A Comparison of the Kinetic and Kinematic Characteristics of Plyometric Drop-Jump and Pendulum Exercises

Neil E. Fowler and Adrian Lees

The aim of this study was to compare the kinetic and kinematic characteristics of plyometric drop-jump and pendulum exercises. Exercises were filmed (100 Hz) from the sagittal view and manually digitized; the data were smoothed and differentiated using cross-validated quintic splines. Ground reaction force data were sampled using a Kistler force platform sampling at 500 Hz. Differences between movement amplitudes and coordination strategies were assessed using t tests and conjugate cross-correlations. Pendulum exercises involved a greater range of motion at the ankle and knee but less motion at the hip joint than drop-jumps. Although different in absolute terms, the exercises used a similar coordination strategy. Drop-jumps resulted in greater peak vertical ground reaction forces than the pendulum exercises although the latter involved a greater net impulse. The similarity between the movement patterns for the two modes of exercise led to the conclusion that pendulum exercises offer a training stimulus similar to that of drop-jumps.

Key Words: stretch–shorten cycle, strength, jumping

Plyometric or stretch–shorten cycle exercises have been popular in sports training for many years. One of the most commonly reported methods of plyometric training is the drop-jump, in which a subject drops from a raised platform and immediately upon landing initiates a rebound vertical jump. Plyometric exercises are effective for improving strength and vertical jump performance (Bobbert, 1990). However, they also carry a high risk of injury due to the large ground reaction forces (Bosco & Komi, 1979).

In response to the perceived risk of performing drop-jumps, alternative exercise modalities have been developed that attempt to mimic the positive effects of drop-jumps while reducing the negative effects (Dvir, 1985; Tenisci, 1980). One training device that has been widely used in Eastern Europe as an alternative to the drop-jump is the pendulum swing (Trzaskoma, Wit, Iskra, & Karpilowski, 1989). The athlete is seated in a swing positioned directly in front of a vertical rebound surface (Figure 1). The athlete swings backward and forward in the swing, rebounding against this vertical surface. The eccentric stretch of the muscle occurs during the impact phase of the action as the athlete stops the forward motion of the swing. The concentric shortening of the muscle occurs during
the drive-off phase, as the athlete propels the pendulum swing backward into its next oscillation.

If the pendulum exercises are to offer the performer a training stimulus similar to that offered by drop-jumps, then the two exercises must have similar kinematic characteristics, in line with the theory of training specificity (Sale & MacDougall, 1981). Increases in muscle strength are related to a number of kinematic factors that are important to the movement specificity. These include the type of muscular contraction used (Dons, Bollerup, Bonde-Petersen, & Hancke, 1979), the range of joint angles through which exercises are performed (Kanehisa & Miyashita, 1983a; Lindh, 1979), and the velocity of muscular contraction, normally measured by the velocity of joint movement (Kanehisa & Miyashita, 1983b). In addition, the physiological effort must be similar across the two exercises (Dons et al., 1979).

It has been argued that much of the benefit of plyometric exercise is related to neuromuscular coordination, and therefore coordination of the joint and muscle movements is important (Sale, 1986). Researchers investigating coordination in vertical jumps have examined the timing of key moments (Bobbert & Van Ingen Schenau, 1988; Hudson, 1986). Such a method, while informative, does not allow the relationships among variables to be quantified. Similar timing of key moments in the action does not necessarily indicate a similarity in the movement strategies, since the nature of the movement between these key moments may differ. In addition, it is often difficult to determine the degree of similarity in the relative sequencing of movements on the basis of purely descriptive methods. Amblard, Assaiante, Lekhel, and Marchand (1994) proposed the use of

Figure 1 — The pendulum swing, showing a subject rebounding from the vertically mounted Kistler force platform.
conjugate cross-correlations to assess movement strategies. This method can be used to assess any kinematic variables and yields the relative direction and latency of coordinated movement. From this it is possible to identify discrete movement strategies for both individuals and groups. The correlation coefficients produced can be transformed (Z transformation) and employed to compare the strategies used to perform different movements.

The aim of this study was to compare the kinetic and kinematic characteristics of the drop-jump with exercises performed using a pendulum swing.

**Methods**

Eight male subjects gave their written informed consent to participate in the study. Mean ± SD age of the subjects was 23.2 ± 3.2 years, body mass was 81.6 ± 9.9 kg, and height was 1.75 ± 0.2 m. All subjects had previous experience with drop-jumps and were given instruction and three familiarization sessions using the pendulum swing (Figure 1).

Following the familiarization sessions, 10 maximal effort repetitions for drop-jumps from a height of 0.28 m were performed. Subjects were allowed to rest between trials to ensure that there was no effect of fatigue on performance. Similarly, 10 consecutive pendulum swings were performed. The amplitude of each pendulum oscillation was determined by the effort in a preceding preparatory swing. Since the pendulum contained no priming device for presetting the amplitude of the swing, the maximal effort repetitions were used to regulate swing amplitude. The velocity of the pendulum at impact was recorded for comparison with the vertical velocity of the body at impact during drop jumps. For both exercises, a “bounce” style of rebound was requested (i.e., an immediate rebound).

Filming was performed at 100 Hz using a Locam high-speed cine camera, positioned approximately 5 m from the subject and perpendicular to the plane of motion. Vertical and horizontal scales were recorded in the plane of the movement to allow reconstruction of real-world distances from the film-image coordinates. The largely two-dimensional nature of both the drop-jump and pendulum exercises made them suitable for analysis from a sagittal view.

From each set of 10 repetitions, three trials that were considered to be of maximal effort on the basis of jump height or swing amplitude were analyzed for each subject using manual digitization on a TDS HR48 digitizing tablet. Subjects were dressed in shorts and a vest to facilitate location of joint centers. An 18-point, 14-segment model (Hanavan, 1964) of the human body was used for the analysis, with segmental mass and mass center locations calculated according to the cadaver data of Dempster (1955) and Clauser, McConville, and Young (1969), respectively. Raw coordinate data were smoothed and differentiated using cross-validated quintic splines.

The ground contact time was divided into three phases defined by four key moments:

- **Countermovement phase**: From first foot contact with the rebound surface (*impact*) to minimum vertical displacement of the mass center (*minimum*).
- **Coupling phase**: From the end of the countermovement phase to the first upward vertical displacement of the mass center (*initiation*).
- **Drive-off phase**: From the end of the coupling phase to the last contact with the rebound surface (*maximum*).

Ankle, knee, and hip joint angular displacement and velocity data were recorded at these key moments. Differences between drop-jump and pendulum exercises were assessed using t tests. A probability value of .05 was considered as significant. The Bonferroni
technique was used to reduce the chance of Type I errors occurring from the use of multiple difference tests.

Conjugate cross-correlations were performed to determine the relationship between ankle, knee, and hip angular displacement and velocity data. Correlation coefficients for each rebound were transformed to Z values for analysis (Amblard et al., 1994). The degree of similarity in the coordination strategies for the pendulum and drop-jump exercises was assessed by determining the boundaries of agreement between the two sets of Z-transformed coefficients (Bland & Altman, 1986).

Ground/wall reaction force data were recorded at 500 Hz using a Kistler force platform interfaced by a 12-bit analog-to-digital converter to an Archimedes 310 microcomputer. The force platform was mounted horizontally on the landing surface for the drop-jumps and vertically on the landing surface in front of the pendulum.

Results

Kinematic data, summarized in Table 1, show the pendulum exercise to involve a 14% ($p < .05$, effect size = 1.85) greater range of ankle dorsiflexion and a 21% ($p < .05$, effect size = 1.15) greater range of knee flexion during the countermovement phase, even though no differences were shown between pendulum and drop-jump exercises for touchdown angles. The range of hip motion during the countermovement phase was 43% less in the pendulum exercise ($p < .05$, effect size = 1.6) due to a more flexed hip position at touchdown ($p < .05$, effect size = 2.3). The combination of joint motions resulted in a similar mass center displacement during the countermovement phases for the drop-jumps (0.21 ± 0.03 m) and pendulum exercises (0.21 ± 0.05 m).

Joint angular velocities (Table 2) of the hip, knee, and ankle for the two exercises were of a similar magnitude during the countermovement phase. The only notable difference between exercises, during the drive-off phase, was a 35% greater peak knee angular velocity in the pendulum swing ($p < .05$, effect size = 2.16).

The temporal sequences (Figure 2) of the two exercises show similar relative lengths for the countermovement (drop-jump = 45 ± 9%; pendulum = 50 ± 9%) and drive-off

| Joint | Exercise mode | Angle (degrees) | | | |
|-------|---------------|-----------------|-----------------|-----------------|
|       |               | Impact          | Countermovement | Drive-off       |
|       |               | $M$  | $SD$ | $M$  | $SD$ | $M$  | $SD$ |
| Hip   | Pendulum      | 123* | 9    | 98   | 9    | 138* | 6    |
|       | Drop-jump     | 148  | 12   | 105  | 14   | 170  | 7    |
| Knee  | Pendulum      | 153  | 12   | 88*  | 17   | 178  | 2    |
|       | Drop-jump     | 154  | 8    | 103  | 7    | 175  | 4    |
| Ankle | Pendulum      | 113  | 6    | 71*  | 7    | 129  | 7    |
|       | Drop-jump     | 117  | 6    | 81   | 3    | 134  | 4    |

*Significant ($p < .05$) difference between exercises.
Table 2  Hip, Knee, and Ankle Joint Angular Velocities (deg · s\(^{-1}\)) During Drop-Jumps and Pendulum Exercises

<table>
<thead>
<tr>
<th>Joint</th>
<th>Exercise mode</th>
<th>Angular velocities (deg · s(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Countermovement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M</td>
</tr>
<tr>
<td>Hip</td>
<td>Pendulum</td>
<td>–223</td>
</tr>
<tr>
<td></td>
<td>Drop-jump</td>
<td>–279</td>
</tr>
<tr>
<td>Knee</td>
<td>Pendulum</td>
<td>–495</td>
</tr>
<tr>
<td></td>
<td>Drop-jump</td>
<td>–488</td>
</tr>
<tr>
<td>Ankle</td>
<td>Pendulum</td>
<td>–552</td>
</tr>
<tr>
<td></td>
<td>Drop-jump</td>
<td>–606</td>
</tr>
</tbody>
</table>

*Significant (p < .05) difference between exercises.

Figure 2 — Mean duration (s) of countermovement, coupling, and drive-off phases during drop-jumps and pendulum exercises; percentage values indicate the length of each phase with respect to total contact time.

(drop-jump = 37 ± 8%; pendulum = 36 ± 6%) phases in the two actions although the pendulum resulted in a greater (p < .05, effect size = 2.44) total contact time (drop-jump = 0.33 ± 0.04 s; pendulum = 0.45 ± 0.05 s). The coupling phase, the period of zero velocity between eccentric and concentric phases of the movement, was the same for both exercises: drop-jump 0.06 ± 0.02 s and pendulum exercises 0.06 ± 0.01 s.

The sequencing of the joint and mass center movements (Figures 3–5) shows that the maximum ankle and knee flexion velocities were achieved 0.04 ± 0.02 s after touchdown for the both drop-jumps and pendulum exercises. Maximum hip flexion velocity occurred fractionally later at 0.05 ± 0.02 s for the drop-jumps and 0.08 ± 0.04 s for the pendulum exercises. Minimum mass center velocity occurred at touchdown in both exer-
Angular velocity/deg·s⁻¹

![Graph](image)

**Figure 3** — Ankle joint angular velocity (deg · s⁻¹) as a function of relative time during drop-jump and pendulum exercises. The time axis has been normalized to the total contact time for each exercise.

cises. All joints reached their minimum angles at the end of the countermovement phase: drop-jumps 0.15 ± 0.03 s and pendulum 0.22 ± 0.04 s ($p < .05$, effect size > 1.9).

For the drop-jumps, the drive-off phase was initiated by extension of the hip with the peak angular velocity 0.06 ± 0.02 s into the drive-off phase. Knee extension velocity peaked 0.02 s later, and the maximum vertical velocity of the center of gravity was achieved after 0.09 ± 0.02 s of the drive-off phase. Maximal joint angles were not achieved until after takeoff. During the pendulum exercises, peak joint angular velocities were achieved later in the drive-off phase: hip 0.14 ± 0.02 s, knee 0.16 ± 0.01 s, and ankle 0.15 ± 0.02 s. The maximum joint displacements occurred after takeoff, as with the drop-jumps.

Conjugate cross-correlations were performed to assess the coordination strategies employed during the two activities (Figures 6 and 7). Analysis of the boundaries of agreement between the two sets of Z-transformed cross-correlation data revealed similarities between the drop-jump and pendulum exercises for the coordination of movements of the ankle with respect to the knee and the knee with respect to the hip. Ankle and knee movements with respect to mass center velocity were also similar, while a different pattern was shown at the hip for the two modes of exercise.

Three force peaks could be identified for both drop-jump and pendulum exercises (Figure 8). The magnitude of each of the three force peaks and the time to each peak were recorded from the force time data. Time to peak force was recorded with respect to the
Figure 4 — Knee joint angular velocity (deg · s⁻¹) as a function of relative time during drop-jump and pendulum exercises. The time axis has been normalized to the total contact time for each exercise.

point of first ground contact. These peaks were interpreted to represent the passive impact loading (Peak 1), the eccentric resistance (Peak 2), and the concentric drive-off (Peak 3).

Analysis of the differences between exercises (Table 3) revealed significantly ($p < .05$) greater forces for Peaks 2 (effect size = 1.3) and 3 (effect size = 1.2) during the drop-jumps than pendulum exercises. There was a nonsignificant ($p > .05$, effect size = 0.6) trend for drop-jumps to produce greater forces for Peak 1. The failure to find significance in this difference may be related to the greater variance in this data point, although the effect size suggests the difference to be moderately strong.

There were no differences in the time to Peaks 1 or 2 ($T_1 = 0.08$ s and $T_2 = 0.15$ s), but Peak 3 occurred significantly ($p < .05$, effect size = 1.8) later in the pendulum exercises ($T_3$ drop-jumps = 0.23 s, pendulum = 0.32). Pendulum exercises also had a longer ($p < .05$, effect size = 0.8) contact time (drop-jumps = 0.36 s, pendulum = 0.43). The total impulse was greatest during the pendulum exercises possibly as a result of the greater contact time ($p < .05$, effect size = 1.2). Peak loading rate was greatest ($p < .05$, effect size = 1.4) during drop-jumps (33.3 × body weight/s vs. 24.8 × body weight/s).

**Discussion**

The time history of force data for drop-jumps and pendulum exercises were similar, with both characterized by three peaks in the force trace. These peaks can be interpreted as
representing the initial passive loading of the body upon first ground contact (Peak 1), this peak occurring within the first 80 ms of impact. Although this is slightly later than the 50–60 ms cited by Nigg (1986) as the passive loading time, it is unlikely that any active force could be generated within this period. The second peak, at 0.15 s and 0.16 s for drop-jumps and pendulum rebounds, respectively, represents the positive acceleration peak during which the downward (drop-jumps) or forward (pendulum) velocity of the body was reduced through the eccentric action of hip, knee, and ankle extensors. The timing of this peak was coincident with the response time for the functional stretch reflex (Jones & Watt, 1971), that is, the delay between the initiation of a muscular stretch and the peak reaction to that stretch. The final peak, occurring shortly before takeoff, was the result of concentric contraction of the previously stretched muscles to drive the body away from the force platform.

Comparison of the magnitude of these peak forces indicated that there were significantly larger forces during the performance of drop-jumps than pendulum exercises for Peak 2 and Peak 3. Although not statistically significant, Peak 1 also tended to be greater for the drop-jump exercise. A relatively consistent difference in force of $0.6 \times$ body weight (490 N) was evident at both Peak 2 and Peak 3. As the drop-jumps were performed against the resistance of gravity, there would be a residual force, equal to one body weight, acting even if there were no acceleration of the body. During pendulum rebounds, body weight was supported by the seat and the exercises were performed hori-

![Figure 5 — Hip joint angular velocity (deg · s⁻¹) as a function of relative time during drop-jump and pendulum exercises. The time axis has been normalized to the total contact time for each exercise.](image-url)
Figure 6 — Z-transformed conjugate cross-correlation coefficients for the relationships between (a) ankle and knee and (b) knee and hip angular displacements plotted against phase lag (s) for drop-jump and pendulum exercises.
Figure 7 — Z-transformed conjugate cross-correlation coefficients for the relationships between (a) ankle and knee and (b) knee and hip angular velocities plotted against phase lag (s) for drop-jump and pendulum exercises.
zhou horizontally; therefore, under zero acceleration conditions the ground reaction force would be zero.

The difference between the peak forces during drop-jump and pendulum exercises was less than this “one body weight” residual force, possibly due to the greater mass (and inertia) of the pendulum–subject system. If the residual force due to body weight was considered to be a passive force and subtracted from the peak force data, the remainder could be considered to represent the peak active force generated. If this were done, greater

Table 3  Peak Forces (N), Time to Peak Forces T1, T2, T3 (s), Total Contact Time (s), and Loading Rate (N · s⁻¹) for Drop-Jump and Pendulum Exercises Performed With a Bounce Style

<table>
<thead>
<tr>
<th></th>
<th>Drop-jumps M</th>
<th>Drop-jumps SD</th>
<th>Pendulum M</th>
<th>Pendulum SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak 1 (N)</td>
<td>2,200</td>
<td>660</td>
<td>1,770</td>
<td>760</td>
</tr>
<tr>
<td>Peak 2 (N)</td>
<td>2,330</td>
<td>400</td>
<td>1,820*</td>
<td>360</td>
</tr>
<tr>
<td>Peak 3 (N)</td>
<td>2,610</td>
<td>440</td>
<td>2,110*</td>
<td>430</td>
</tr>
<tr>
<td>Time T1 (s)</td>
<td>0.08</td>
<td>0.01</td>
<td>0.08</td>
<td>0.02</td>
</tr>
<tr>
<td>Time T2 (s)</td>
<td>0.15</td>
<td>0.01</td>
<td>0.16</td>
<td>0.02</td>
</tr>
<tr>
<td>Time T3 (s)</td>
<td>0.23</td>
<td>0.05</td>
<td>0.32*</td>
<td>0.05</td>
</tr>
<tr>
<td>Total impulse (N · s)</td>
<td>622</td>
<td>106</td>
<td>729*</td>
<td>67</td>
</tr>
<tr>
<td>Loading rate (N · s⁻¹)</td>
<td>26,750</td>
<td>5,810</td>
<td>19,880*</td>
<td>4,290</td>
</tr>
</tbody>
</table>

*Significant (p < .05) difference between groups.
values would be found for the pendulum exercises by approximately $0.4 \times \text{body weight}$. This could be interpreted as representing a greater degree of muscular effort during these exercises. Further support for this notion is provided by the greater impulse recorded during the pendulum rebounds. However, the residual force was not purely passive and care must be taken when comparing peak forces derived under different loading conditions.

The data derived for the drop-jumps in this study were comparable to those previously reported for drop-jumps from a similar height (Bobbert, Huijing, & Van Ingen Schenau, 1987b). The magnitude of the peak impact force, less than three times body weight for both exercises, was lower than that reported for drops from greater heights (Komi & Bosco, 1978) and only marginally greater than that reported for running (Frederick & Hagy, 1986). This may indicate that when performed from a modest height, plyometric rebound exercises do not expose the body to excessive impact forces and that the performance of pendulum exercises further reduces the magnitude of these forces.

When considering the relative safety of exercises based on ground reaction force data, it is important to determine the rate of force loading as well as the magnitude of the peak forces. All biological materials are viscoelastic in nature whose material properties are rate dependant (Nigg & Herzog, 1994). It is generally accepted that greater loading rates are more injurious than lower rates as materials generally are stiffer under these faster loading conditions. The peak loading rate was greatest for the drop-jump exercises reaching $33.3 \times \text{body weight} \cdot \text{s}^{-1}$ compared to $24.8 \times \text{body weight} \cdot \text{s}^{-1}$ for the pendulum exercises. These are greater than values of $18–20 \times \text{body weight} \cdot \text{s}^{-1}$ typically reported for running, although the difference is not substantial.

The kinematic characteristics of drop-jumps have been discussed previously in the literature (Bobbert, Huijing, & Van Ingen Schenau, 1987a, 1987b; Bobbert & Van Ingen Schenau, 1988), and the general data patterns for drop-jumps in this study do not contradict the findings of these earlier works. Subjects dropped an average of 0.27 m from the box height of 0.28 m. The difference between these figures can be accounted for by the subjects’ knee flexion at takeoff from the box ($150 \pm 10^\circ$) and plantar flexion upon landing ($117 \pm 6^\circ$).

The magnitude of the mass center excursion during the countermovement phase ($0.21 \pm 0.05 \text{m}$) was similar to that found by Bobbert et al. (1987a) of $0.21 \pm 0.03 \text{m}$ for what they described as “bounce drop-jumps.” The duration of the downward phase of the motion was also comparable to that reported by Bobbert et al. and supports the view that subjects in this study followed the instruction and performed the drop-jumps with a “bounce” technique. A similar mass center displacement was experienced during the pendulum exercises, although in this case the displacement was horizontal rather than vertical.

The duration of the countermovement phase for the pendulum swings ($0.22 \pm 0.04 \text{s}$) was 0.07 s longer than that of the drop-jumps ($0.15 \pm 0.03 \text{s}$). Although longer than for the bounce drop-jumps, this phase duration was similar to that of the countermovement style of drop-jumps most commonly reported in the literature ($0.19 \pm 0.04 \text{s}$; Bobbert et al., 1987a). The duration of the drive-off phase was longer for the pendulum exercises than the drop-jumps, giving a greater total contact time during the pendulum swings. The relative lengths of the three phases, countermovement, coupling time, and drive-off (Figure 2), show that the greatest difference between the exercises lies in the longer countermovement time of the pendulum exercises. This indicates that subjects adopted less of a bounce style during the pendulum swings than during the drop-jumps.

Bobbert et al. (1987a) showed that subjects are able to perform both countermovement and bounce styles of jump. It may therefore be surmised that subjects in this study
were consciously adopting a more countermovement style while performing pendulum exercises. This may have been due to the relative novelty of the exercise mode and the subjects’ reluctance to perform these exercises with a bounce technique.

While reviewing the effect of increasing drop height, Bobbert et al. (1987b) showed that subjects tended to adopt a more countermovement style with increases in the drop height. During this experiment, the magnitude of impact during the pendulum exercises was determined by the amplitude of the preceding oscillation of the swing. It is therefore possible that subjects adapted their impact style as if performing drop-jumps from a greater height. This adaptation could have been the result of subjects perceiving the pendulum impacts as more strenuous than the drop-jumps and thus adapting their impact style accordingly. Robbins and Gouw (1991) reported finding adaptations in subjects’ impact strategies in response to their perception of the severity of impact and not necessarily to the magnitude of the impact forces or loading rates. This may also have been the case during the pendulum swings, where subjects perceived the impacts as being more severe than the drop landings and therefore elected to adopt a “softer” impact style. Analysis of ground reaction force data for the drop-jump and pendulum exercises showed that although the impact forces were lower during the pendulum exercises, there was a nonsignificant trend for the ground reaction impulse to be greater than seen in drop-jumps. This greater impulse, rather than the impact force, may have led to the perception of pendulum exercises being more stressful.

Another possible factor in the longer countermovement phase on the pendulum was the movement constraint placed upon the subject by the seated position on the pendulum. A more flexed hip position is required at the point of impact, and the range of hip motion during the contact phase was significantly less than during drop-jumps. This limited hip motion was coupled with an increase in the ranges of knee and ankle flexion. These movements resulted in a greater emphasis upon the role of knee and ankle extensors during the impact phase and a reduced contribution from the hip extensors. This concentration of load onto fewer muscles, of lesser size, may increase the time required to perform this work and reverse the direction of pendulum motion.

The coupling time, the period between the end of the countermovement and initiation of the drive-off phases, of 0.06 ± 0.01 s was considerably lower than the 0.23 s reported by Bosco, Komi, and Ito (1981) for countermovement jumps. Few studies have attempted to quantify this period for drop-jump exercises. The importance of achieving a short coupling time has been highlighted by various studies in which the period between eccentric and concentric movements has been controlled. These have found that the greater the interval, the less effective is the utilization of the stretch–shorten cycle (Bosco et al., 1981; Wilson, Elliot, & Wood, 1991). The time delay has been linked to the coupling time of the cross-bridges in the muscle. Both exercises were shown to use a similar coupling time and could thus be assumed to have similar potential for utilizing the stretch–shorten effect.

The angular velocity of the ankle joint did not differ significantly between exercises, although the pendulum exercises produced lower mean values both during countermovement and drive-off phases. For both exercises the rates of dorsiflexion and plantar flexion were lower than those reported by Bobbert et al. (1987a, 1987b), particularly during the drive-off phase. This may reflect differences in the subjects’ training status, since Bobbert et al. recruited trained volleyball players. It is reasonable to assume that the highly trained jumpers in Bobbert’s study would achieve greater joint angular velocities during the active drive-off phase of the jump than would the less experienced individuals in the present study. This more rapid plantar flexion may have resulted in the greater net height jumped by Bobbert’s subjects.
Maximum knee flexion and extension velocities were similar to those reported by Bobbert et al. (1987a) for bounce-style jumps but lower than those for countermovement-style drop-jumps reported by Bosco and Komi (1979). Similar results were also shown for hip angular velocities. The only significant difference in angular velocity between the two modes of exercise was for peak knee extension velocity during the drive-off phase.

No differences were found between the movement strategies adopted during drop-jump and pendulum exercises. Figures 6 and 7 show the cross-correlation values plotted against phase lag. These plots reveal no differences between the locations or values of the correlation peaks for the relationships examined. Such similarity between cross-correlation profiles can, according to Amblard et al. (1994), be interpreted as evidence for the existence of a comparable movement strategy. This indicates that, although different in absolute terms, the coordination of ankle, knee, and hip movements in pendulum exercises and the coordination in drop-jumps were similar.

The sequencing of joint movements has received attention in the literature although no clear consensus has been reached as to the optimal coordination strategy for jumping (Bobbert & Van Ingen Schenau, 1988; Hudson, 1986). The cross-correlation analysis showed that the strongest relationships for all combinations of ankle, knee, and hip variables occur at a phase lag of less than ±0.02 s. This indicates that the temporal sequences of the movements were most closely mirrored when there was little if any phase lag introduced between them (Amblard et al., 1994). This finding supports the view of Hudson (1986) that coordination in vertical jumps follows a more simultaneous than sequential pattern. That is, the segments are coordinated such that movements are initiated, reach a peak, and are reversed simultaneously rather than in a sequential, proximal-to-distal fashion.

The cross-correlation function was used to determine the relationship between variables across the whole temporal sequence of the movement. The results from this analysis are useful in determining the existence of discrete coordination strategies but may not be sensitive to small changes in the timing of motions in different phases of the action. Therefore, although the general movement strategy suggested by the cross-correlation indicates a simultaneous movement of ankle, knee, and hip joints, a proximal-to-distal sequence was suggested in the timing of the maximum joint angular velocity data. Angular velocity during the drive-off phase of drop-jumps peaked first for the hip joint followed by the knee then ankle joints 0.03 s later. The same sequence was seen during pendulum exercises with a delay between hip and ankle peak velocities of 0.04 s. A similar phasing was reported by Bobbert and Van Ingen Schenau (1988), although in their study the delay between peaks was greater at 0.07 s.

With reference to the specificity of training, the pendulum exercise appears to meet, to some extent, most of the requirements for offering a similar stimulus to the drop-jump. The basic movement patterns were similar with clear countermovement and drive-off phases involving flexion and then extension of hip, knee, and ankle joints. The absolute ranges of motion did differ, however, with a greater degree of knee motion and a limited hip motion during the pendulum swings. The increased range of knee motion can be accepted as there will be a training stimulus throughout the range of motion used and the greater range can be considered an asset rather than a problem. The limited hip motion, on the other hand, will restrict the training stimulus to the joint angles used (Lindh, 1979).

The rate of movement has also been identified as important to the specificity of the training stimulus (Kanehisa & Miyashita, 1983b). The only significant difference in joint angular velocity between the exercises was for knee extension during the drive-off phase. Here the pendulum exercises resulted in a greater velocity than did the drop-jumps. Be-
cause these exercises were performed to develop muscular power, an increase in joint angular velocity may also be considered as advantageous. We made no attempt in this study to determine whether the degree of muscular loading was similar between the two modes of exercise. However, due to the degree of similarity found within the movement patterns of the exercises, we can conclude that pendulum exercises performed with a bounce style offer the potential for a training stimulus similar to drop-jumps.

References


