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HIP AND KNEE EXTENSOR MOMENTS PREDICT VERTICAL JUMP HEIGHT IN ADOLESCENT GIRLS

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Abstract

Biomechanical factors, such as hip and knee extensor moments, related to drop jump (DJ) performance have not been investigated in adolescent girls. The purpose of this study was to determine the key independent biomechanical variables that predict overall vertical jump performance in adolescent girls. Sixteen high school adolescent girls from club-sponsored and high school-sponsored volleyball teams performed DJ at 3 different drop heights (15, 30, and 45 cm). A motion analysis system consisting of 10 digital cameras and a force platform was used to calculate vertical jump height, joint angles, and joint moments during the tasks. A multiple linear regression was used to determine the biomechanical parameters that were best predictive of vertical jump height at each box drop distance. The 2 predictor variables in all 3 models were knee and hip extensor moments. The models predicted 82.9, 81.9, and 88% of the vertical jump height variance in the 15, 30, and 45 cm trials, respectively. The results of the investigation indicate that knee and hip joint moments are the main contributors to vertical jump height during the DJ in adolescent girls. Strength and conditioning specialists attempting to improve vertical jump performance should target power and strength training to the hip and knee extensors in their athletes.

Keywords

female athlete; biomechanics; performance; lower extremity

INTRODUCTION

The potential to achieve peak performance in sports requires a combination of strength, speed, and power (24). The ability to demonstrate full body power is related to the level of play, such as collegiate division, and whether an athlete makes the playing roster or starting position (12,13,27). Jumping is more powerful if an athlete initiates the movement with a countermovement or preparatory descent before the leap (24). Muscle stretch before a rapid shortening to accelerate the body or a limb is termed the stretch-shortening cycle (SSC) (28). The SSC muscle action increases power and performance when compared with pure concentric actions (5,6,24). The increased power output obtained from the SSC phenomenon likely increases force output during jumping (32).

The drop jump (DJ) is an exercise in which the athlete drops from a height before a maximum vertical jump. This task is often used to evaluate an athlete's ability to effectively use SSC (4,5). The DJ can be incorporated into athlete training protocols and can be used to evaluate the effects of different training methods on measures of lower extremity biomechanics and performance. Drop jump training improves vertical jumping ability and energy production (14). In addition, women athletes who have used DJ training incorporated into a comprehensive training protocol have successfully increased strength, power, and countermovement jump performance (23).

Although several theories have been proposed to explain the enhanced power during the rapid muscle stretch before contraction (31), the biomechanical factors that dictate vertical jump performance in adolescent girl athletes have yet to be defined. Previous authors have found that joint moments and kinematic variables can be used to predict, through linear regression analyses, the vertical height in which males jump (1,15). For example, men have exhibited that increased knee and hip extensor moments are correlated with an increased vertical jump height (1,15,18). This indicates that hip and knee extensor musculature strength may be critical components that could be targeted in a strength and conditioning program that aims to improve jumping performance. However, the specific variables that predict vertical jump height in adolescent girls at different drop heights have not been previously investigated. Comprehensive neuromuscular training programs have been used to increase vertical jump height and squat performance in adolescent girls (23). A better understanding of the variables that predict vertical jumping ability is warranted for the improved effectiveness of these performance enhancement programs. The purpose of this study was to determine the key biomechanical variables that predict vertical jump performance. The hypothesis tested by this study was that hip and knee, but not ankle, extensor moments would be significant predictors of vertical jump height.

METHODS

Experimental Approach to the Problem

We used an exploratory research design to determine the independent variables, which predict the dependent variable (vertical jump height). The independent variables were lower extremity joint angles and moments at 3 different drop heights.

Subjects

Sixteen girls from high school volleyball teams volunteered to participate in the study (age 15.5 $\pm$ 1.5 years, height 169 $\pm$ 5 cm, body mass 61.7 $\pm$ 5.4 kg). Informed written consent, approved by the Cincinnati Children's Hospital Medical Center institutional review board was obtained from the parent or parental guardian of each subject. Child assent was also obtained from each subject before participation.

Procedures

Thirty-seven retroreflective markers were placed on the subject as previously described (10). A static trial was first collected with the subjects standing stationary in the anatomical position. They were instructed to stand still with foot placement standardized. This static measurement was used as each subject's neutral (zero) alignment; subsequent kinematic measures were referenced in relation to this position. The subjects performed DJ starting on top of a box with their feet positioned 35 cm apart (distance measured between toe markers) (9). Three trials were performed at 3 different randomly ordered drop heights (15, 30, and 45 cm). They were instructed to drop directly down off the box and immediately perform a maximum vertical jump as soon as they made ground contact. The DJ has been previously shown to have high within-session ($r = 0.988$) and between-session ($r = 0.936$) reliability (intraclass correlation) in adolescent athletes (10).

Trials were collected with EVaRT (Version 5; Motion Analysis Corporation, Santa Rosa, CA) using a motion analysis system consisting of 10 digital cameras (Eagle cameras; Motion Analysis Corporation) and a force platform (AMTI, Watertown, MA). The force platform was sampled at 1,200 Hz and time synchronized with the motion analysis system that was collected at 240 Hz. The force and video data were used in the analysis to define the landing phase of the DJ as described below.

Data Analysis

Three-dimensional Cartesian marker trajectories from each trial were filtered through a low-pass fourth-order Butterworth filter at a cutoff frequency of 12 Hz. Ankle, knee, and hip sagittal plane joint angles were calculated for the right side (7,20). Total range of motion (ROM) during the landing was calculated for each joint. To minimize possible peak impact errors, the force plate data were filtered through a low-pass fourth-order Butterworth filter at a cutoff frequency of 12 Hz (3). These data were used with the kinematic data to calculate joint moments using inverse dynamics (30). By convention, internal sagittal plane ankle, knee, and hip moments are described in this article as positive extensor moments. The average joint moment during the takeoff phase (defined as when the body center of mass (COM) trajectory was moving vertically until toe-off) (26) was calculated. Vertical jump height was calculated from the difference between the standing and maximum vertical trajectories of the estimated COM of the body based on De Leva's segment parameters (8). Data analysis was performed in MATLAB (Version 7.5; The Mathworks Inc., Natick, MA).

Statistical Analyses

Data were exported to SAS for statistical analyses. The key independent variables were selected based on the literature and included sagittal plane hip, knee, and ankle ROM and average joint moment (1). Means and 95% confidence intervals (CIs) were calculated for each variable. Pearson r correlation was calculated between the jump height and each independent variable. A multiple linear regression (PROC REG) was performed with backward elimination (F to leave 0.1) techniques to predict vertical jump height. The “best” model was determined based on the overall R^2 , MSE_p , and Mallows’ C_p and F_p (19). The final model was tested for multicollinearity based on the variance inflation factor and correlation matrix. Plotting of the jackknife residuals and calculation of Cook distance were used to identify possible outliers. Finally, a residual vs. predicted plot was used to confirm a normal distribution.

RESULTS

Means and 95% CIs for the measured variables are presented in Table 1. Knee and hip extensor moments demonstrated the highest correlation coefficients among key independent variables with vertical jump (Table 2). The “best” linear regression model, with vertical jump height as the dependent variable, was selected from backward elimination procedure for each drop height (Table 3). The 2 significant predictor variables in all 3 models were knee and hip extensor moments. Ankle moments did not significantly predict vertical jump height.

Figure 1 presents the relationship between each predictor variable and vertical jump. The final model for the 45-cm DJ explained 88.0% of the vertical jump variance ($R^2 = 0.88$; adjusted $R^2 = 0.86$; $SEE = 2.64$) with 2 predictor variables (knee and hip moments). The final models for the 30 and 15 cm conditions had similar values with knee and hip moments predicting vertical jump height (30 cm: $R^2 = 0.82$; adjusted $R^2 = 0.79$; $SEE = 3.19$; 15 cm: $R^2 = 0.83$; adjusted $R^2 = 0.80$; $SEE = 3.26$).

DISCUSSION

The purpose of this article was to determine the key independent biomechanical variables that predict vertical jump performance. During a DJ, the hip and knee moments were used in a multiple linear regression to predict overall vertical jump height during 3 different drop heights in adolescent girls. The observed R^2 values were similar to the 0.88 reported by Aragon-Vargas and Gross (1) when predicting vertical jump height from whole body power measures in a standard countermovement jump in men. However, when they used segmental analyses, only 60% of the variation in vertical jump height could be explained (1).

Hip and knee joint moments were better predictors than lower extremity joint kinematic variables (angles) during the DJ. Horita et al. (18) observed a close association between knee joint moments, takeoff velocity, and peak knee joint power during DJ performance. Studying agreement with the present findings, Tsiokanos et al. (29) found in men that hip and knee extensor strength, assessed on an isokinetic dynamometer, significantly predicted vertical jump height. Hip extensor moments increase significantly in boys compared with

girls (11). These increased hip joint moments were observed to be associated with an overall improved performance of the vertical jump in boys (11). The hip extensors (gluteus maximus, hamstrings) are not only important in extending from a squat position but also important in establishing or maintaining posture and balance when taking off and landing from a jump (11).

The findings of this study may extend to lower extremity injury prevention protocols, as recent investigations have begun to focus on hip strength as a controller of high-risk lower extremity biomechanics (17,21,22). In addition, other authors have demonstrated that fatigue in knee or hip muscle may lead to altered biomechanics associated with an increased risk of injury (2). Many injury prevention training protocols include exercises targeted to the hip and knee (16). Hip and knee-focused exercises may have a positive synergistic effect on vertical jump performance and reduction of injury risk factors.

Strength and conditioning professionals may be able to use these findings to assist in the determination of deficits in athletes that may limit their vertical jumping ability. For example, based on the results of the regression analysis, an adolescent girl who has decreased vertical jump height, compared with her peers, may have hip and knee extensor strength deficits. This would potentially lead to more precisely targeted and beneficial training. Vertical jump height has been increased in adolescent girls after comprehensive neuromuscular training programs (23). Newton et al. (25) used a “high-power output ballistic training” program to maintain jump performance during an elite volleyball team’s season compared with the decreases found with slow heavy resistance training. Cumulatively, these data indicate that a protocol that targets both the strength and power of the hip and knee extensors simultaneously may be more effective at increasing jump performance.

PRACTICAL APPLICATIONS

Maximal efficacy and efficiency of training is paramount for strength and conditioning professionals; therefore, it is important to determine the modulating factors that dictate athletic performance. These study results indicate that knee and hip joint moments are important modulators of vertical jump height during the DJ in adolescent girls. Hence, strength and conditioning specialists should target these areas (hip and knee extensors) in the development of programs to improve adolescent girls’ vertical jump performance. Future investigations should explore the differences in contributions to vertical jump between sexes.

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Figure 1.

Knee and hip moment scatter plot vs. vertical jump height from the 15-cm (square), 30-cm (circle), and 45-cm (triangle) box drop heights.

TABLE 1

Mean ($\pm 95\%$ CI) for dependent variable (vertical jump) and key independent variable for each box drop height condition.

Variables	15 cm	30 cm	45 cm
Vertical jump (cm)	38.4 (34.9–42.0)	38.2 (34.8–41.7)	38.0 (34.5–41.5)
Hip ROM ($^{\circ}$)	58.5 (55.0–61.9)	60.3 (56.8–63.8)	59.3 (56.5–62.1)
Knee ROM ($^{\circ}$)	78.6 (74.9–82.2)	80.9 (76.9–84.9)	82.1 (78.7–85.5)
Ankle ROM ($^{\circ}$)	63.0 (60.9–65.1)	64.2 (62.2–66.2)	65.2 (63.5–66.8)
Hip moment (N·m)·kg $^{-1}$	0.80 (0.68–0.93)	0.85 (0.71–0.98)	0.84 (0.73–0.96)
Knee moment (N·m)·kg $^{-1}$	1.18 (1.08–1.27)	1.19 (1.09–1.29)	1.18 (1.08–1.28)
Ankle moment (N·m)·kg $^{-1}$	1.24 (1.16–1.31)	1.23 (1.15–1.31)	1.21 (1.14–1.28)

CI = confidence interval; ROM = range of motion.

TABLE 2

Correlation coefficient (r) between vertical jump height (dependent variable) and each key independent variable for the box drop height conditions.

Variables	Jump height (15 cm)	Jump height (30 cm)	Jump height (45 cm)
Hip ROM	0.197	−0.071	−0.019
Knee ROM	0.436*	0.256	0.312
Ankle ROM	0.330	0.352	0.154
Hip moment	0.683*	0.632*	0.614*
Knee moment	0.719*	0.586*	0.755*
Ankle moment	0.304	0.377	0.330

ROM = range of motion.

* A significant ($p < 0.05$) Pearson correlation coefficient.

TABLE 3

Regression model coefficients for each box drop height condition.

Variables	Unstandardized B coefficients	SE	Standardized B coefficients	t ratio	p value
15-cm drop					
Intercept	-1.973	5.42		-0.364	0.722
Knee moment	22.83	4.35	0.613	5.246	<0.001
Hip moment	16.8	3.45	0.569	4.871	<0.001
30-cm drop					
Intercept	-2.936	5.67		-0.518	0.613
Knee moment	21.91	3.99	0.651	5.491	<0.001
Hip moment	17.77	3.04	0.692	5.844	<0.001
45-cm drop					
Intercept	-4.517	4.45		-1.016	0.328
Knee moment	24.20	3.28	0.712	7.379	<0.001
Hip moment	16.52	2.86	0.558	5.785	<0.001