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RELATIONSHIP BETWEEN LONGITUDINAL CHANGES IN LANDING TECHNIQUE AND MUSCULOSKELETAL GROWTH THROUGHOUT THE ADOLESCENT GROWTH SPURT

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INTRODUCTION

Throughout the adolescent growth spurt, girls experience a vast number of structural and functional changes to their musculoskeletal system. These changes include rapid increases in height and lower limb length, a reduction in hamstring flexibility during the earlier, rapid stages of growth, as well as a lag in the development of their hamstring muscle strength relative to their quadriceps [1, 2]. The rapid growth experienced by girls throughout puberty is thought to alter lower limb inertial properties, with the potential to influence landing biomechanics and, in turn, the risk of sustaining a non-contact anterior cruciate ligament (ACL) injury. However, the longitudinal development of lower limb landing technique throughout the adolescent growth spurt, and its relationship to changes associated with musculoskeletal growth, remains unclear. Therefore, the aim of this study was to investigate the longitudinal changes in the three-dimensional lower limb kinematics and joint moments displayed by girls during the performance of a horizontal landing task throughout their adolescent growth spurt.

METHODS

Initially, 71 healthy female volunteers (aged 10-13 years) were screened for their Tanner stage of pubertal development (modified Tanner Stage diagrams) [3] and their estimated maturity offset (sex-specific multiple regression equation) [4]. Thirty-three girls satisfied the initial inclusion criteria for the first test session (Tanner Stage II, maturity offset = -6 to -4 months). The remaining 38 participants who did not satisfy the initial inclusion criteria were re-screened 6 months later, whereby 13 girls satisfied the inclusion criteria for Test 2 (Tanner Stage II-III, maturity offset = 0 months).

During the 12-month period of their adolescent growth spurt, each participant was tested in the laboratory up to four times, based around the timing of maturity offset (Test 1 = -6 to -4 months, Test 2 = 0 months, Test 3 = +4 months, Test 4 = +8 months). At each laboratory testing session, participant height, body mass and lower limb anthropometry were measured. Goniometric measurements of the knee and hip were also performed to determine changes in flexibility of the hamstrings, quadriceps and illiopsoas muscles over time. Concentric and eccentric strength of the quadriceps and hamstring muscles were assessed using an isokinetic dynamometer (KinCom, Chattanooga Inc., USA) at 180°.s^{-1}. Peak torque was also recorded (Nm) to determine changes in lower limb strength throughout the growth spurt.

Following the strength assessment, the participants performed a functional, single-limb landing movement, during which the ground reaction forces (GRF; 1,000 Hz; Kistler force platform, Switzerland) and three-dimensional lower limb kinematics (100 Hz; OptoTRAK 3020, Northern Digital, Canada) were collected. The three-dimensional ankle, knee and hip angles were then calculated at the time of initial contact with the ground and the time of the peak anteroposterior GRF (F_{AP}), to determine lower limb kinematics during the impact phase of landing. Visual3D software (C-Motion Inc., USA) was used to analyze the kinematic data. The magnitude of the peak three-dimensional ankle, knee and hip joint moments, normalized to body mass and lower limb length, were also calculated using Visual3D.

A linear mixed model design was used to determine any significant ($p \leq 0.05$) main effects of time on the lower limb landing variables, controlling for growth variables as covariates. *Post-hoc* comparisons were performed using a *t*-test with a Bonferroni adjustment. A series of Pearsons' correlations were then performed comparing the data sets for each of the outcome variables, to determine any significant relationships between the landing and musculoskeletal variables.

RESULTS AND DISCUSSION

Overall, no significant changes in three-dimensional ankle alignment were displayed over the 12 months. However, a significant effect of time on knee flexion was found (p = 0.028), whereby *post-hoc* analyses revealed significantly less knee flexion during Test 4 compared to Test 1 at F_{AP} (p = 0.017; see Figure 1a). Furthermore, significant changes in hip flexion were displayed over time (p = 0.010), such that participants displayed significantly greater hip flexion during Test 4 compared to Test 1 (p = 0.050; see Figure 1b).

It is suggested that the greater knee flexion and lesser hip flexion displayed by participants upon landing during the more rapid stages of growth (Test 1 and 2), may be due to the reduction in hamstring flexibility displayed at this time [1]. This notion was supported by the significant, positive correlation (at the time of Test 2) found between hamstring flexibility and knee flexion during landing (r = 0.518, p < 0.001), such that girls with lower hamstring flexibility also displayed greater knee flexion upon landing. It is speculated that this increase in hamstring flexibility may enable girls to 'stride-out' further during landing, potentially increasing the risk for ACL injury [5].

Although no significant effect of time was found on the three-dimensional ankle joint moments at F_{AP} (see Table 1), participants displayed significantly greater (p = 0.006) knee abduction moments at F_{AP} during Test 2 compared to Test 4 (see Table 1). Furthermore, participants also displayed significantly greater hip abduction moments during Test 1 compared to Test 3 (p = 0.016) and Test 4 (p = 0.006; see Table 1).

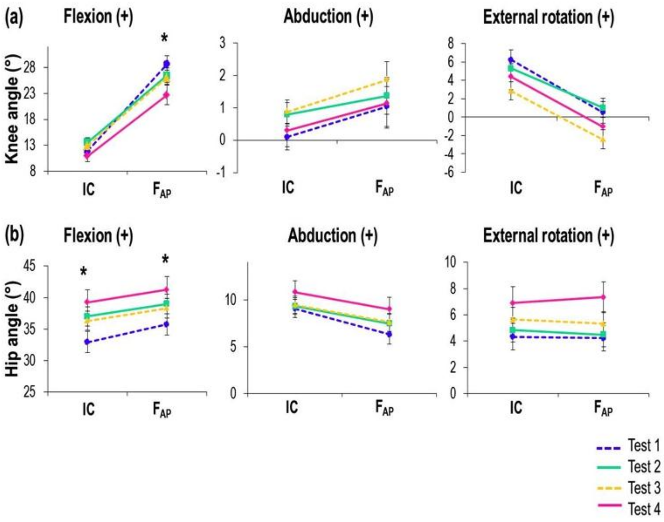

Figure 1: Means ± SE for the three-dimensional (a) knee and (b) hip joint angles (°) at the time of initial contact (IC) and peak anteroposterior ground reaction force (F_{AP}) during Test 1 (n = 33), Test 2 (n = 46), Test 3 (n = 43) and Test 4 (n = 19; * indicates a significant effect of time at $p \leq 0.05$).

Interestingly, at the time of Test 2, a significant, negative correlation was found between quadriceps torque and hip abduction moments (r = -0.455, p = 0.002), as well as knee abduction moments (r = -0.488, p = 0.001). This finding suggests that the greater hip and knee frontal plane joint moments during the earlier and more rapid stages of growth, are associated with lower quadriceps muscle torque. We speculate that the lower quadriceps strength during the earlier stages of the growth spurt, may contribute to these higher frontal plane knee and hip joint loads. However, whether this increases the potential for ACL injury requires further investigation.

CONCLUSIONS

During their adolescent growth spurt, pubescent girls display a change in the strategy with which they control their lower limb to land after performing a horizontal leap movement. Overall, it was found that girls displayed a reduction in knee flexion and an increase in hip flexion over time, as well as significantly greater knee and hip abduction moments during the earlier and more rapid stages of the growth spurt. These changes are likely to be in response to the longitudinal changes in hamstring flexibility and quadriceps strength occurring during this period of rapid growth.

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Table 1: Means ± SE for the normalized internal ankle, knee and hip joint moments at the time of the peak anteroposterior ground reaction force throughout the four test sessions (* indicates a significant effect of time at $p \leq 0.05$).

Joint Moment (Nm/kg/m)	Test 1 (n = 33)	Test 2 (n = 46)	Test 3 (n = 43)	Test 4 (n = 19)	*p*-value
Ankle[a]					
Dorsiflexion	-1.00 ± 0.13	-0.75 ± 0.11	-0.92 ± 0.11	-0.82 ± 0.17	0.392
Eversion	-0.26 ± 0.06	-0.20 ± 0.05	-0.26 ± 0.05	-0.22 ± 0.07	0.541
Forefoot abduction	0.001 ± 0.01	0.005 ± 0.01	0.005 ± 0.01	-0.008 ± 0.01	0.789
Knee[b]					
Extension	1.32 ± 0.17	1.03 ± 0.15	0.86 ± 0.15	0.73 ± 0.22	0.057
Abduction	0.08 ± 0.06	0.13 ± 0.05	0.01 ± 0.05	-0.15 ± 0.08	0.008*
External rotation	-0.10 ± 0.04	-0.08 ± 0.03	-0.05 ± 0.04	-0.03 ± 0.04	0.060
Hip[c]					
Flexion	-1.08 ± 0.12	-1.15 ± 0.11	-1.28 ± 0.11	-1.25 ± 0.15	0.426
Abduction	0.52 ± 0.09	0.36 ± 0.08	0.21 ± 0.08	0.08 ± 0.12	0.003*
External rotation	0.42 ± 0.06	0.43 ± 0.05	0.38 ± 0.05	0.33 ± 0.07	0.626

a. Positive ankle internal joint moments: dorsiflexion, eversion, forefoot abduction.
b. Positive knee internal joint moments: extension, abduction, external rotation.
c. Positive hip internal joint moments: flexion, abduction, external rotation.