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Use of an Overhead Goal Alters Vertical Jump Performance and Biomechanics

Kevin R. Ford,[1] Gregory D. Myer,[1] Rose L. Smith,[2] Robyn N. Byrnes,[2] Sara E. Dopirak,[2] and Timothy E. Hewett[1,2,3]

[1]Cincinnati Children's Hospital Research Foundation, Sports Medicine Biodynamics Center, and Human Performance Laboratory, Cincinnati, Ohio 45229; [2]University of Cincinnati, College of Allied Health Sciences, Physical Therapy Department, Cincinnati, Ohio; [3]University of Cincinnati, College of Medicine, Departments of Pediatrics and Orthopaedic Surgery, Cincinnati, Ohio.

Abstract. Ford, K.R., G.D. Myer, R.L. Smith, R.N. Byrnes, S.E. Dopirak, and T.E. Hewett. Use of an overhead goal alters vertical jump performance and biomechanics. *J. Strength Cond. Res. 19(2):394–399. 2005.*—This study examined whether an extrinsic motivator, such as an overhead goal, during a plyometric jump may alter movement biomechanics. Our purpose was to examine the effects of an overhead goal on vertical jump height and lower-extremity biomechanics during a drop vertical jump and to compare the effects on female (N = 18) versus male (N = 17) athletes. Drop vertical jump was performed both with and without the use of an overhead goal. Greater vertical jump height (p = 0.002) and maximum takeoff external knee flexion (quadriceps) moment (p = 0.04) were attained with the overhead goal condition versus no overhead goal. Men had significantly greater vertical jump height ($p < 0.001$), maximum takeoff vertical force (p = 0.009), and maximum takeoff hip extensor moment (p = 0.02) compared with women. A significant gender × overhead goal interaction was found for stance time (p = 0.02) and maximum ankle (p = 0.04) and knee flexion angles (p = 0.04), with shorter stance times and lower angles in men during overhead goal time. These results indicate that overhead goals may be incorporated during training and testing protocols to alter lower-extremity biomechanics and can increase performance.

Key Words. plyometric training, neuromuscular training, hip extensor moment, drop vertical jump

Introduction

The potential to achieve peak performance in sports competition requires an athlete to generate strength, speed, and power (30). The ability to demonstrate full-body power in off-season testing is related to the level of play (collegiate division I, II, or III) and to whether or not an athlete makes the starting roster (11, 12). Athletic movements such as jumping and cutting are more powerful if an athlete initiates the movement with a countermovement or preparatory descent before the leap (30). This plyometric action, in which the muscle is stretched before a rapid shortening to accelerate the body or a limb, is termed the stretch-shortening cycle (SSC) (33). The SSC muscle action increases power and performance when compared to pure concentric actions (2, 3, 30). The increased power output obtained from the SSC phenomenon likely increases force output during sports maneuvers (38). The drop vertical jump (DVJ), an exercise in which the athlete drops from a height before a maximum vertical jump, is often used to evaluate an athlete's ability to effectively use SSC during sports-related maneuvers (1, 2). DVJ jumps 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. DVJ training improves vertical jumping ability and energy production (13). The addition of extrinsic motivation may improve the effectiveness of testing or training athletes (30).

An extrinsic motivator, such as an overhead goal, has been used to increase the effort level in the vertical jump maneuver. Myer et al. (27) were able to establish gender-related biomechanical differences when the athletes performed a goal-oriented task and to increase the involvement of the upper body during the DVJ, which can increase vertical jump performance (8). Newton and Kraemer (30) suggest using feedback during plyometric training through the use of target jump heights or force plate analysis to maximize training efficiency. Conversely, employing a target or goal in a complex movement may negatively alter the motor programming of the athletes. Henry and Rogers (15) suggested that reaction time may increase when the complexity of a task increases. Therefore, coaches may opt to simplify movements during training sessions so as to not negatively affect the players' skill. Objective evaluation of motivational techniques during the DVJ may alter the way in which athletes are tested and trained.

Others have evaluated the effects of extrinsic motivators on performance and lower-extremity biomechanics. Cowling and Steele (4) demonstrated that the addition of sport-specific motivational techniques significantly altered muscle onset times. Motivation, including verbal encouragement and feedback, has been used in study protocols designed to improve performance and decrease injury risk (18, 28, 29). Augmented feedback (verbal and visual) given to an athlete performing a maximum effort vertical jump can significantly reduce impact ground reaction forces (32). These studies indicate that verbal analysis and feedback are critical to technique development, which can reduce injury risk and improve performance (18, 28, 29). The DVJ has specifically been used in injury risk assessment through evaluation of lower-extremity biomechanics in women athletes (10). Poor landing mechanics, which are potentially related to increased risk of an anterior cruciate ligament injury, were identified in female athletes compared with male athletes during the DVJ maneuver (10).

The same testing methods were applied to middle school and high school basketball and soccer players to determine whether maturation affected performance of the DVJ. The results demonstrated that plyometric tests

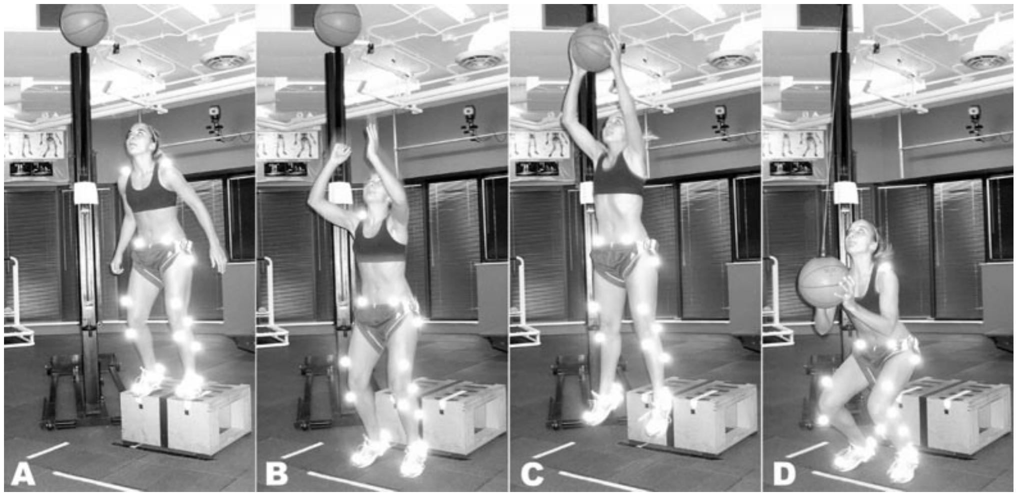

FIGURE 1. Drop vertical jump with the use of an overhead goal. (A) Subject starts on top of a 31-cm box. (B) Initial landing phase after the drop of the box. (C) Subject immediately performs a maximum vertical jump and grabs the suspended ball. (D) Final landing from the drop vertical jump.

(SSC maneuvers) were effective at detecting differences in maturing athletes (16). More important, Hewett et al. (17) found that measures obtained from the DVJ could be used to predict anterior cruciate ligament injury risk in a population of women athletes.

The purpose of this study was to examine the effects of an overhead goal on vertical jump performance in collegiate athletes. Specifically, we examined performance and biomechanical measures in men and women athletes during the DVJ without an overhead goal (NOG), and with the use of an overhead goal (OG) set to their predetermined peak vertical jump height. The hypotheses were that the overhead goal condition would increase performance and alter lower-extremity biomechanics in both men and women athletes and that gender differences would exist between the OG and NOG conditions.

METHODS

Experimental Approach to the Problem

A randomized, repeated-measures experimental design was used to determine the effects of an overhead goal on performance and lower-extremity biomechanics. The dependent performance variable in this study was maximum DVJ height. The dependent biomechanical variables were ankle, knee, and hip kinematics and moments; peak vertical ground reaction force; and stance time. The independent variables in this study were the use of suspended ball placed directly above the athlete for OG and for NOG. These variables were randomly assigned during the DVJ testing. The DVJ has been previously shown to have high within- and between-session reliability (9, 10).

Subjects

Two Division I collegiate soccer teams, consisting of 18 women (height 165 $\pm$ 5 cm, weight 66 $\pm$ 10 kg, age 20.0 $\pm$ 1.2 years) and 17 men (height 177 $\pm$ 6 cm, weight 74 $\pm$ 7 kg, age 21.1 $\pm$ 1.6 years), volunteered to participate in this study. The subjects were tested immediately before their competitive fall season (preseason mesocycle cycle). All subjects read and signed the informed written consent, approved by the Institutional Review Board, before participation. After the informed consent was obtained, height, weight and dominant leg were assessed. The dominant leg was determined for each subject by asking which leg they would use to kick a ball as far as possible (10). Each subject wore standard practice soccer shorts that were taped on each side to allow marker attachments to the skin.

Procedures

Standing countermovement vertical jump was tested on each subject with a MX-1 vertical jump trainer (MXP Sports). This device incorporated a suspended ball, which could be raised or lowered, with a digital readout of the height of the midline of the ball. The subjects were instructed to perform a countermovement jump and grab the ball with both hands at the top of their jump. The height of the ball was adjusted until the subject was unable to successfully grab the ball after 3 trials. The highest successful attempt was recorded and used as the suspended ball height during the DVJ.

Each subject was instrumented with 25 retroreflective markers placed on the sacrum and bilaterally on the shoulder, ASIS, greater trochanter, midthigh, medial and lateral knee, tibial tubercle, midshank, medial and lateral ankle, heel, and toe (between the second and third metatarsals). The subjects were shown the DVJ and allowed to practice the maneuver. The DVJ involved the athlete dropping off a 31-cm box and immediately performing a maximum vertical jump (Figure 1) (10).

Three trials of each condition, OG and NOG, were collected on each subject in random order. A suspended ball was placed directly above the athlete as an overhead goal and adjusted to the athlete's previously determined maximal jump height. The athlete was instructed to perform a maximal vertical jump immediately following the drop from the box. During the trials with the suspended ball, the subjects were further instructed to try to grasp the ball with both hands at the top of their jump.

Data Analysis

Motion and force data was collected with 8 digital cameras (Eagle cameras, Motion Analysis Corporation) and 2 force platforms (AMTI) sampled at 240 and 1200 Hz, re-

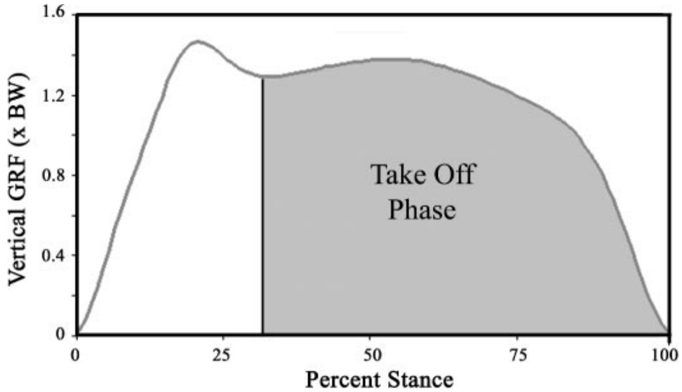

FIGURE 2. Identification of take-off phase from the vertical ground reaction force curve.

spectively. The data were time synchronized and collected with EvaRT (Version 3.3, Motion Analysis Corporation) and imported into KinTrak (Version 6.2, Motion Analysis Corporation) for data reduction and analysis. Before each data collection session, the motion analysis system was calibrated to manufacturer recommendations.

The 3-dimensional Cartesian marker trajectories from each trial were estimated using the direct linear transformation method. The video and force data were filtered at the same cut-off frequency (12 Hz), using a second-order, low-pass Butterworth filter (34). The dominant side ankle, knee, and hip flexion angles were then calculated from an embedded joint coordinate system (14). The maximum angle during the initial stance phase (landing off the box) was recorded. Ankle, knee, and hip flexion moments were calculated from the motion and force data using inverse dynamics (36). Net internal moments are described in this article and represent the body's response to external forces. Maximum flexion moments during the initial stance phase were calculated during the takeoff phase of the DVJ maneuver and were normalized to percentage body mass times height (N·m/(BW·ht)·100). The takeoff phase was defined from the first trough in the vertical ground reaction force, after the initial landing peak, to toe off (Figure 2). The maximum vertical ground reaction force was also calculated during the takeoff phase and was normalized to percent body mass (*N/BW*).

Vertical jump height was calculated from the right and left greater trochanter markers in the vertical axis. The difference between the standing height and the maximum height during the DVJ of each marker was averaged over 3 trials for each condition.

Statistical Analyses

Statistical means and standard errors of the mean of each variable were calculated for each subject's dominant side. The within-session reliability for each dependent variable was calculated with an Intraclass Correlation Coefficient (jump height $R = 0.993$; stance time $R = 0.959$; vertical takeoff force $R = 0.954$; maximum ankle, knee, and hip angle $R = 0.832$, 0.958, and 0.959, respectively; and maximum takeoff ankle, knee, and hip moments $R = 0.963$, 0.923, and 0.946, respectively). A 2-way mixed-design ANOVA was used to determine the main effects and interaction of overhead goal and gender on each dependent variable ($p \leq 0.05$). A post hoc paired *t*-test, split by gender, was used when a significant interaction was found. Statistical analyses were conducted in SPSS (SPSS for Windows, Release 11.5).

RESULTS

Performance

Vertical jump height was greater with the overhead goal for both women and men athletes ($p = 0.002$) (Table 1). Differences between genders were also found in performance measures, regardless of whether the overhead goal was used. A main group effect for gender was found in vertical jump height ($p < 0.001$), with men jumping 32% higher than women. In addition, men had 19% greater maximum takeoff vertical force ($p = 0.009$). Descriptive mean and standard errors are presented in Table 1 for each variable.

Movement Biomechanics

Differences were also found in movement biomechanics. Males had 18% greater maximum takeoff hip extensor moment than females, regardless of whether or not the overhead goal was used ($p = 0.02$) (Figure 3). The knee

TABLE 1. AUTHOR: Please provide table title.

	Men		Women	
	NOG	OG	NOG	OG
Flexion angle				
Ankle (°)	26.7 ± 0.8	26.3 ± 0.8‡	23.6 ± 2.1	24.4 ± 2.2‡
Knee (°)	79.2 ± 2.3	78.3 ± 2.4‡	84.0 ± 1.9	85.1 ± 1.9‡
Hip (°)	57.8 ± 2.8	55.0 ± 2.6	59.0 ± 2.4	58.8 ± 2.4
Extensor moment				
Ankle (Nm/(BW·ht)·100)	12.0 0.6	12.3 ± 0.5	10.2 ± 0.6	10.1 ± 0.6
Knee (Nm/(BW·ht)·100)	9.6 ± 0.6	10.2 ± 0.7*	8.5 ± 0.8	8.8 ± 0.8*
Hip (Nm/(BW·ht)·100)	15.0 ± 0.7	14.8 ± 0.8†	12.9 ± 0.7	12.5 ± 0.6†
Jump height (cm)	48.3 ± 1.1	49.4 ± 1.2*†	36.8 ± 1.1	37.3 ± 1.0*†
Stance time (sec)	0.42 ± 0.02	0.39 ± 0.02‡	0.41 ± 0.02	0.42 ± 0.02‡
Vertical force (N/BW)	1.62 ± 0.07	1.69 ± 0.07†	1.42 ± 0.05	1.42 ± 0.05†

Data presented as mean ± *SE*. NOG = no overhead goal; OG = overhead goal.
* Significant goal effect $p < 0.05$.
† Significant gender effect $p < 0.05$.
‡ Significant goal × gender interaction $p < 0.05$.

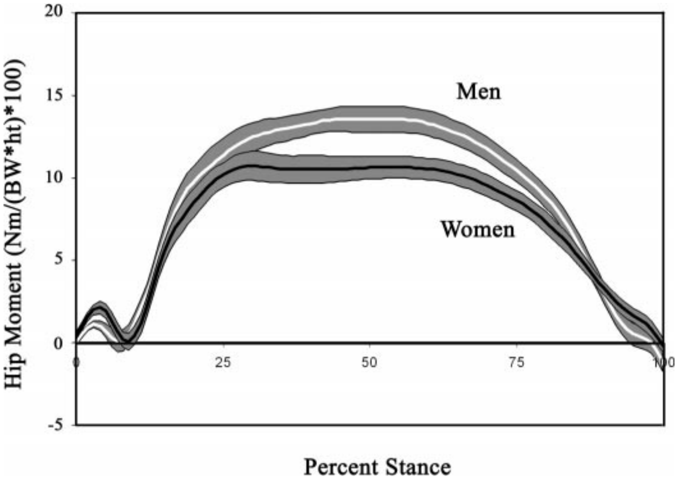

FIGURE 3. Average men (white) and women (black) hip moment normalized to stance phase.

moment was significantly greater with the use of the overhead goal, indicative of increased knee extensor recruitment. A main effect for the OG was found for the maximum takeoff knee extensor moment ($p = 0.04$).

The men and women performed the DVJ differently with the overhead goal. A significant goal × gender interaction was found for stance time ($p = 0.02$) and maximum ankle ($p = 0.04$) and knee flexion angles ($p = 0.04$). Post hoc paired *t*-test analysis demonstrated that stance times (the time in contact with the force plate) were significantly shorter in men ($p = 0.02$) with the overhead goal, whereas women showed no difference in stance time between OG and NOG conditions ($p = 0.51$). Knee angle in women was not different between goal conditions, but kinematic analysis did show a trend ($p = 0.09$) toward increased knee range of motion with the overhead goal. In addition, maximum ankle angle in women showed a similar trend ($p = 0.08$), with an increased range of motion during the overhead goal condition. Maximum ankle ($p = 0.31$) and knee ($p = 0.20$) angles were not significantly different in men with and without the goal.

DISCUSSION

The purpose of this study was to examine the effects of an overhead goal on vertical jump height and movement biomechanics in collegiate athletes. In support of our hypothesis, we found that both men and women had increased vertical jump height with the overhead goal. The overhead goal significantly affected the vertical jump performance in both men and women. Horita et al. (20) found a close interrelationship between knee joint moment, takeoff velocity, and peak knee joint power during DVJ performance. This indicates that the increased knee moments found in this study may have played a role in both male and female athletes achieving greater jump heights. However, additional mechanisms behind the improved performance in the OG condition appeared to be different between genders. Men likely increased their vertical jump performance by decreasing the stance phase, or time of the landing, which may more effectively use the SSC. A decrease in the amortization phase on landing requires faster muscle recruitment. Decreasing stance time may relate to increased initial knee stiffness and better performance, whereas a longer stance time (absorbing type landing) and subsequent increased knee flexion may decrease performance during SSC (20). The men had relatively increased recruitment of the hip musculature compared to women, which may have been partially responsible for the increased force in a shorter period of time in men during the overhead goal condition. Women also increased their jump height with the overhead goal. However, their strategy for increased jump height was not through a mechanism of decreased stance of the SSC. The women athletes appeared to improve their work output through a trend toward increased knee and ankle maximum angles. Inexperienced jumpers have previously been shown to exhibit greater maximum flexion angles during DVJ maneuvers compared with skilled jumpers (35).

Gender differences were found during the plyometric movement both with and without the overhead goal. Men used 18% greater hip extensor moments during the concentric phase of the DVJ. The hip extensors (gluteus maximus, hamstrings) are important not only in extending from a squat position but also in establishing or maintaining posture and balance when landing from a jump. Imbalances in hip strength and function have also been indicated to be potential factors related to lower-extremity and anterior cruciate ligament injuries in women athletes (21, 22). Decker et al. (5) showed a decrease in negative joint work at the hip in women athletes compared to men during a landing from a 60-cm height. Similarly, anterior cruciate ligament reconstructed patients had greater hip moments during stance phase of gait, which may provide increased protection for the anterior cruciate ligament (6).

The suspended ball used in the current study was the goal the athletes attempted to reach during the DVJ. Goal setting is well-established in the field of psychology and is the object or aim of an action (26). Lee and Edwards demonstrated that a specific goal produced a higher level of performance than if the athlete was merely asked to perform optimally (24). In this study, the overhead goal was set to the athlete's previously measured maximal jump height. Further investigation into the effects of varying the difficulty of attaining the goal should be considered. The increased complexity of the task did not appear to be detrimental to performance during the DVJ maneuver. Coaches may want to include a goal or target during training sessions to improve performance.

Athletes and coaches work to attain a greater maximum vertical jump to enhance performance in sport. Not only does greater vertical jump allow the athlete to play "closer to the rim," reach the ball first, and so on, but it is an excellent and reproducible indicator of whole-body power. For example, vertical jump reliability has been reported to range between 0.90 and 0.99 (37). There are several different training methods used to increase the maximum vertical jump height. Newton et al. (31) demonstrated that ballistic resistance training is effective in improving vertical jump performance in elite jumping athletes. Landing mechanics and lower-extremity strengthening have also been shown to affect vertical jump height (19). Following short-duration (6 weeks) plyometric training, Hewett et al. (19) found an approximate 10% increase in mean vertical jump height in women athletes. The addition of upper-extremity movements can also have an effect on vertical jump performance (8, 25). A 12.7% increase in vertical jump height was predicted in a biomechanical model when arm movements were included (25). Increases in both hip and knee extension torques were reported in volleyball players when an arm swing was added to a vertical jump movement (8). The increased vertical jump height in this study may be related to increased arm thrust toward the target in the OG situation.

Several general theories have been proposed to explain the enhanced power afforded by rapid muscle stretch before contraction. Stretch of the series elastic component of the muscle, stretch of the muscle spindle that leads to a forward feedback loop that increases muscle contraction, and increased proximity of actin-myosin molecules with stretch have all been proposed as potential mediators of the plyometric effect (37). Although different theories exist, what is known from the literature is that performance can be improved when adding a plyometric movement to an exercise (23, 38) and when adding plyometric exercises to a training program (7, 19, 31). An athlete properly trained with plyometrics may achieve increased levels of performance and be better prepared to handle high joint forces that are generated during athletic competition, which may reduce their risk of injury.

The use of soccer players in this study is a potential limitation, as the results may not transfer to other sport populations. Plyometric training and testing appear to be increasingly popular with a variety of athletic teams, and differences between sports should be considered in future investigations. Another potential limitation is that differences in size and muscle factors may exist between genders. We did, however, normalize the variables to height and weight, so capturing an entire team may be a better representation of the population with which coaches and professionals work.

Practical Applications

The study findings indicate that adding a goal both increased DVJ height and altered biomechanical measures in both men and women athletes. Vertical jump testing protocols for athletes should use an extrinsic motivator to encourage maximal effort during the task. The gender differences in performance and biomechanics found with an OG should be further investigated, as these findings may have important implications for the development of screening protocols, and plyometric training programs have been advocated for injury prevention and performance enhancement (18, 21).

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Address correspondence to Kevin R. Ford, M.S., Kevin.Ford@cchmc.org.