0195-9131/87/1904-0332$02.00/0
MEDICINE AND SCIENCE IN SPORTS AND EXERCISE

Vol. 19, No. 4
Printed in U.S.A.

# Drop jumping. I. The influence of jumping technique on the biomechanics of jumping

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ABSTRACT

BOBBERT, M. F., P. A. HUIJING, and G. J. VAN INGEN SCHENAU. Drop jumping. I. The influence of jumping technique on the biomechanics of jumping. *Med. Sci. Sports Exerc.*, Vol. 19, No. 4, pp. 332–338, 1987. In the literature, drop jumping is advocated as an effective exercise for athletes who prepare themselves for explosive activities. When executing drop jumps, different jumping techniques can be used. In this study, the influence of jumping technique on the biomechanics of jumping is investigated. Ten subjects executed drop jumps from a height of 20 cm and counter-movement jumps. For the execution of the drop jumps, two different techniques were adopted. The first technique, referred to as bounce drop jump, required the subjects to reverse the downward velocity into an upward one as soon as possible after landing. The second technique, referred to as counter-movement drop jump, required them to do this more gradually by making a larger downward movement. During jumping, the subjects were filmed, ground reaction forces were registered, and electromyograms were recorded.

The results of a biomechanical analysis show that moments and power output about knee and ankle joints reach larger values during the drop jumps than during counter-movement jumps. The largest values were attained during bounce drop jumps. Based on this finding, it was hypothesized that bounce drop jump is better suited than counter-movement drop jump for athletes who seek to improve the mechanical output of knee extensors and plantar flexors. Researchers are, therefore, advised to control jumping technique when investigating training effects of executing drop jumps.

DROP JUMPING, TECHNIQUE, BIOMECHANICS, ELECTROMYOGRAPHY, MECHANICAL OUTPUT

Athletes preparing for explosive activities such as sprinting and jumping are recommended to include plyometric drills in their training programs (15, 27–29, 37). During a plyometric drill, also known as stretch-shortening cycle drill (32), a movement to an intended direction is achieved by starting it with a movement to the opposite direction. One of the most popular plyometric drills is drop jumping. Executing a drop jump, also called depth jump (37), involves jumping down from a height and, upon landing, performing a maximal jump (26). Athletes participating in training programs in which drop jumps were included have been reported to increase their vertical jumping achievement (2, 7, 14, 29, 32, 35, 36). It is usually assumed implicitly that the improvement in vertical jumping achievement is the result of an improvement in mechanical output of muscles. This latter improvement is supposed to be triggered by an over-load of the muscles during the execution of the drop jumps (27–29, 37).

Results of investigations into forces and power output during jumping have shown that these variables may reach larger values during the execution of drop jumps than during the performance of counter-movement jumps (CMJs) (jumps starting from ground level) (4, 5, 36). The results also indicate, however, that the magnitude of the enhancement of forces and power output depends upon jumping technique (4, 5, 36). Thus, jumping technique might be a major factor influencing the effectiveness of executing drop jumps as training mode. Unfortunately, many researchers pay no attention to this factor when describing their training programs (e.g., 2, 14).

The influence of technique on the effectiveness of executing drop jumps as training mode needs to be determined in long-term training studies. For those who design such studies, results of a systematic investigation into the influence of jumping technique on biomechanical variables may prove to be relevant. In the present study, kinematic, kinetic, and electromyographic data recorded during the execution of drop jumps are compared with those recorded during the performance of CMJs. Two different techniques for executing the drop jumps were utilized. The first technique required the subjects to reverse the downward velocity into an upward one as soon as possible after landing. The second technique required them to do this more gradually by making a larger downward movement upon landing, comparable to the one made during CMJs. Drop jumps executed according to these two techniques will be referred to as bounce drop jump (BDJ) and counter-movement drop jump (CDJ), respectively.

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Submitted for publication January, 1986.
Accepted for publication March, 1987.

## MATERIALS AND METHODS

**Subjects and experimental protocol.** Ten trained male volleyball players (age = 23 ± 4 yr, height = 1.95 ± 0.06 m, and body mass = 84.8 ± 9.5 kg) participated in this study. Informed consent was obtained from the subjects in accordance with the policy statement of the American College of Sports Medicine. The execution of CMJ, CDJ, and BDJ (Fig. 1) was demonstrated by the experimenter. In pilot work, it had been found that after this demonstration and after two or three practice jumps of a particular type, the subjects were able to perform jumps of that type consistently (i.e., the kinematics and kinetics of the jumps remained nearly identical). Therefore, after following their usual warm-up routine, the subjects executed from each type three practice jumps. Subsequently, they performed from each type another two jumps. During these latter jumps, ground reaction forces, cinematographic data, and electromyograms (EMGs) were recorded. The order in which CMJ, CDJ, and BDJ were executed was random. In CDJ and BDJ, dropping height was 20 cm. The subjects were instructed to keep their hands on their hips and to jump as high as they could.

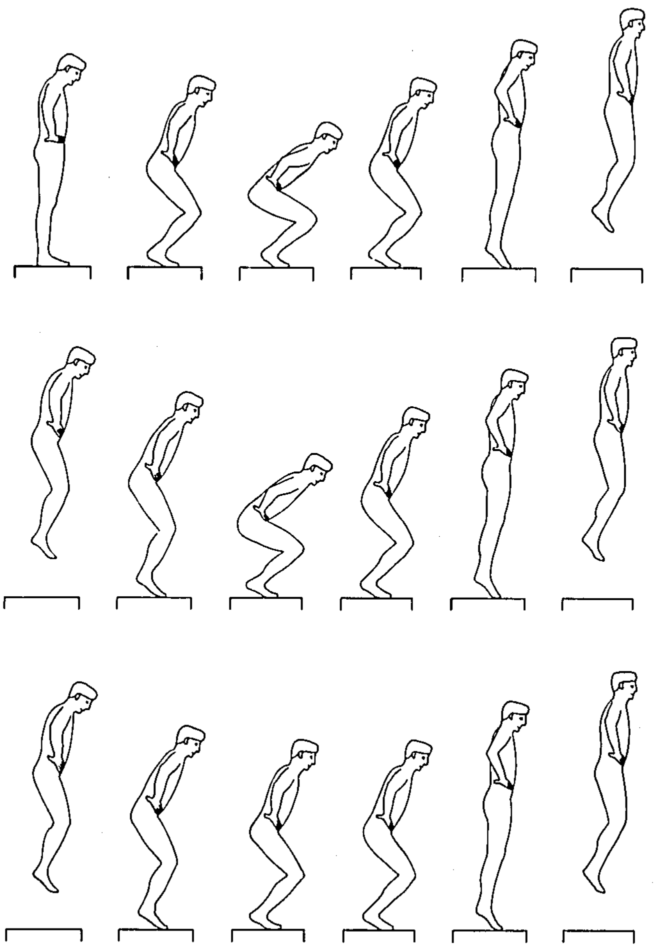

Figure 1—Jumping techniques. This figure illustrates how CMJs, BDJs, and CDJs were executed in this study. In CMJs (*top*), the subject starts from upright standing on the force platform, makes a downward movement, and consecutively begins to push-off. In CDJs (*middle*), the subject also jumps down from a height of 20 cm, but this time reverses the downward movement more gradually into an upward one by making a larger downward movement upon landing. In BDJs *(bottom)*, the subject jumps down from a height of 20 cm and reverses the downward velocity as soon as possible after landing on the force platform into an upward one.

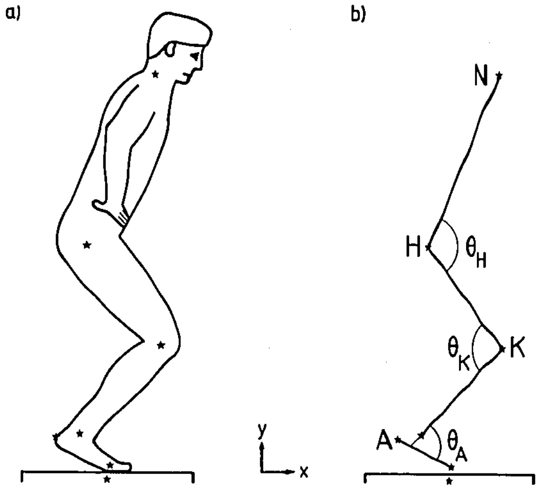

Figure 2—(a) Positions of landmarks applied to the skin of the subject and to the force platform. (b) Definition of angles in joints. N, H, K, and A indicate neck, hip, knee, and ankle, respectively. $\theta_H$, $\theta_K$, and $\theta_A$ indicate angles in hip, knee, and ankle joints, respectively.

**Kinematics and kinetics.** As illustrated in Fig. 2a, landmarks were placed on the lateral aspect of neck (at the height of C5), greater trochanter, knee joint (on the lateral collateral ligament at the height of the joint cleft), lateral malleolus (0.5 cm anterior to the tip), heel, and fifth metatarsophalangeal joint. The landmarks defined the positions of upper body (head, arms, and trunk being taken together), upper legs, lower legs, and feet. During jumping, the subjects were filmed with a 16 mm high speed motion picture camera (Teledyne type DBM 55, Teledyne Camera Systems, Arcadia, CA) operating at a nominal frame rate of 100 Hz. The optical axis of the camera was perpendicular to the plane of motion. Simultaneously, vertical and fore-aft components of the ground reaction force, as well as the center of pressure under the foot, were recorded by means of a force platform (Kistler type 9281B, Kistler Instrument Corp, Amherst, NY) and sampled (500 Hz). For each cine frame, the positions of landmarks relative to the position of a landmark on the force platform were determined with the aid of a motion analyzer (Supergrid digitizer model SPG-1212-RP, Summagraphics Corp., Fairfield, CT). After smoothing of the position signals (Butterworth fourth-order zero lag filter with a cut-off frequency of 16 Hz), joint angles (Fig. 2b) were calculated. Consecutively, the co-ordinates were properly scaled. The absolute co-ordinates were combined with data from Clauser et al. (13) to obtain positions of mass centers of body segments, as well as the position of the mass center of the whole body. Linear and angular velocities and accelerations were calculated by numerical differentiation.

After synchronization of film and force platform data, a link segment model (21) was used to obtain instantaneous net moments about hip, knee, and ankle joints. Moments with a hip extending, knee extending, or plantar flexing influence were defined positive. Net power output about joints was obtained by multiplication of net moments and angular velocities.

**Electromyography.** Pairs of surface electrodes (Beckman Instruments, Inc., Fullerton, CA; lead-off area of 0.5 $cm^2$ and center to center electrode distance = 3 cm) were applied to one leg after standard skin preparation techniques (1). They were placed in longitudinal direction on the skin covering m. rectus femoris, m. vastus medialis, m. gastrocnemius (medial head), and m. soleus. The positioning of the electrodes is described by Gregoire et al. (23). The electrical signals were amplified (Disa type 15 C 01, Disa Elektronik AIS, DK-2740, Skovlunde, Denmark) and coupled via a high-pass filter (cut-off frequency of 5 Hz) to a full-wave rectifier. The output of this rectifier was low-pass filtered (slope 6 dB/octave, cut-off frequency of 7.2 Hz) and sampled simultaneously with the vertical component of the ground reaction force (300 Hz). For each muscle, the resulting values of EMG levels were expressed in terms of percent of the maximum value attained during CMJ. Pilot work has shown this method of processing EMG signals to yield time histories of EMG levels that are reproducible and can be compared among different subjects.

**Treatment of data.** The push-off phase was defined as the phase between the instant that the mass center of the body passed its lowest position and the instant that the toes lost contact with the force platform (henceforth referred to as instant of toe-off). Height jumped was defined as the difference between the highest position reached by the body's mass center and the position of this mass center in upright standing. From each subject, the highest jump of each type was selected for analysis. The selection of results to be presented was fixed upon those curves and variables that characterized the kinematics and kinetics of the different jumps. For illustration of the electromyographic results, mean curves of time histories of EMG levels were calculated for the whole group of subjects after synchronization of the individual curves on the instant of toe-off.

Hypotheses concerning differences between experimental conditions were tested using a Student's *t* test for paired comparisons (17). Testing was done two-tailed with a 5% level of confidence. When presenting and discussing results, the text will confine itself to the results of the comparison of BDJ with CMJ. The results of the other comparisons are given in parentheses. If the value of a particular variable is significantly larger or smaller during one condition than during another condition, this will be indicated with ">" or "<," respectively. If no significant difference is found between conditions, the sign "=" will be used.

## RESULTS

Figure 3 shows for one subject time histories of the vertical component of the ground reaction force ($F_y$) found in the three experimental conditions. The curves are typical of those of the other subjects. At the start of CMJ, the subject is standing still on the force platform, and consequently $F_y$ is equal to body weight (BW). In the beginning of the downward movement, the mass center of the body is accelerated in a downward direction, which is reflected by a decrease of $F_y$ to values below BW. The direction of the acceleration reverses from downward to upward when $F_y$ equals BW. At the start of BDJ and CDJ, the subject is standing on the raised platform, and consequently the force platform records no force. $F_y$ does not deflect from zero until the toes of the subject come down on the platform.

Table 1 presents for the group of subjects values of general variables concerning jumping performance. The subjects lowered the mass center of their body 12 cm less during BDJ than during CDJ, while they lowered it another 12 cm less during CDJ than during CMJ. At toe-off, the height of the body's mass center ($y_{MCB}$) was slightly smaller (less than 1 cm) during the drop jumps than during CMJ (BDJ = CDJ < CMJ). The differences in the distance over which the mass center of the body was moved in downward and upward directions were accompanied with differences in the duration of the movements (BDJ < CDJ < CMJ).

In spite of the large differences in the time during

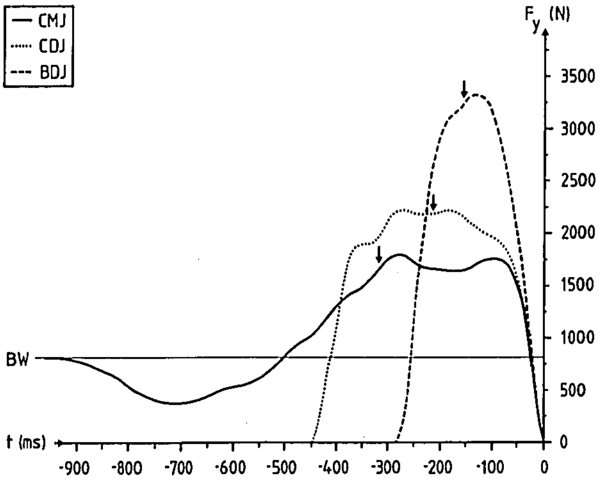

**Figure 3—Vertical component of ground reaction force. This figure shows for one subject time histories of the vertical component of the ground reaction force ($F_y$), which were found during a CMJ, during a CDJ and during a BDJ. Time is expressed relative to the instant of toe-off (t = 0). *Arrows* indicate the start of the push-off phase; BW indicates body weight.**

which the mass center of the body was accelerated upwards in the push-off phase, only slight differences were found in the vertical velocity of this mass center on the instant of toe-off and in height jumped (BDJ < CDJ = CMJ). During the push-off phase, $F_y$ reached greater values during the performance of drop jumps than during the execution of CMJ (BDJ > CDJ > CMJ).

TABLE 1. General variables.

| | CMJ | CDJ | BDJ |
|---|---|---|---|
| $y_{MCB,spo}$ (m) | −0.37 ± 0.07 | −0.25 ± 0.06* | −0.13 ± 0.04*† |
| $y_{MCB,to}$ (m) | 0.15 ± 0.01 | 0.14 ± 0.01* | 0.14 ± 0.01* |
| $y_{MCB,max}$ (m) | 0.54 ± 0.06 | 0.52 ± 0.06 | 0.48 ± 0.08*† |
| $t_{downward}$ (s) | 0.55 ± 0.06 | 0.19 ± 0.04* | 0.13 ± 0.02*† |
| $t_{push\text{-}off}$ (s) | 0.29 ± 0.04 | 0.21 ± 0.03* | 0.13 ± 0.02*† |
| $\dot{y}_{MCB,to}$ (m·s$^{-1}$) | 2.78 ± 0.21 | 2.75 ± 0.29 | 2.52 ± 0.26*† |
| $F_{y,spo}$ (N) | 2,012 ± 207 | 2,612 ± 464* | 4,015 ± 873*† |
| $F_{y,max}$ (N) | 2,094 ± 218 | 2,649 ± 499* | 4,099 ± 815*† |
| $F_{y,mean}$ (N) | 1,715 ± 191 | 1,918 ± 262* | 2,561 ± 377*† |

This table shows mean values (±SD) of a number of general variables concerning the performance of CMJs, CDJs, and BDJs. $N = 10$.

$y_{MCB,spo}$, $y_{MCB,to}$, and $y_{MCB,max}$ are the heights of the body's mass center at the start of the push-off phase, at toe-off, and at the apex of the jump, respectively. The values are expressed relative to the height of the body's mass center in upright standing.

$t_{downward}$ and $t_{push\text{-}off}$ are the duration of the phase of downward movement and the duration of the push-off phase, respectively.

$\dot{y}_{MCB,to}$ is the vertical velocity of the body's mass center on the instant of toe-off.

$F_{y,spo}$, $F_{y,max}$, and $F_{y,mean}$ are for the vertical component of the ground reaction force ($F_y$) the value at the start of the push-off phase, the maximum value, and the mean value during the push-off phase, respectively.

* The value during CDJ or BDJ differs from the value during CMJ ($P < 0.05$).

† The value during BDJ differs from the value during CDJ ($P < 0.05$).

Figure 4, a and b, depicts for one subject (same as in Fig. 3) time histories of angles, angular velocities, net moment, and net power output at hip, knee, and ankle joints. Note that in BDJ and CDJ, net joint moments reached their maximum somewhere about the instant that the push-off started. This was found in all subjects. Differences in angles and angular velocities decrease rapidly in the course of the push-off phase, whereas differences in net moments and power output about knees and ankles remain relatively large until shortly before toe-off. For instance, at 75 ms before toe-off, the differences between BDJ and CMJ in angle and angular velocity in the ankle are negligible, whereas moment and power output about the ankle are almost twice as large in BDJ as in CMJ.

Table 2 shows for the group of subjects values for joint variables. Differences between conditions in $y_{MCB}$ at the start of the push-off phase (Table 1) appear to be due to larger hip and knee angles (BDJ > CDJ > CMJ). Moments about the knee and ankle joints are larger during BDJ than during CMJ (BDJ > CDJ > CMJ). Moments about the hip joints, on the other hand, reach

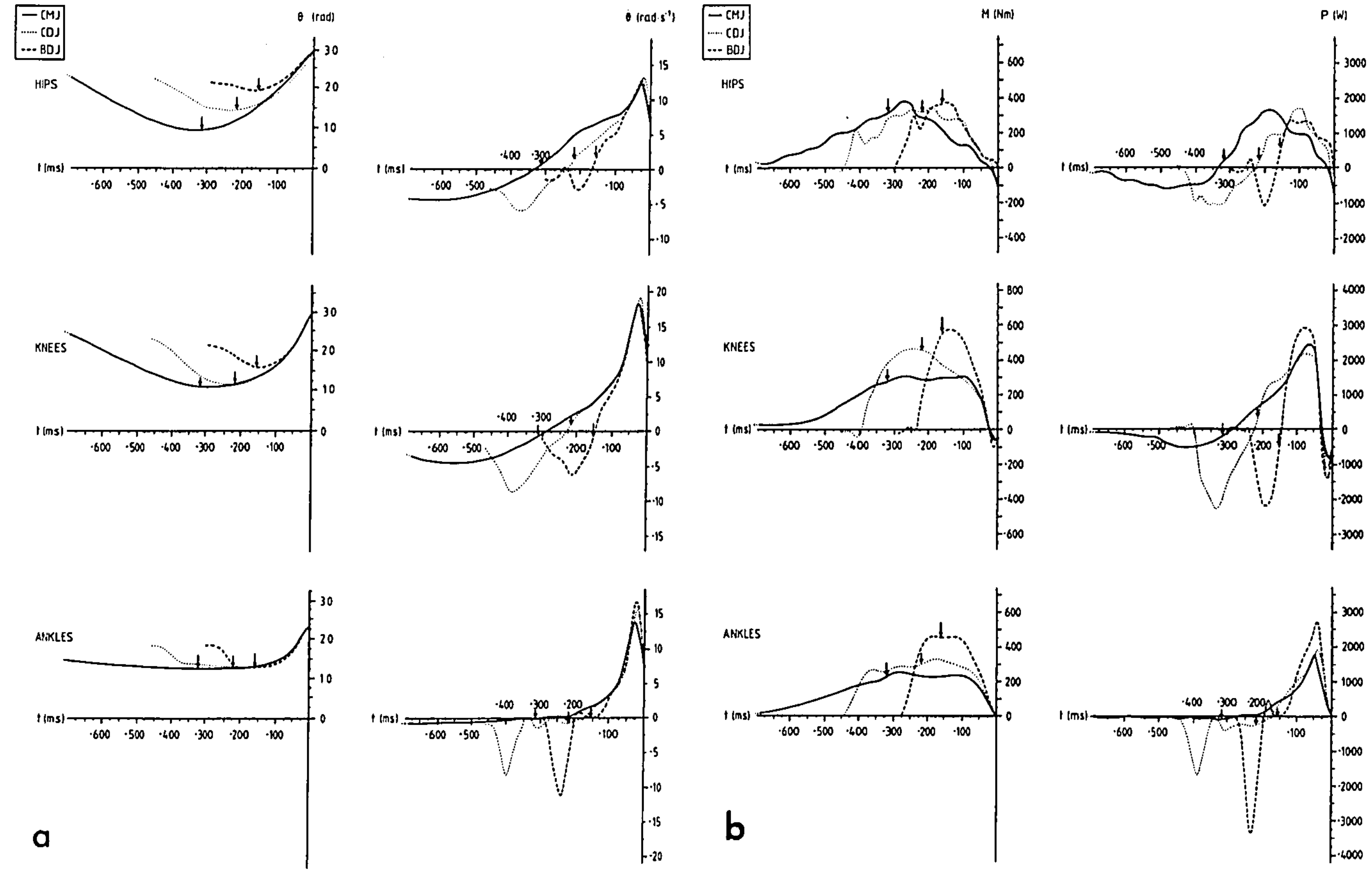

Figure 4—(a) Angles and angular velocities. This figure shows for one subject (same as in Fig. 3) time histories of angles (θ) and angular velocities (θ̇) at joints, which were found during a CMJ, during a CDJ, and during a BDJ. Time is expressed relative to the instant of toe-off (t = 0). *Arrows* indicate the start of the push-off phase. (b) Joint moments and power output. Same as (a), but this time for net moments (M) and net power output (P) about joints.

TABLE 2. Joint variables.

| | Joints | CMJ | CDJ | BDJ |
|---|---|---|---|---|
| $\dot{\theta}_{min}$ (rad · s$^{-1}$) | Hips | −5.6 ± 0.5 | −5.2 ± 1.6 | −3.2 ± 1.2*† |
| | Knees | −4.9 ± 0.5 | −7.2 ± 1.2* | −6.8 ± 1.4* |
| | Ankles | −1.9 ± 0.3 | −9.5 ± 1.4* | −11.4 ± 1.0*† |
| $\dot{\theta}_{max}$ (rad · s$^{-1}$) | Hips | 11.1 ± 1.2 | 10.7 ± 1.4 | 9.1 ± 2.1*† |
| | Knees | 16.7 ± 1.1 | 16.6 ± 1.6 | 14.5 ± 2.6*† |
| | Ankles | 16.1 ± 2.7 | 17.5 ± 2.7* | 18.7 ± 2.9*† |
| $\theta_{spo}$ (rad) | Hips | 1.23 ± 0.19 | 1.74 ± 0.25* | 2.29 ± 0.22*† |
| | Knees | 1.40 ± 0.26 | 1.51 ± 0.17* | 1.93 ± 0.20*† |
| | Ankles | 1.23 ± 0.12 | 1.25 ± 0.15 | 1.26 ± 0.12 |
| $M_{spo}$ (Nm) | Hips | 403 ± 63 | 326 ± 109 | 287 ± 109* |
| | Knees | 314 ± 92 | 473 ± 160* | 546 ± 140*† |
| | Ankles | 263 ± 67 | 349 ± 84* | 586 ± 168*† |
| $M_{max}$ (Nm) | Hips | 422 ± 56 | 367 ± 78* | 310 ± 108*† |
| | Knees | 366 ± 64 | 488 ± 151* | 558 ± 146*† |
| | Ankles | 310 ± 50 | 361 ± 81* | 602 ± 165*† |
| $P_{max}$ (W) | Hips | 1,524 ± 345 | 1,255 ± 401 | 1,165 ± 418 |
| | Knees | 2,549 ± 437 | 2,796 ± 622 | 3,004 ± 759*† |
| | Ankles | 2,449 ± 672 | 2,482 ± 945 | 4,529 ± 1,917*† |

This table shows mean values (±SD) of a number of joint variables for the performance of CMJs, CDJs, and BDJs. $N = 10$.

$\dot{\theta}_{min}$ and $\dot{\theta}_{max}$ are the minimum and maximum values of angular velocities in joints, respectively.

$\theta_{spo}$ is the joint angle at the start of the push-off phase.

$M_{spo}$ is the net moment about the joints at the start of the push-off phase.

$M_{max}$ is the maximum value of the net moment about the joints.

$P_{max}$ is the maximum value of the net power output about the joints.

* The value during CDJ or BDJ differs from the value during CMJ ($P < 0.05$).

† The value during BDJ differs from the value during CDJ ($P < 0.05$).

the largest values during CMJ (BDJ < CDJ = CMJ). (It should be borne in mind, however, that the values refer to net moments; a smaller net moment about the hip joints does not necessarily mean that the moment exerted by hip extensors is smaller.)

Figure 5 shows for the push-off phase mean curves of EMG levels of m. rectus femoris, m. vastus medialis, m. gastrocnemius (caput mediale), and m. soleus. Maximum values in EMG levels were reached at slightly different times in different subjects. This explains why the mean curves for EMG levels during CMJ do not attain 100%. When comparing time histories of EMG levels with time histories of other variables, the reader should keep in mind that there is a delay time between EMG and mechanical output (25). From individual values for EMG levels, the peak values were selected. These peak values were averaged for the group of subjects. The results are presented in Table 3. Differences between average peak values shown in Table 3 and peak values read off from Figure 5 may occur. This is also caused by the fact that the peak values are reached at slightly different times in different subjects.

## DISCUSSION

**Comparison of results among jumps.** A comparison of the kinematics among the jumps shows that the height of the body's mass center at the start of the push-off phase was 12 cm greater in BDJ than in CDJ, and 12 cm greater in CDJ than in CMJ (Table 1). This was due to greater angles in hip and knee joints at the start of the push-off phase (Table 2: BDJ > CDJ > CMJ). If the mass center of the body is located higher at the start of the push-off phase, it is displaced over a shorter distance during the push-off phase. Therefore, it is not surprising that the push-off takes less time in BDJ than in CMJ (Table 1: BDJ < CDJ < CMJ). In spite of considerable differences in duration of the push-off phase, only slight differences were found in vertical velocity of the mass center of the body on the instant of toe-off and in height jumped (Table 1: BDJ < CDJ = CMJ). From the above, it can be derived that the average vertical acceleration ($\ddot{y}_{MCB}$) during the push-off phase is higher in BDJ than in CMJ. Note that this also follows from the larger average $F_y$ during the push-off phase (BDJ > CDJ > CMJ) because $\ddot{y}_{MCB} = F_y/m - g$ (m indicates body mass and g indicates acceleration due to gravity).

Acceleration of the mass center of the body is the result of rotations in joints caused by moments about joints. From results presented in Figure 4b and Table 2, it can be derived that the higher $\ddot{y}_{MCB}$ during the push-off phase is due to larger moments about knee

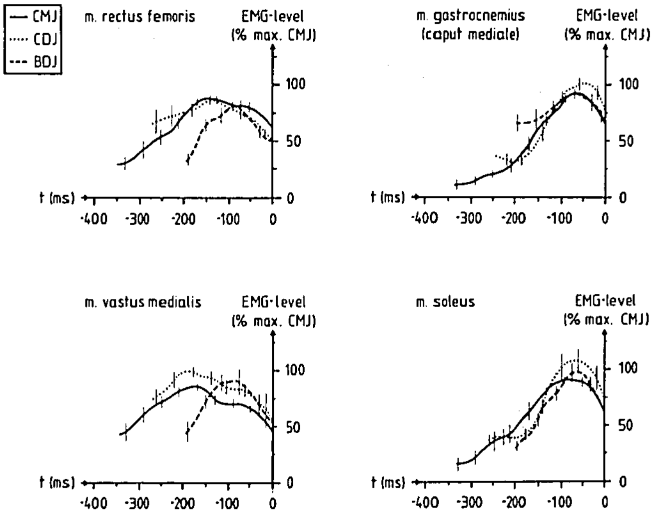

**Figure 5—EMG levels. This figure shows mean curves of the group of subjects ($n$ = 10) for time histories of EMG levels, which were found during CMJs, CDJs, and BDJs. Time is expressed relative to the instant of toe-off (t = 0). EMG levels are expressed in terms of percent of the maximum level attained during CMJ. *Curves* have been plotted beginning at 50 ms before the average start of the push-off phase. *Vertical bars* indicate SE of the mean.**

TABLE 3. Peak values of EMG levels.

| | CMJ | CDJ | BDJ |
|---|---|---|---|
| m. rectus femoris | 100 ± 0 | 102 ± 21 | 92 ± 35 |
| m. vastus medialis | 100 ± 0 | 121 ± 25* | 102 ± 36† |
| m. gastrocnemius | 100 ± 0 | 114 ± 15* | 114 ± 20* |
| m. soleus | 100 ± 0 | 114 ± 34 | 108 ± 30 |

This table shows mean values (±SD) of EMG levels of m. rectus femoris, m. vastus medialis, m. gastrocnemius (medial head), and m. soleus for CMJs, CDJs, and BDJs. The values are expressed in terms of percent of the maximum level attained during the push-off phase in CMJ. $N = 10$.

* The value during CDJ or BDJ differs from the value during CMJ ($P < 0.05$).

† The value during BDJ differs from the value during CDJ ($P < 0.05$).

and ankle joints (BDJ > CDJ > CMJ). In BDJ, the muscles are able to cause not only larger moments but also a larger power output about these joints than in CMJ (Table 2: BDJ > CDJ = CMJ).

**Possible explanations of differences in mechanical output among jumps.** The moment exerted by a muscle about a joint is the product of the force exerted by the muscle and its moment arm. Among the factors influencing the exerted force are length and contraction velocity of contractile parts, as well as level of muscle excitation. Moment arm, distance between origin and insertion, and rate of change of this distance ($V_{OI}$), all depend upon joint angles and/or angular velocities. In these latter variables, only slight differences were found between conditions during a major part of the push-off phase. For example, in the subject whose results are presented in Figure 4, differences in joint angles and angular velocities are negligible during the last 75 ms of the push-off phase. This does not mean, however, that length and shortening velocity of the contractile parts of muscles were equal in the three jumping conditions. The reason is that differences in length and shortening velocity of series elastic elements may occur. For example, during the last 75 ms of the push-off phase, the plantar-flexing moment declines more rapidly in BDJ than in CMJ (Fig. 4b). As a result, series elastic elements may shorten faster in BDJ than in CMJ. Thus, contractile elements may shorten less rapidly in BDJ than in CMJ in spite of equal $V_{OI}$. According to the force-velocity relationship, a larger force can be exerted at this lower shortening velocity, and this yields a higher power output (force multiplied by $V_{OI}$). A quantitative analysis of the influence of the behavior of series elastic components, as described elsewhere (3), is beyond the scope of this study.

The results of the EMG analyses make it likely that some differences in excitation level did occur between experimental conditions. For example, the EMG level of the medial head of m. gastrocnemius reached higher values during BDJ than during CMJ (Table 3). However, EMG levels were not found to be higher during BDJ than during CDJ (Table 3), in spite of considerably larger moments about knee and ankle joints in BDJ (Table 2). Thus, the EMG results do not seem to be very helpful in explaining the differences in moments.

A final factor to be considered is the influence of a preceding eccentric action on the contractile properties of muscles. Literature supplies evidence that, under the influence of such an eccentric action, also known as pre-stretch, a change takes place in the contractile properties of supra-maximally stimulated skeletal muscles (10–12, 22) and isolated muscle fibers (18, 20). This change is called potentiation (9). Its magnitude increases with the speed of the eccentric action (18) and decreases with the amount of time elapsed after this action (12, 18, 20). Both variables are likely to differ among the jumping conditions investigated in this study. From the angular velocities of knee flexion and dorsiflexion (Table 2), it can be derived qualitatively that the highest velocity of eccentric action (at least of the mono-articular knee extensors and plantar flexors) was reached during BDJ, and that the lowest velocity occurred during CMJ. Moreover, the time interval between the peak velocity of eccentric action and the start of concentric contraction attains the smallest value in BDJ and the largest value in CMJ (Fig. 4a).

The above makes it plausible that differences in the amount of potentiation are responsible for the differences in mechanical output between jumps, with the greatest potentiation occurring in BDJ and the smallest occurring in CMJ. Several mechanisms have been proposed to explain this phenomenon. One of them states that during pre-stretch, the heads of cross-bridges are rotated backward to a position in which they are able to exert more force (6, 8). It should be realized, however, that this favorable position is lost as soon as the cross-bridges detach. And even at 0°C, the average attachment time of cross-bridges is less than 30 ms (16, 33), whereas the influence of pre-stretch lasts much longer (12, 18–20). Thus, if changes in configuration of cross-bridge heads occur, it is very unlikely that they explain potentiation completely. For a discussion of other possible mechanisms, the reader is referred to Edman et al. (18) and van Ingen Schenau (34).

**Executing drop jumps as training mode.** The results of the biomechanical analysis demonstrate that, during the execution of drop jumps, the mechanical output about knee and ankle joints is enhanced over and above the mechanical output during the performance of CMJ. The magnitude of the enhancement was found to depend, however, on drop jumping technique. Moments and power output about knee and ankle joints reached larger values during BDJ than during CDJ. Based on this finding, it may be hypothesized that BDJ is better suited than CDJ to provide the training stimulus, which is required for a long-term improvement in the capacity of knee extensors and plantar flexors to deliver force and power. This hypothesis has to be tested in long-term training studies in which drop jumping technique is controlled.

In the context of the above, it should be pointed out that the mechanical output of individual muscle groups is not the only quality that determines achievement in a motor task. Another important quality is co-ordination, which is assumed to be task-specific (30, 31). The key to developing this quality is supposed to be executing the motor task repeatedly in the correct way (24). Thus, if the end goal of a training program is, for instance, an increase in height jumped during a CMJ, executing drop jumps should be viewed as merely an exercise to be integrated into the training whole. Another ingredient of the training should then be repeatedly executing CMJs. Otherwise, the athletes risk to unlearn the proper coordination.

From the results, it is derived that during the execution of drop jumps from a height of 20 cm as described in this study, the mechanical output of knee extensors and plantar flexors is larger than during the execution of CMJs. However, the differences between jumps in output of knee extensors seem to be relatively small when compared with the differences in output of plantar flexors (Fig. 4, Table 2). Moreover, the output of the hip extensors seems to be smaller during BDJ and CDJ than during CMJ (Fig. 4, Table 2), and height jumped was less during BDJ than during CMJ (Table 1). In subsequent studies, it should be investigated if the performance of hip extensors and knee extensors can be enhanced by jumping down from greater heights or by using other jumping techniques. A drop jumping technique that seems well-suited for this purpose is the technique described by Bosco and Pittera (7), which requires the athletes to land with considerably flexed hip and knee joints.

The authors gratefully acknowledge the technical assistance of M. E. Roebroeck and A. J. van Soest.

A portion of this study was supported by The Netherlands Organization for the Advancement of Pure Research (Z. W. O.).

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