Kinetic Analysis of the Role of Upper Extremity Segmental Inertia on Vertical Jump Performance

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ABSTRACT

Williams SJ, Barron TR, Ciepley AJ, Ebben WP. Kinetic Analysis of the Role of Upper Extremity Segmental Inertia on Vertical Jump Performance. JEPonline 2017;20(2):28-34. This study assessed the contribution of forceful arm swing during the eccentric and concentric phases of the countermovement jump (CMJ), in order to determine the effect on CMJ performance. Fourteen women performed three test exercises, including the CMJ with no shoulder extension during the eccentric phase, CMJ with no shoulder flexion during the concentric phase, and normal CMJ including maximal shoulder flexion and extension. Jump height (JH), power (P), and ground reaction force (GRF) were assessed using a force platform. A repeated measures ANOVA was used to assess the differences between the test exercises for JH, P, and GRF. A Bonferroni post hoc analysis was performed to identify specific differences between test exercises. Analysis demonstrated significant differences between test conditions for JH (P<0.001) and P (P<0.001), but not for GRF (P>0.05). This study demonstrated significant differences between jumping conditions that maximized arm swing. Conditions omitting the upward and downward arm swing resulted in jump heights 12.1% and 3.51% less than the normal CMJ, respectively. Therefore, arm swing is important to both the eccentric and concentric phase of jumping.

Key Words: Arm Swing, Force, Ground Reaction Force, Power
INTRODUCTION

Segmental inertia and eccentric overload enhance jumping performance (11). These mechanisms are created through the use of shoulder extension and flexion during the countermovement jump (CMJ) (15). During the CMJ the countermovement potentiates all elastic components of the muscle tendon complex, which has a favorable effect on the stretch shortening cycle resulting in increased work output. As a result, jump height and power increase (16,20).

Altering the position and distribution of body mass during an arm swing is the most efficient way to provide optimal loading of the lower extremities, thus resulting in a maximum vertical jump performance (12). The muscular forces associated with the downward arm swing enhance eccentric loading and increase kinetic energy of the lower body, which increases jump height (9,10,14,19).

Muscular force produced during the upward arm swing creates a vertical energy that can be exchanged throughout the kinetic chain, increase vertical velocities, and elevate the center of mass and, therefore, improve jump performance (1,2,3,5,6,13). Countermovement jumps performed with forceful upward arm swing resulted in a higher moment of inertia (16). Shoulder flexion at take-off likely increases muscle capabilities that can be used during jumping (15). For example, kinetic energy that is developed by the downward arm swing is transferred through shoulder flexion and pulls on the rest of the body. This pull is important for increasing jump height (7,14).

Previous research has shown that both the eccentric and concentric phases of the countermovement are influenced by arm swing, producing more power and greater jump heights (8,13). However, no previous study has evaluated the separate components of the arm swing and their independent role in increasing power and jump height. Understanding the role of each component of the arm swing can help practitioners in training athletes to optimally use the arm swing to maximize jump performance. Therefore, the purpose of this study was to assess the contribution of forceful arm swing during the eccentric and concentric phases of the CMJ in order to determine the effect on CMJ performance.

METHODS

Subjects
Fourteen women subjects (age = 20.5 ± 1.2 yrs; weight = 71.19 ± 12.27 kg; height = 166.96 ± 5.73 cm; collegiate experience = 2.67 ± 1.1 yrs) participated in this study. Subjects were NCAA Division III student athletes who participated in volleyball, softball or basketball. All subjects gave informed consent and filled out a Physical Activity Readiness Questionnaire (PAR-Q). This study was approved by the Institutional Review Board. Researchers assessed subject history of sport participation. The subjects were free of orthopedic, cardiac, and pulmonary pathology that would inhibit full participation in their formal and informal athletic activities. All subjects met the clearance protocol of the concussion policy as set forth by the NCAA and the Lakeland University athletic training staff.
Procedures
All habituation and test exercises were performed on a 30 x 40 inch force platform (ACP, Advanced Mechanical Technology, Inc., Watertown, MA, USA). The platform was connected to a laptop from which the data were analyzed using the proprietary software program (Accupower Software, Advanced Mechanical Technology, Inc., Watertown, MA, USA). Data analysis included ground reaction force, power, and jump height.

The subjects performed habituation and testing sessions. Prior to each session, the subjects performed a general and specific warm-up. During the habituation session, subjects were taught the three test exercise conditions including: (a) a normal CMJ; (b) a downward arm swing CMJ; and (c) an upward arm swing CMJ. The normal CMJ included forceful downward and upward arm swings. During the downward arm swing CMJ, the subjects used only the forceful downward arm swing during the eccentric, or countermovement, phase of the jump, and then maintained their arms by their side in the anatomically correct position through the rest of the jump. Finally, during the upward arm swing CMJ, the subjects maintained their arms at their side in the anatomically correct position during the countermovement, and then used only a forceful upward arm swing during the concentric phase of the jump. After the exercises were taught, the subjects were given time to practice each of the test exercises on the force platform to ensure proper technique and to gain familiarity with jumping on the force platform.

The testing session was held 48 to 96 hrs after the habituation session. The three exercises that were taught in the habituation session were tested. The exercise order was randomized to reduce the likelihood of fatigue or potentiation effects related to exercise order. Three repetitions for each test exercise were conducted with 20 sec of rest between each repetition. This amount of rest has been shown to allow sufficient recovery, and thus maximum effort for each exercise performed (17).

Statistical Analyses
The subject’s jump performance was evaluated for all jumping conditions using kinetic data obtained from the force platform. The ground reaction force (GRF) was taken as the highest force recorded on the force time record for the takeoff phase of each jump. Power (P) and jump height (JH) were determined from force-time record summary obtained from the software.

A 2-way mixed analysis of variance with repeated measures was used to assess the difference between the test exercises for JH, P, and GRF. When significant differences were found, a Bonferroni post hoc analysis was performed in order to identify specific differences between the test exercises. The trial to trial reliability of each dependent variable was determined using average measures intraclass correlation coefficients. An a priori alpha level of P≤0.05 was used for statistical significance.

RESULTS
Analysis demonstrated significant differences between test conditions for JH (P<0.001) and P (P<0.001), but not for GRF (P>0.05). Results are shown in Table 1. Intraclass correlation coefficients for the test exercises and all dependent variables ranged from 0.95 to 0.99.
Table 1. Jump Height and Power (mean ± SD) for Each Test Exercise.

<table>
<thead>
<tr>
<th>Test Exercise</th>
<th>Jump Height (cm)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMJ</td>
<td>35.05 ± 10.03a</td>
<td>4203.86 ± 1271.49a</td>
</tr>
<tr>
<td>CMJ with shoulder flexion only</td>
<td>33.82 ± 9.18a</td>
<td>4055.71 ± 1202.61a</td>
</tr>
<tr>
<td>CMJ with shoulder extension only</td>
<td>30.13 ± 8.98a</td>
<td>3622.43 ± 1100.10a</td>
</tr>
</tbody>
</table>

*aSignificantly different than all other test exercises (P<0.05)

**DISCUSSION**

This is the first study to evaluate the separate components of the arm swing during the CMJ. This study compared the downward and upward movements of the arm swing and the role in jump performance. These ballistic movements may influence segmental inertia and eccentric loading. Collectively, these factors can improve jump performance.

The most significant finding of the current study showed the condition including only the downward arm swing during the CMJ resulted in jump heights that are 12.1% less than the normal CMJ. The absence of the upward arm swing produces sub-optimal jump conditions. Previous research has shown that during the upward arm swing, muscular force in the shoulder during maximal shoulder flexion creates a vertical energy that is transmitted through the kinetic chain (2,3,13). The transmitted energy is stored in the upward arm swing, which pulls the body upward resulting in the higher jump heights (14). Shoulder flexion transmits inertia between body segments during the jump, producing higher jump heights (7,16). This study found that using maximal shoulder flexion produced higher jumps with more power when compared to CMJs without shoulder flexion. These results suggest that the greatest contributor to jump height is the upward transmission of segmental inertia through the kinetic chain.

The condition using only upward arm swing during the CMJ resulted in jump heights that are 3.51% less than the normal CMJ. Upward arm swing during the CMJ resulted in significantly higher jump heights and power than the downward arm swing during the CMJ. No previous studies demonstrate the effect of downward arm swing during the CMJ and its role on eccentric loading. Previous studies have shown that the downward arm swing creates segmental inertia that is transmitted to the lower body creating an overload (9-11,19). The eccentric load of the lower body is established by the increase in kinetic energy produced during the downward arm swing, which creates more power (14). Eccentric loading through external sources has been found in previous research to alter loading of the lower body to improve peak power and jump height for CMJs (12). The current study provided evidence that the downward arm swing was the external source that provided optimal loading of the lower extremities to produce maximum jump performance.
The current study showed that using both upward and downward arm swings produced greater jump heights than each arm swing condition independently. This finding is consistent with research that found that jump heights are greatest when using an arm swing, especially when compared to a no arm swing condition (1,2,5,6,13,18,20). Full arm swings create more power, and thus more kinetic energy to be transmitted through the body resulting in higher jumps (15). Previous research found that CMJs performed with an arm swing had larger vertical velocities and raised the center of mass when compared to jumps without an arm swing (1,5,6,13). Research has found that power and jump height are related in that subjects who produce more power typically yield a higher jump height (4). Other studies found that the components of the arm swing have different roles but both contribute to jump height (8). The current study demonstrates that CMJs using a full arm swing created more power during the jump than the test exercises that excluded either the upward or downward part of the arm swing. The larger vertical velocities and higher centers of mass found when using an arm swing could produce the increase in power and jump height found in the current study.

The current study found that as power increased, so did jump height. Therefore, the components of the arm swing contributed differently to jump height and power, with shoulder extension likely improving eccentric loading and shoulder flexion increasing segmental inertia. The shoulder flexion offered a higher contribution to jump performance, but shoulder extension is also important for producing maximum jump performance. These results provide evidence that the optimal jump performance is the result of a full and forceful arm swing. Greater subject heterogeneity would improve the generalization ability of these study results. Future studies could include male subjects and assess gender differences.

CONCLUSIONS

By examining the components of the arm swing separately, the current study provides evidence that arm swing is important to both the eccentric and concentric phases of jumping. During training, and the performance of jumping in sport, practitioners should teach athletes to maximally accelerate their arms into shoulder extension during the countermovement phase of CMJ. Athletes should also be instructed to use full range of motion ballistic shoulder flexion during the concentric phase of CMJ. By doing so, athletes will be able to maximize power and jump height.

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