biomechanical, video analysis and cadaveric studies. In a prospective study, landing biomechanics were measured at baseline for 205 female athletes participating in high school basketball and soccer and followed for one to two seasons.(17) Measures of ligament dominance (high knee valgus angle and moment) and leg dominance (high side-to-side differences in knee valgus angle and moment) during landing from a jump were strong predictors of future ACL injury. Another study followed 277 collegiate athletes and found that deficits in trunk control are strong predictors of ACL injury among females, therefore providing support for the trunk dominance theory.(35, 36) A prospective study followed 55 team handball female athletes and found that measures consistent with the quadriceps dominance theory were predictive of future ACL injury.(37) Additional support for the four theories of biomechanical deficits is provided by studies that analyzed videos of ACL injuries and found that a common mechanism involves excessive knee valgus (ligament dominance), excessive lateral trunk displacement (trunk dominance), low knee flexion angle (quadriceps dominance), and side-to-side asymmetries (leg dominance).(5, 6, 19, 22, 23, 29) A recent finite element analysis study that combined landing mechanics and the location of bone bruises confirmed that knee valgus collapse is a major ACL injury mechanism.(31) However, despite of the strong support for the four theories as predisposing factors to ACL injury the most common ACL injury risk profiles of female athletes are currently unknown.

Very limited research exists on the co-existence of the biomechanical deficits in the same athletes. A biomechanical study (N=58) found that biomechanical deficits consistent with the ligament and quadriceps dominance co-exist in the same group of athletes.(30) It has also been suggested that athletes who exhibit trunk control deficits in the frontal plane (trunk dominance) have higher knee valgus moments as the center of mass displaces more laterally.(34, 35) In summary, the current literature indicates that biomechanical deficits consistent with the ligament dominance theory co-exist in the same athletes with one more deficit (trunk or quadriceps dominance) while there is no evidence of overlap between the trunk, leg and quadriceps dominance deficits. However, the links at this point are very preliminary as they are based on biomechanical rationale or on small laboratory studies that were not designed to comprehensively evaluate the prevalence and overlap of biomechanical deficits in female athletes. To date, there have been no large studies that attempted to quantify the prevalence of all four biomechanical deficit patterns and their inter-connections in a large cohort of female athletes during an unanticipated cutting task. This knowledge will advance science on the etiology of ACL injury by identifying the most prevalent biomechanical profiles and concentrating injury prevention efforts on programs that are targeting these profiles. This will allow the development of injury prevention programs (IPP) that would be effective, efficient and easy to implement as they will tailored to the most common aberrant biomechanical profiles. The purpose of the current study was to identify the prevalence and overlap of the most common biomechanical deficit profiles associated with ACL injury in a large cohort of adolescent female athletes during an unanticipated cutting task. Based on previous literature we hypothesized that the most common risk profiles will be a) ligament and trunk dominance deficits combined and b) ligament and quadriceps dominance deficits combined.

# METHODS

## Subjects

A total of 790 female basketball, volleyball and soccer players with no history of knee ligament injury or any knee surgery were tested prior to the start of the competitive season. They represented more than 95% of the high school athletes in these sports of an entire county in a Midwestern state therefore eliminating selection bias. Subjects with a prior history of knee injury or surgery were excluded from the study, and all participants indicated no lower-extremity injury at the time of data collection. Data from 69 athletes were incomplete and could not be used in the analysis leaving 721 athletes in our sample with mean age 13.8(2.2) years, mean height 159.4(8.2) cm and mean weight 53.9 (12.3) kg.

## Power Analysis

Preliminary studies using cut-off points demonstrated that biomechanical deficits are present in more than 40% of female athletes(28), which would be the equivalent to almost 300 athletes with biomechanical deficits in our sample. The power of detecting the optimal number of latent classes is a multifaceted process that depends on the number of observed indicators, the number of latent classes, class prevalence, and class separation. Based on the findings of a previous LPA simulation study we expect that we will need 25–35 subjects per class (26). Thus, the overall sample of 721 athletes is sufficiently large to identify clinically important subgroups of athletes with distinct biomechanical risk profiles even after accounting for discarded trials and possible large class separation.

## Procedures

After obtaining parent or guardian consent and athlete assent consistent with the local Institutional Review Board approval, athletes were measured for anthropometric variables.

**Biomechanical measures—**The same investigator (GM) placed 37 retroreflective markers on each athlete on the sacrum, left posterior superior iliac spine (PSIS), and sternum and then bilaterally on the shoulder, elbow, wrist, anterior superior iliac spine (ASIS), greater trochanter, mid thigh, medial and lateral knee, tibial tubercle, mid shank, distal shank, medial and lateral ankle, heel, dorsal surface of the midfoot, lateral foot (5th metatarsal), and toe (between 2nd and 3rd metatarsals).(21) A static trial was first collected as the participant was instructed to stand still and was aligned as closely with the laboratory coordinate system as possible. This position was designated as the participant’s neutral (zero) alignment, and subsequent kinematic measures were related back to this position.

**Cutting tasks—**Each participant was shown the sidestep cutting maneuvers (45° cut) and allowed to practice the movement. The athletes were instructed to line up behind a black line with feet 36 cm apart in an athletic position. A custom computer program simulated a stoplight on a monitor (red, yellow, green) and was used to cue the participant when to initiate the forward jump (0.4 m).(9, 21) The computer monitor displayed a randomized unanticipated arrow 0.3 seconds after initiation of jump, directing the participant to cut in the appropriate direction (left or right). The athlete jumped across the designated line when signaled by the stoplight and then completed the appropriate sidestep cut in the direction according to the arrow. The two force plates were situated beyond the black line and 8 cm apart so that each foot would contact a different platform during the tasks. After performing each maneuver, the participant ran as quickly as possible at the 45° angle through a 61 cm gate that was placed 2.5m away. The athlete was instructed to complete these tasks as quickly as possible to achieve the fastest potential time through the ending gate as to simulate game situations. The cutting direction was randomized over 6 trials (3 in each direction).(21) Trials were excluded (and re-randomized) if the participant performed a crossover cut, if the entire foot did not land on the force plate, or if the athlete cut in the wrong direction. Prior reliability analyses on athletic maneuvers collected and processed by the same investigators and with the same data collection equipment indicate that the proposed techniques provide reliable and repeatable data.(8)

**Data Collection and Processing—**A ten camera, high-speed motion analysis system (Eagle, Motion Analysis Corp., Santa Rosa, CA, USA) and two force platforms (AMTI, Watertown, MA) were used for data collection. Video and force data were time synchronized and collected at 240 Hz and 1,200 Hz, respectively. EvaRT software (version 4, Motion Analysis, Santa Rosa, CA, USA) was used to process all trials. The motion and force data was analyzed in Visual3D (Version 4.0, C-Motion, Inc.). The procedures within Visual3D first consist of the development of a static model customized for each subject(8). 3D marker trajectories from each trial were filtered at a cutoff frequency of 12 Hz(8). 3D joint angles were calculated according to the Cardan/Euler rotation sequence(7). Kinematic and force platform data were utilized to calculate knee joint moments using standard inverse dynamics techniques(2, 33). The model consisted of eight skeletal segments including the trunk, pelvis and bilateral foot, shank, and thigh segments. The kinematic analysis used in this study incorporated a global least-squares optimization approach that has been previously detailed elsewhere(25). Sagittal, coronal, and transverse plane joint rotations at the trunk, hip, knee, and ankle were calculated and expressed relative to a neutral position where all segment axes were aligned. The vertical ground reaction force (VGRF) weas used to calculate initial contact (IC) with the ground immediately after the participant landed from the jump across the line. The IC was defined when VGRF first exceeds 10 N(21). Toe off (TO) was subsequently calculated after IC when the VGRF falls below 10 N.

## Statistical analysis

LPA was the primary analytical approach. It is a *model-based* multivariate clustering technique that arises from a general approach of finite mixture modeling. The overall goal of LPA is to empirically classify individuals based on similar characteristics into subgroups (profiles), where the number of profiles and their characteristics are analytically inferred from the data. The clusters or groups are not known *a priori* and are defined by common means, variances, and covariances. Model identification was addressed by using 500 random sets of starting values. Information criteria indices including Akaike (AIC), Bayesian (BIC) and adjusted BIC as well as interpretability of profiles were used for model selection.(10) LPA analysis was performed in MPlus. Through a progressive sequence of model fitting, models with different numbers of profiles (2 through 5) were fit to the data to establish the number of underlying subgroups that provide the optimal balance of fit and parsimony.(10) Based on the best-fitting model, the number of profiles, their prevalence, and biomechanical characteristics were identified.

The variables that were entered in the model represented the biomechanical variables associated with each biomechanical deficit. Specifically, variables associated with the four biomechanical deficits were entered in the initial analysis. A preliminary analysis revealed that using the same variables for both legs was redundant due to the high intercorrelation, thus the variables from the left leg (during the right cutting tasks) were removed. Peak values were chosen for the kinetic variables while angles at initial contact, peak values and excursion were chosen for the kinematic variables. The 48 variables that were entered in the initial analysis were hip adduction and rotation angles and moments as well as knee valgus angles and moments for the ligament dominance theory; trunk flexion and rotation angles for the trunk dominance theory; hip and knee flexion angles and moments for the quadriceps dominance theory. For the leg dominance theory, the absolute side-to-side differences of the kinetic and kinematic variables that were used in the previous three theories (as described above) were calculated and entered into the initial analysis. Through the iterative process, the model was progressively simplified by removing indicators that did not discriminate well between classes. The biomechanical deficit variables that remained in the model at the end of the iterative process were knee valgus range of motion (ROM, i.e. the difference between the minimum and maximum values) and peak knee valgus moment (both associated with the ligament dominance theory), trunk side flexion ROM (associated with the trunk dominance theory), hip and knee flexion ROM (associated with the quadriceps dominance theory) and side-to-side differences in hip flexion ROM (associated with the leg dominance theory). Asymmetry in knee valgus moment and knee flexion ROM were removed because of high correlations with hip flexion ROM asymmetry. None of the remaining Pearson correlations exceeded the value of 0.5 (Table 1). For the six biomechanical variables that remained in the final model, 0.4% of the data were missing. We assumed that data were missing at random and accounted for them using a full-information maximum likelihood procedure.(11)

Based on the model selection, the four and five profile solutions appeared to fit the best. Although the five profile solution was statistically supported (Table 2), it added complexity that did not assist in the interpretability of the findings. Specifically, the 5-profile solution separated the low risk profile into two smaller subgroups. Because our goal was to generate a parsimonious model and because the 5-class solution did not add additional insight into latent profiles, we retained the 4-profile solution as it has been suggested previously.(20)

## RESULTS

As described above, the final model was comprised of four latent profiles. Approximately 40% of female athletes exhibited below average values for the variables associated with the biomechanical deficit theories; therefore this profile was labeled *low risk* (LR). Compared to the total sample, the LR profile had lower knee valgus ROM, lower peak knee valgus moment, lower trunk side flexion ROM, and lower side-to-side differences in hip ROM while there was no difference for hip and knee flexion ROM (although there was a trend for higher knee flexion ROM; p=0.083; Figure 1 and Table 3) The second most prevalent profile (24%) demonstrated a combination of high quadriceps and leg dominance deficits and was labeled as *quadriceps-leg* (QL). Compared to the total sample, the QL profile had lower knee and hip flexion ROM, higher side-to-side differences in hip ROM but lower knee valgus ROM but lower peak knee valgus moment and lower trunk side flexion ROM; thus less ligament and trunk dominance deficits (Figure 1 and Table 3). The third most prevalent profile (22%) demonstrated a combination of trunk and leg dominance deficits and to lesser extent ligament dominance deficits, and was labeled as *trunk-leg-ligament* (TLL). Compared to the total sample, the TLL profile had higher trunk side flexion ROM, higher side-to-side differences in hip ROM, higher peak knee valgus moment but also higher knee and hip flexion ROM; thus less quadriceps dominance deficits (Figure 1 and Table 3). Finally, the fourth profile (14%) demonstrated very high ligament dominance deficits only and it was labeled as *ligament dominance* (LD). Compared to the total sample, the LD profile had higher knee valgus ROM, higher peak knee valgus moment; however, unlike the other two biomechanical deficit profiles all other variables were not different than the sample means; thus the TLL group had very high ligament dominance deficits while the other biomechanical deficits were not lower (Figure 1 and Table 3).

## DISCUSSION

Several ACL IPP have been developed to reduce injuries among female athletes. A meta-analysis has demonstrated that these programs have substantial variation in success rates, duration of each training session and number of training sessions.(16) A crucial shortcoming shared by current IPP is that they attempt to simultaneously address a variety of possible biomechanical deficits by administering the same program on all athletes without tailoring it to the most common deficits or to the deficits present in each athlete. Therefore, they are frequently time-consuming and they are allocating time and resources to address deficits that may not be present in female athletes. As evidenced by a number needed-to-treat meta-analysis it requires training 89 female athletes per year with the current generic IPP to prevent one ACL injury.(14) These IPP are generic, cumbersome and of mixed success, and as a result their implementation is problematic as evidenced by epidemiological studies that demonstrate no reduction on ACL injury rates among female athletes.(1) Developing ACL IPP that are shorter, more specific to the deficits present in each subgroup of athletes, easier to implement, and more effective is hindered by the lack of knowledge on the prevalence of biomechanical deficits and their inter-connections among female athletes.

This is the first study to identify the most common profiles associated with ACL injury during a cutting task in a large cohort of female athletes. The main findings are that: a) approximately 60% of female athletes belong to one of the high-risk profiles and b) with the exception of the LD profile, the current analysis indicates that risk profiles consist of a combination of biomechanical deficits. The findings provide important insight into the prevalence of biomechanical deficits and future directions for the development of IPP. Our hypothesis that the two most prevalent profiles would be the ligament-trunk and ligament-quadriceps was not supported; instead, from the three biomechanical deficit profiles the QL and TLL were almost equally prevalent while the LD has a prevalence of 14%. However, it is important to note that the biomechanical deficit profiles have been established by previous research projects; thus, it is currently unclear if the profiles identified in the current project are directly linked to higher ACL injury risk.

One important implication of the findings of the current project is that 40% of adolescent female athletes who participate in high school level soccer, basketball and volleyball belong in the LR group and, thus may be at low risk for ACL injury based on the novel cutting task. Thus, it may be unwise to invest effort and resources in this group of athletes or continue with the current status quo of training with IPP all members of a team. The high prevalence of the LR group may explain the low efficiency of IPP(14) as, in essence, many of the athletes who receive them have no biomechanical deficit associated with ACL injury. Once easy and accurate methods to identify the athletes who belong in the LR group are developed, the efficiency of the IPP and probably their implementation should increase.

Two of the remaining profiles included a combination of biomechanical deficits. The QL profile consisted of quadriceps and leg dominance deficits suggesting that one out of four athletes demonstrates a combination of side-to-side asymmetries and anterior-posterior thigh musculature imbalances. Single leg plyometric activities have been suggested as training methods to address both leg and quadriceps dominance deficits by using neuromuscular feedback loops that restore symmetry and by recruiting the posterior thigh muscles, especially when they encourage deep knee and hip flexion angles.(15) Other training exercises for leg dominance deficits include single leg balance and biofeedback that visually demonstrates deficits and encourages restoration of symmetry. “Russian hamstring curls” that utilize an elastic band to emphasize eccentric/concentric contraction of the knee flexors are commonly used to address quadriceps dominance deficits.(15)

The TLL profile most closely matched our a priori hypothesis as it combined trunk, leg and ligament dominance deficits. The co-existence of multiple risk factors within the same group of athletes reiterates the multifactorial nature of ACL injuries and it further emphasizes the challenge faced by previous studies that attempted to identify risk factors in a univariate manner. There is a direct biomechanical link between trunk side flexion in the direction of the standing leg and knee valgus moment.(18) As the center of mass moves away from the midline, knee valgus moment is expected to increase as the moment arm of the external force around the knee joint increases. Training that emphasizes the activation of core musculature and perturbation training may assist in the decrease of trunk dominance deficits while biofeedback that encourages proper knee alignment during functional tasks may assist with ligament dominance deficits.

The least prevalent group demonstrated very high ligament dominance deficits. However, as this group demonstrated the highest magnitude of deficits (standardized scores 1.3–1.5 for the knee valgus angles and moment, Table 3) it may be at the highest risk for ACL injury. The large difference in knee valgus angle and moment compared to the other groups may also explain the strong association between these variables and ACL injury risk.(17) Finally, it is important to note that the LD profile demonstrated very high ligament dominance deficits in combination with average values in the other biomechanical variables. The QL and TLL profiles had lower than average values in the variables associated with the other biomechanical deficits which further suggests that the LD profile may be at the highest risk for ACL injury. However, this needs to be confirmed in longitudinal biomechanical-epidemiological studies.

Another possibility that future studies should explore is to decrease the number of variables for each profile. In the current study, knee valgus moment and knee valgus ROM were both used for the ligament dominance deficits. Similarly, both knee and hip flexion ROM were used for the quadriceps dominance deficits. The variables within each dominance theory had moderate correlations; thus it may be worth investigating if the profiles can still be identified when only one variable is used from each deficit.

Several limitations are acknowledged. First, the lack of long-term follow-up precludes from analyzing actual ACL injuries, instead we relied on biomechanical risk factors to identify the risk profiles. All athletes were adolescent females, thus the prevalence of biomechanical profiles may be different in males or older female athletes.

This study provides crucial information on the prevalence of the most common profiles associated with ACL injury risk among adolescent female athletes. This information can be used in two ways to enhance the prevention of ACL injuries. It can be utilized to create IPP that address the most common or the most serious deficits by incorporating the exercises that were described above. Secondly, and most importantly it can be used to guide the development of quick and easy tests that accurately categorize athletes into one of the profiles. Then, they can be prescribed a tailored IPP that will be more effective and efficient than the current generic IPP as it will address their specific deficits. This would represent an important step in ACL injury prevention.

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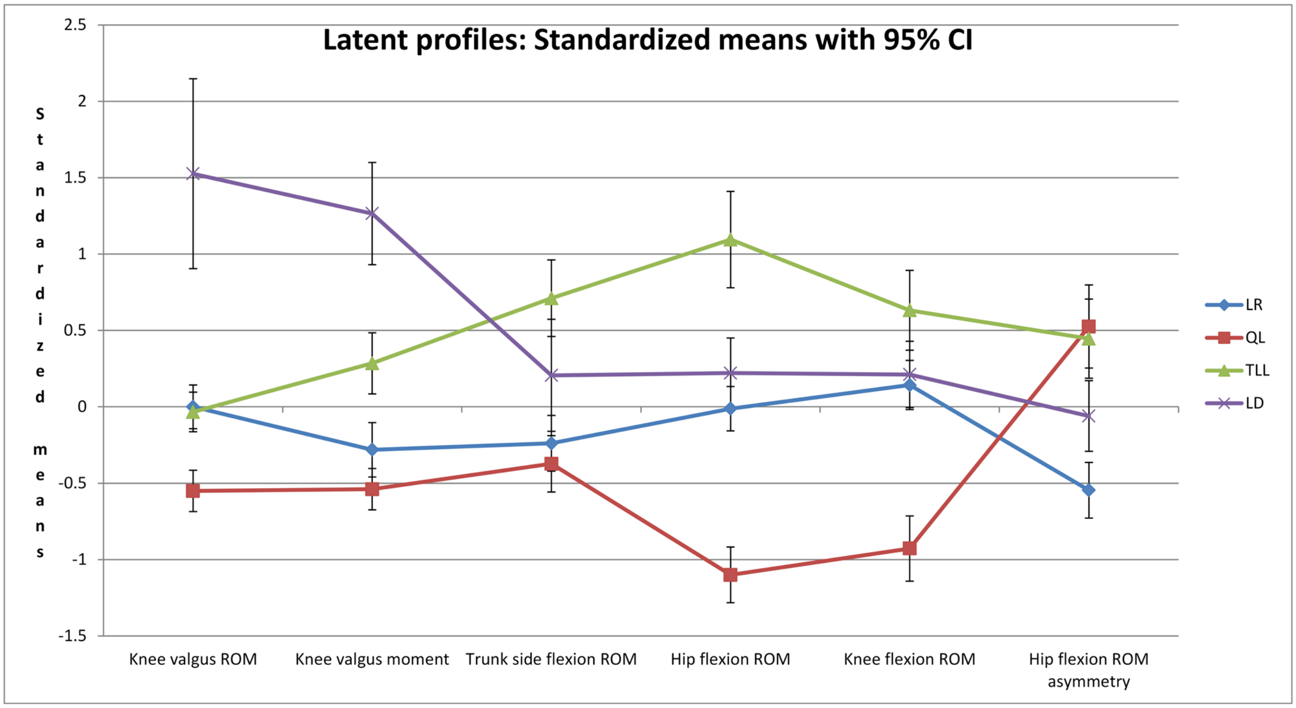

**Figure 1.**

Latent Profiles: standardized means with 95% confidence intervals. The horizontal line at 0 indicates the sample means. The Y axis indicates the standard deviation above and below sample means.

## Table 1

Pearson correlation coefficients between the variables retained in the final latent profile analysis

| | **Knee valgus ROM** | **Peak knee valgus moment** | **Trunk side flexion ROM** | **Knee flexion ROM** | **Hip flexion ROM** | **Hip flexion ROM asymmetry** |
|---|---|---|---|---|---|---|
| Knee valgus ROM | 1 | 0.467 | 0.114 | 0.172 | 0.194 | −0.032 |
| Peak knee valgus moment | 0.467 | 1 | 0.287 | 0.084 | 0.241 | 0.018 |
| Trunk side flexion ROM | 0.114 | 0.287 | 1 | 0.061 | 0.374 | 0.018 |
| Knee flexion ROM | 0.172 | 0.084 | 0.061 | 1 | 0.467 | −0.092 |
| Hip flexion ROM | 0.194 | 0.241 | 0.374 | 0.467 | 1 | −0.047 |
| Hip flexion ROM asymmetry | −0.032 | 0.018 | 0.018 | −0.092 | −0.047 | 1 |

ROM = range of motion

## Table 2

Information criteria indices for the Latent Profile Analysis

| Classes | df | AIC | BIC | ABIC |
|---|---|---|---|---|
| 2 | 25 | 11827 | 11941 | 11862 |
| 3 | 38 | 11639 | 11759 | 11585 |
| 4 | 51 | 11463 | 11697 | 11535 |
| 5 | 64 | 11399 | 11692 | 11488 |

df degrees of freedom; AIC Akaike information criteria; BIC Bayesian information criteria; ABIC sample size-adjusted BIC. Lower values in the information criteria indicate a superior model.

## Table 3

Latent profile analysis standardized means, standard errors and p-values (comparison between each group and the overall mean) for each profile)

| | LR profile | | | QL profile | | | TLL profile | | | LD profile | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Est mean** | **SE** | **P-value** | **Est mean** | **SE** | **P-value** | **Est mean** | **SE** | **P-value** | **Est mean** | **SE** | **P-value** |
| KVLGROM (knee valgus ROM) | −0.190 | 0.073 | 0.009 | −0.551 | 0.069 | <0.001 | −0.034 | 0.066 | 0.603 | 1.526 | 0.317 | <0.001 |
| KVLGMOM (peak knee valgus moment) | −0.281 | 0.091 | 0.002 | −0.539 | 0.069 | <0.001 | 0.285 | 0.102 | 0.005 | 1.265 | 0.171 | <0.001 |
| TSFROM (trunk side flexion ROM) | −0.239 | 0.093 | 0.010 | −0.373 | 0.094 | <0.001 | 0.711 | 0.128 | <0.001 | 0.206 | 0.187 | 0.270 |
| HFLXROM (hip flexion ROM) | −0.012 | 0.074 | 0.874 | −1.100 | 0.093 | <0.001 | 1.095 | 0.161 | <0.001 | 0.221 | 0.117 | 0.059 |
| KFLXROM (knee flexion ROM) | 0.143 | 0.082 | 0.083 | −0.927 | 0.109 | <0.001 | 0.632 | 0.133 | <0.001 | 0.212 | 0.111 | 0.057 |
| HFLXROMD (hip flexion ROM) asymmetry) | −0.546 | 0.093 | <0.001 | 0.526 | 0.139 | <0.001 | 0.446 | 0.132 | 0.001 | −0.060 | 0.118 | 0.610 |

For all variables higher values indicate higher deficits except for HFLXROM and KFLXROM where the lower values indicate greater deficits.

LR=low risk, QL=quadriceps-leg, TLL=trunk-leg-ligament, LD=ligament dominance

The standardized means represent standard deviations above or below the sample mean. For example, a standardized mean of 1.0 denotes that the profile mean was 1 standard deviation above the sample mean while a standardized mean of −0.8 denotes that the profile mean is 0.8 standard deviation below the sample mean.