TRAINING SPECIFICITY OF HURDLE VS. COUNTERMOVEMENT JUMP TRAINING

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ABSTRACT

Cappa, DF and Behm, DG. Training specificity of hurdle vs. countermovement jump training. *J Strength Cond Res* 25(X): 000–000, 2011—The objective of this study was to compare bilateral and unilateral hurdle jumps with traditional countermovement jumps (CMJs). Thirteen athletes were tested during continuous forward bilateral and unilateral hurdle jumps and single CMJ. Countermovement jump height was used to establish the hurdle height. Subjects jumped forward over 4 hurdles with the force plate positioned after the second hurdle to measure vertical ground reaction force (VGRF), contact time (CT), and rate of force development (RFD). For bilateral jumps, hurdle height was established at maximal (100%) CMJ height and at 120, 140, and 160% of the CMJ height. The athletes were instructed to jump as fast as possible to mimic a training session drill. For unilateral jumps, hurdle height was set at 70, 80, and 90% of the CMJ height. Bilateral 160% jumps showed a significantly longer CT than bilateral 100, 120, and 140% jumps. The bilateral 100, 120, and 140% jumps had significantly shorter CT than the unilateral jumps and CMJ. The VGRF during bilateral jumps was higher than unilateral jumps and CMJ. Bilateral 160% jump RFD was significantly higher than CMJ and unilateral jumps but significantly lower than the other bilateral jumps. In conclusion, the characteristics of the bilateral jumps were substantially different from those of the CMJ and unilateral hurdle jumps. As bilateral hurdle jumps with a height between 100 and 140% of the CMJ provide similar CTs and VGRF as many reported sprint or jump actions, they may be considered a more training-specific power training drill than the CMJ.

KEY WORDS contact time, rate of force development, unilateral jumps, bilateral jumps, stretch-shortening cycle

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INTRODUCTION

In power-related sports, plyometric training is an important component of athletic preparation to increase muscular power. Plyometric exercises combine speed and strength to produce an explosive-reactive movement (12) involving eccentric and concentric muscle contractions (stretch-shortening cycle [SSC]) using the body as an overload stress (6). Plyometric activities can include drop jumps, hops, bounding, countermovement jumps (CMJs), and other activities. These various activities may involve quite different movement speeds, rate of force development (RFD), contact times (CTs), and reaction forces.

Schmidtbleicher (31) defined 2 types of SSC actions to train explosiveness. A jump performed with a CT <250 milliseconds was classified as a short SSC and >250 milliseconds was considered a long SSC. Many coaches emphasize jump drill training with a goal of a short CT and maximal height or maximal movement velocity (15,36,37). Examples of a short SSC are jumps over low to moderately high obstacles or drop jumps. These training techniques are based on the literature, which report that elite sprinters use approximately 100 milliseconds of ground CT during a maximal sprint (23), ~200, ~180, and ~160 milliseconds of CT for the first 3 steps from starting blocks (21), ~250 milliseconds with handball players performing maximal cutting side-step maneuvers (3) and ~177 milliseconds during a high jump using flop technique (1). This information provokes the question of whether the prolonged CT associated with CMJ (>~700 milliseconds of CT) (10,19) is an appropriate sport-specific training or testing technique.

Vertical ground reaction forces (VGRFs) during agility and jump actions can reach up to 2–7 times the body weight. Reaction forces with agility-related change of directions have been is reported to reach approximately 2,500 N (~3× body weight) (3), and sprinting can attain approximately 4,600 N (~6× body weight) (1,13). It is important to consider that these reaction force values are generated and sustained with just 1 leg. For training specificity, it is important to quantify the appropriate training techniques that provide similar reaction forces as these sport actions.

During activities such as running, hopping, and some jumps (i.e., drop jumps), the leg behaves like a spring (4,14). Subjects adjust their leg stiffness to match different movement conditions. Generally, as the movement velocity increases, the force and RFD increase as well (28). During hopping or jumping, VGRF force–time curves can show a single peak (spring-like behavior) (14) or a double peak (non–spring-like behavior) (9,14,24). The double peaked force possibly indicates a pausing between the ending of the eccentric movement and the starting of the concentric movement (28). Cavagna (8) proposed that a double peak is a failure and represents a loss of mechanical energy because the stored elastic energy during the eccentric phase is not converted into kinetic energy during muscle concentric phase. Austin et al. (2) believe that this condition is related to an asymmetric deceleration of the 2 limbs in 2-legged hopping. Jump training should provide a specific environment with short CTs, high reaction forces, and RFD without causing a failure (double peaked reaction forces). Thus, it is important to evaluate current training and testing practices to ensure they provide sport-specific temporal and kinetic parameters.

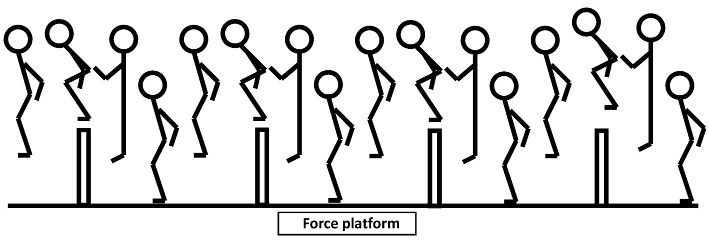

Figure 1. Illustration of bilateral hurdle jumps.

Coaches use many kinds of jump drills because variability is an important principle in training process (26,33). There has been extensive research in single jumps such as drop jump (5,36), squat jump (18), CMJ (19,32), and loaded jump squats (10,16). However, the effects of multiple SSC actions on plyometric actions have not been previously investigated. Thus, the literature has not provided extensive information on common training practice as plyometric training is normally performed with several continuous repetitions and not just a single action (27).

The main objective of this study was to compare the kinetic characteristics of unilateral and bilateral hurdle jumps with CMJ. It was hypothesized that hurdle jumps would provide significantly shorter CT, higher RFD, and reaction forces compared to CMJ.

Table 1. Contact time.*

Type of jump	Mean ± *SD* (ms)
CMJ	809.8 ± 112.58†
Bilateral 100%	177.7 ± 21.06‡
Bilateral 120%	184.7 ± 23.72‡
Bilateral 140%	189.2 ± 19.91‡
Bilateral 160%	209.2 ± 32.61‡§
Unilateral 70%	256.3 ± 41.3
Unilateral 80%	259.4 ± 34.52
Unilateral 90%	262.1 ± 30.56

*CMJ = countermovement jump.
†Significant differences between CMJ and all bilateral and unilateral jumps ($p < 0.001$).
‡Significant differences between the bilateral vs. unilateral jumps ($p < 0.001$).
§Significant differences between bilateral 160% hurdle jump and the other bilateral 100, 120, and 140% hurdle jumps.

Table 2. Force production.*

Type of jump	Mean ± *SD* (N)
CMJ	2,149.4 ± 273.45†
Bilateral 100%	4,305.1 ± 662.17‡
Bilateral 120%	4,335.0 ± 765.11‡
Bilateral 140%	4,261.0 ± 553.92‡
Bilateral 160%	4,007.8 ± 680.85‡
Unilateral 70%	2,421.4 ± 450.98
Unilateral 80%	2,473.0 ± 554.64
Unilateral 90%	2,375.0 ± 485.19

*CMJ = countermovement jump.
†Significant differences between CMJ and all bilateral jumps ($p < 0.001$).
‡Significant differences between the bilateral vs. unilateral jumps ($p < 0.001$).

Methods

Experimental Approach to the Problem

The athletes visited the laboratory on 2 occasions separated by at least 2 days. The first session included general anthropometric measurements, an aerobic and jump warm-up followed by 2 trials of a maximum height CMJ on a force platform. The second session included the same warm-up followed by bilateral and unilateral jumps over hurdles. Subjects jumped forward over 4 hurdles (50-cm distances between hurdles) as fast as possible with the force plate positioned after the second hurdle. The initial hurdle height was established at the maximal CMJ height, and this value was considered as the reference height (100%). Using a randomized selection process, hurdle height was modified from 100, 120, 140, and 160% of the CMJ height for the bilateral jumps and 70, 80, and 90% of the maximum CMJ height for unilateral hurdle jumps. The data were analyzed for CT, VGRFs, and RFD.

Subjects

Thirteen male athletes (12 were provincial rugby players and 1 Argentinean soccer first division goalkeeper) were assessed within the regular competitive season. Age, weight, height, years of training, and CMJ height were as follows: 22.3 ± 2.2 years, 80.1 ± 7.1 kg, 178.6 ± 5.4 cm, 12 ± 1 years, and 46.1 cm ± 3.9, respectively. All participants provided written consent to participate in this study. All the athletes were accustomed to performing multiple jumps over hurdles and strength training in their training programs. Exclusion criteria were any musculoskeletal injuries, squat less than their body weight, and leg pain, which did not allow the athlete to jump properly. The study was approved by the Memorial University of Newfoundland Human Investigation Committee.

Protocol

Subjects refrained from performing any exercise 24 hours before the testing sessions. Sessions were separated by at least 2 days. Warm-up during both sessions consisted of 10 minutes of cycling (75 W–60 rpm), 5 sets of 5 submaximal hopping, 5 single submaximal CMJs, and 2 maximal CMJs. Then, the subjects stood on the force platform and were asked to perform a maximal CMJ. For ecological validity, subjects were allowed use of their arms to mimic the natural training conditions. Subjects did not receive any specific instructions about the leg position or knee movement during the jump. Two trials were tested with 1-minute rest to avoid fatigue. The average flight time of the 2 jump results was used to calculate jump height with the software using the following formula: CMJ height (m) = (9.81 × flight time [seconds] × flight time [seconds])/8. Because this value was used to establish and calculate the hurdle heights during the subsequent bilateral and unilateral hurdle jumps, CMJs were always performed in the first testing session.

During the second session, athletes were asked to perform jumps over hurdles. Subjects jumped forward over 4 hurdles with the force plate positioned after the second hurdle (Figure 1). Hurdles were spaced 50 cm apart. For bilateral jumps, the athletes were instructed to jump with 2 legs as fast as possible with a solid and balanced foot base (feet shoulder width apart) trying to mimic a training session drill. The hurdle height was established as a percentage of the maximal CMJ height. Using a randomized selection process, hurdle height was modified from 100, 120, 140, and 160% of the CMJ height for the bilateral jumps. For unilateral hurdle jumps, hurdle height was set in a random order at 70, 80, and 90% of maximum CMJ height, and athletes were asked to jump over the hurdles as quickly as possible with the dominant leg and the contralateral leg. Pilot data tested unilateral jumps with 100% of the CMJ height, but most of the athletes showed problems controlling balance upon landing. Hence, it was decided not to assess >90% of the CMJ height for unilateral hurdle jumps. The relative jump heights were based on both empirical evidence from elite athlete training and the characterization of high impact plyometric exercises by Bompa (6). The order

TABLE 3. Rate of force development.*

Jump	Mean ± *SD* ($N \cdot s^{-1}$)
CMJ	4,681.6 ± 1,541.42†
Bilateral 100%	40,981.2 ± 10,352.6‡
Bilateral 120%	39,671.6 ± 11,770.28‡
Bilateral 140%	35,926.2 ± 8,212.09‡
Bilateral 160%	32,153.9 ± 8,971.00‡§
Unilateral 70%	14,167.0 ± 4,537.91
Unilateral 80%	14,293.3 ± 4,827.50
Unilateral 90%	13,390.5 ± 3,861.80

*CMJ = countermovement jump.
†Significant differences between CMJ and all bilateral and unilateral jumps ($p < 0.001$).
‡Significant differences between the bilateral vs. unilateral jumps ($p < 0.001$).
§Significant differences between bilateral 160% hurdle jump and the other bilateral 100, 120, and 140% hurdle jumps.

TABLE 4. Intercorrelation matrix between CMJ and bilateral jumps.*

	CMJ CT	CMJ reaction force	CMJ jump height	CMJ RFD
Bl100% CT	−0.32	−0.21	−0.35	0.33
Bl100% force	−0.09	0.36	0.05	−0.12
Bl100% RFD	0.04	0.28	0.18	−0.21
Bl120% CT	−0.13	−0.31	−0.05	0.10
Bl120% force	−0.16	0.37	−0.11	−0.11
Bl120% RFD	−0.07	0.20	−0.02	−0.11
Bl140% CT	−0.30	−0.10	−0.34	0.34
Bl140% force	−0.26	0.39	−0.11	0.19
Bl140% RFD	0.03	0.30	0.05	−0.19
Bl160% CT	−0.13	−0.03	−0.15	0.05
Bl160% force	−0.11	0.37	−0.06	−0.04
Bl160% RFD	−0.04	0.24	0.09	−0.13

*CMJ = countermovement jump; RFD = rate of force development; CT = contact time.

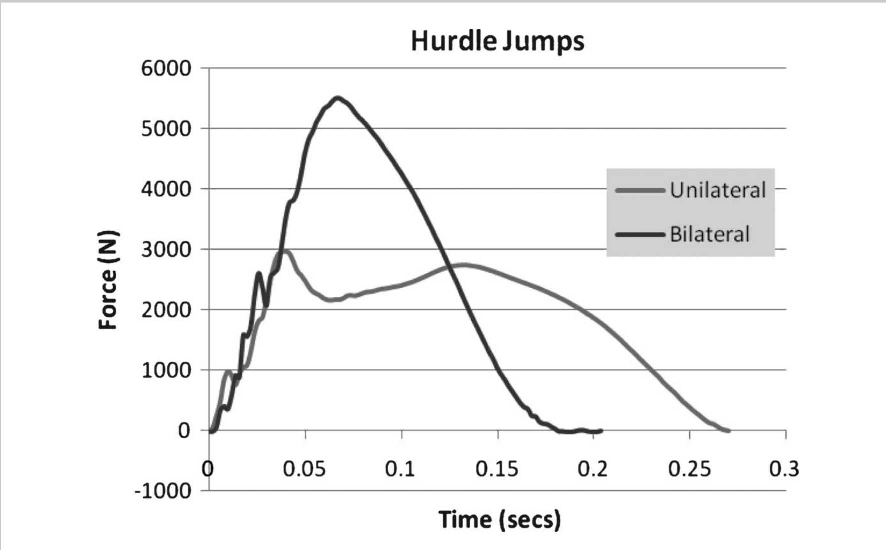

Figure 2. Reaction force traces of a bilateral jump at 140% of maximum countermovement jump (CMJ) height and a unilateral hurdle jump at 90% of maximum CMJ height. Force on the *y* axis is in Newtons (N).

of bilateral and unilateral jumps was randomized with 2 trials for each jump and 1minute of rest between jumps to avoid fatigue. The take-off was strictly monitored with no intermediate jumps or delays during the eccentric–concentric transition phases.

Data Collection

Two Pasco force platforms (PS 2142 Roseville, CA, USA) were used to evaluate VGRFs at a sample rate of 500 Hz. The force platforms were connected to an interface (Pasport Power Link PS-2001). Force platforms were calibrated by using the shunt technique provided by the company. Data were collected and analyzed with DataStudio software (Pasco).

Statistical Analyses

The following variables were analyzed. Contact time (milliseconds) was defined as the sum of the eccentric and concentric phase time. Vertical ground reaction force (N) was calculated from the peak force value reached during the concentric phase. Rate of force development was considered as the peak force developed during the concentric portion of the contraction divided by the time employed ($N \cdot s^{-1}$) (22).

The statistical analyses were undertaken with SPSS 16.0 for Windows (SPSS, Inc., Chicago, IL, USA). Descriptive statistics were calculated and a 1-way, repeated-measure analysis of variance was used to test for main effects between the jump conditions. Significant main effects were further analyzed with Bonferroni-adjusted pairwise comparison of within-subject differences among the variables. The criterion for significance was set at a level of $p \leq 0.05$. Pearson correlation coefficients were used to analyze interrelationships among variables.

Results

There was no statistically significant difference between right and left legs with reaction force, CT, or RFD. Hence, the following results will represent the average data of both legs.

Bilateral 160% hurdle jumps showed a significantly longer CT than did bilateral 100, 120, and 140% hurdle jumps. The CT associated with the bilateral hurdle jumps was significantly different from the unilateral jumps and CMJs (Table 1).

Reaction forces were not different between the bilateral jumps, but they showed significant differences with the unilateral jumps and CMJ. There were no significant differences between the CMJ and unilateral jumps (Table 2).

Bilateral 160% hurdle jumps RFD showed a significant difference compared with the other bilateral jumps, CMJs, and unilateral jumps (Table 3). Table 4 illustrates the lack of significant correlations between the bilateral and unilateral hurdle jumps with the CMJ variables.

Discussion

One of the most important results of this research was that a ubiquitous training and testing bilateral activity such as the CMJ was shown not to correlate with any of the bilateral hurdle jumps, which have a number of similar performance characteristics as many common sport actions. Although the CT of the CMJs in this study was approximately 810 milliseconds, Dintiman (13) reports the average CT of 90, 175, 130, 110, 250, and 400 milliseconds for elite sprinting, bounding, high jumping, long jumping, change of direction, and elite marathon running, respectively. Bilateral hurdle jumps at 100–140% of the CMJ height exhibited CT of ~178–190 milliseconds, whereas unilateral hurdle jumps were slightly slower around 250 milliseconds (see Figure 2 for typical reaction force traces). Furthermore, although the reaction force of the CMJ in this study was approximately 2,150 N, reaction forces for elite sprinting, bounding, high jumping, long jumping, and change of direction are reported to range from 3,120 to >6,000 N (13). Once again, bilateral hurdle jumps provided reasonably comparable reaction forces with a range of 4,000–4,335 N. Nonetheless, CMJs are traditionally used to control training program results (17,29), to assess specific sports fatigue (25), or to classify performance level (7). Because plyometric training is used to increase sport performance, which is represented by common explosive sport actions like sprinting and side-step cutting maneuvers, specific plyometric exercises should provide similar or superior characteristics as the competitive activities (30).

Weyand et al. (34) demonstrated that to increase running velocity, a shorter CT and a higher force is needed. Bilateral and unilateral hurdle jumps resulted in shorter CT and higher force levels and RFD than CMJs did. For example, bilateral 100% hurdle jumps demonstrated the shortest CT with 177 milliseconds, whereas CMJ CT (809 milliseconds) was 4.5 times greater duration. Furthermore, bilateral 120% hurdle jumps generated mean reaction forces of 4,335 N, which represented 5.5 times the body weight and was approximately 100% greater than CMJs. This study suggests that CMJs do not adequately represent many common explosive sport actions.

Bilateral hurdle jumps also showed higher forces than other traditional resistance exercises such as loaded squat jumps. The force during bilateral jumps exceeded 4,000 N, which was greater than loaded jump squats using 85% of the maximum squat force (3,000 N) as reported by Cormie et al. (10). Bilateral jumps in this study generated approximately 30% more concentric force than in the Cormie et al. study even with lower athlete body weights (~80 vs. ~90 kg). In addition, bilateral jumps generated higher force in comparison with change of direction movement (2,000 N) in handball players (3).

These results suggest that bilateral jumps over hurdles are an excellent exercise to simulate CT and reaction forces because the values are similar or even superior than traditional resistance exercises such as squats, hang cleans, and loaded jumps (10). Optimal obstacle height could be set at 100–120% of the maximum CMJ height. The use of a greater height does not provide statistically significant improvements in CT, reaction force, or RFD. From our observations, the use of a higher obstacle (i.e., 160% of CMJ height) forces the athlete to flex their knees to a much greater extent to pass over the hurdle. This situation does not allow the athletes to increase performance.

Although there was a statistically significant difference between bilateral 160% hurdle jumps and all the other bilateral jumps heights, CT was still below 250 milliseconds. By Schmidtbleicher's (31) definition, this CT could still be considered a short SSC. Moreover, bilateral 160% hurdle jumps used just 18% more CT than bilateral 100% hurdle jumps (177 milliseconds). However, in team sports such as soccer or field hockey, the maximal sprint velocity could be 25 $km \cdot h^{-1}$ (7 $m \cdot s^{-1}$) or more. At these velocities, CT could be 120–130 milliseconds according to Weyand et al. (34) in active subjects tested on a treadmill and 160 milliseconds in less-skilled sprinters running at 7 $m \cdot s^{-1}$ (23). It must be recognized that even bilateral 100% hurdle jumps may not perfectly replicate competition CT.

Moreover, running is performed alternating 1-leg ground contacts. Thus, alternating jumps with CT below 150 milliseconds should be included to optimize training programs. During unilateral hurdle jumps, CT was slightly >250 milliseconds in all hurdle heights. This CT is not considered a fast SSC (31). However, the CT is similar to that of Aura and Viitasalo (1) who tested unilateral hops over hurdles with CT of approximately 265 milliseconds. Because unilateral hurdle jump CT at 70–90% of the CMJ height exceeds many common sports actions such as sprinting, it is speculated that by decreasing the hurdle height to 50% or less of the CMJ height, it will allow the athletes to decrease the CT and to increase the RFD. Furthermore, the reaction force produced during unilateral hurdle jumps was not statistically different from CMJ. However, it must be remembered that these forces were generated on a single leg rather than on the 2 legs with the CMJ. Unilateral jumps with a hurdle height between 70 and 90% represent a high stress level for muscles, joints, and ligaments (6). Figure 2 is a typical reaction force trace illustrating that unilateral hurdle jumps at 90% of the CMJ can be performed without a double peak, thus exhibiting spring-like behavior (14). The appearance of a double peak would represent non–spring-like behavior (9,14,24) caused by a pausing between the end of the eccentric movement and the start of the concentric movement (28). However, this loss of mechanical energy or failure (elastic energy during the eccentric phase is not converted into kinetic energy) (8) did not occur with any of the bilateral or unilateral hurdle jumps in this study using trained athletes. Hence, if high reaction forces are sought with unilateral hurdle jumps, then 70–90% of the CMJ height could provide a high reaction force stress without compromising spring-like behavior of the musculotendinous unit. Other activities such as sprint bounding have also been recommended to increase maximal velocity (35). The training specificity and characteristics associated with varying heights and lengths of unilateral hopping, jumping, bounding, and other activities is an area for future research.

Some authors consider RFD as one of the best predictors of performance (38). The RFD is frequently used to represent human performance and is sometimes used as a synonym with explosive strength, impulse, and power (11,20). Bilateral 100% hurdle jumps resulted in the highest RFD value (40,981 $N \cdot s^{-1}$) and were ninefold greater than CMJs. Because the Pearson correlation coefficients between bilateral 100% hurdle jumps and CMJ were very low ($r = -0.21$), an athlete who can perform a high CMJ height may not necessarily perform fast continuous jumps over hurdles. As discussed previously, the bilateral jumps were more similar to many explosive sport measures than CMJ.

Bilateral hurdles jumps using 100–140% of the CMJ height provide a training-specific plyometric drill as the CT, reaction forces and RFD are similar to the reported performance characteristics of many explosive sport actions. Although the use of CMJs for training and testing is widespread, the characteristics of the CMJ do not adequately mimic most explosive sport actions. Unilateral hurdle jumps using 70–90% of the maximum CMJ height had slower CT and lower reaction forces as compared to typical match competition requirements reported in the literature.

Practical Applications

Coaches and athletes should reconsider the importance of the CMJ as a testing and training exercise. Because the performance characteristics of the CMJ do not reflect most explosive sport actions, it does not adhere to the concept of training specificity. However, the CMJ can be used to help determine appropriate jump heights for activities such as bilateral hurdle jumps, which more closely resemble the performance characteristics of explosive sport actions. Coaches and athletes should include within their plyometric training program, bilateral hurdle jumps using 100–140% of the maximum CMJ height. If the bilateral hurdle height is calculated as a percentage of body height, maximal performance represents 25.8 ± 2.42% of body height. To ensure training specificity with alternating limb activities such as running and sprinting, unilateral hurdle jumps should be incorporated as well. However, the heights used in this study (70–90% of CMJ height) suggest that lower hurdle heights should be used to achieve comparable CT times as with common explosive sport actions.

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