Speed Skating the Curves:  
A Study of Muscle Coordination  
and Power Production

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The purpose of this study was to describe the intermuscular coordination and power production for the constrained asymmetrical movement during skating the curves. Seven elite male speed skaters took part in the experiments. The speed skaters were simultaneously filmed from frontal and sagittal views. EMGs were obtained telemetrically and push-off force was registered with special skates. Inverse dynamic analysis yielded power production data, which differed for left and right leg. Marked differences were also found in intermuscular coordination of each leg. The activation patterns of the muscles were influenced by the asymmetrical nature and the typical body position during the speed skating movement. External power output was determined by three methods. The mean joint power output for left and right leg showed similar values as the external power output calculated from air and ice friction. These values were lower than the values predicted with a geometrical model for skating the curves.

Speed skating is a unique way of human locomotion in the sense that forward velocity is achieved by sideward push-offs (Ingen Schenau, de Boer, & de Groot, 1987). Competitions of this Olympic sport are usually held at a 400-m skating rink, including straights as well as curves. In skating the curves, the required centripetal force is provided by the push-off force. But there is no essential difference in propulsion mechanism of skating the straights or skating the curves (de Boer, Ettema, van Gorkum, de Groot, & Ingen Schenau, 1988), because in both situations the direction of the push-off must be perpendicular to the gliding direction of the skate. In skating the straights, the push-off of the left leg changes the direction of the mass center of the body to the right, and the push-off of the right leg changes it to the left. In skating the curves, the push-off forces are directed to the left for both legs, which results in a highly asymmetrical movement pattern of the legs (cyclic movements are mostly symmetrical in nature).

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To accelerate the body in a desired direction, muscles must be activated to produce joint rotations. These joint rotations produce a translational velocity of the mass center of the body. This transformation is influenced by geometrical and anatomical constraints (Ingen Schenau, 1989a, 1989b). The geometrical constraint is associated with the decrease of translational velocity of the hip relative to the ankle when the knee approaches full extension during the push-off. The anatomical constraint is associated with the need to decelerate the knee angular velocity to zero at the end of push-off, to prevent hyperextension.

Research on vertical jumping (Bobbert & Ingen Schenau, 1988) and on speed skating the straights (de Koning, de Groot, & Ingen Schenau, 1991) demonstrates that a temporally ordered sequential segment motion pattern from proximal body segments to distal body segments diminishes the adverse influence of these constraints on the production of work.

Speed skaters are forced to produce a certain amount of mechanical work to overcome the frictional forces. The production of mechanical work, or its time derivative power, can be determined in different ways. In this study external power is defined as the sum of power liberated in the joints (Ingen Schenau & Cavanagh, 1990). For speed skating the curves it is also possible to calculate the external power output on the basis of a geometrical model of the curve (de Boer et al., 1988) and on the basis of frictional losses (Ingen Schenau, 1982). There is no method for measuring the true external power output of speed skating, as for instance in ergometer cycling. For this reason the external power output defined as the sum of joint powers is compared with the other means of power calculation.

Methods

Subject, Protocol, and Kinematics

Seven elite male speed skaters participated in this study. Table 1 shows the relevant data of the subjects. The experiments were done under good conditions of ice and weather on a 400-m outdoor skating rink. After warming up, the speed skaters performed 10 trials during which films were taken. The push-off forces and electromyographical data were collected for left and right leg.

Table 1
Mean Values and Standard Deviations for Height, Body Mass, Age, and Skating Velocity for 7 Male Subjects

<table>
<thead>
<tr>
<th></th>
<th>$M$</th>
<th>$SD$</th>
</tr>
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<tbody>
<tr>
<td>Height</td>
<td>(m)</td>
<td>1.83</td>
</tr>
<tr>
<td>Body mass</td>
<td>(kg)</td>
<td>78.5</td>
</tr>
<tr>
<td>Age</td>
<td>(years)</td>
<td>19.5</td>
</tr>
<tr>
<td>Velocity</td>
<td>(m $s^{-1}$)</td>
<td>9.5</td>
</tr>
</tbody>
</table>
The subjects were filmed with two 16-mm high-speed cine cameras while skating the curve. A sagittal camera (Teledyne DBM 55, Teledyne Camera Systems, Arcadia, CA) was placed in the middle of the curve outside the track and was operated at a nominal frame rate of 100 Hz. The optical axis of a frontal camera (Bolex M16, Paillard, Sancta Croix, Switzerland) was positioned at right angles to the sagittal camera. The frame rate of the frontal camera was 50 Hz.

To define the positions of the body segments (foot, lower leg, upper leg, and upper body), markers were placed on the skates and on the aerodynamic skinsuit corresponding with the tip of the skate shoe, lateral and medial malleolus, knee joint, greater trochanter, and neck (Figure 1a). Marker locations were digitized for each frame using a motion analyzer (Supergrid Digitizer SPG-1212-RP, Summagraphics Corp., Fairfield, CT). With the coordinates of the markers, the segmental positions, angles of the segments with respect to the horizontal, and joint angles were calculated (Figures 1b, 1c). From the frontal film, the angle $\varphi$ between the leg and the vertical in the frontal plane was derived.

The angles as observed on the sagittal film were corrected (G.J.C. Ettema, personal communication, January 1985) with the frontal film data to obtain the angles in the sagittal plane, that is, the plane through the foot, knee, and hip joint. All angles, positions, velocities, and accelerations in this study are described in this moving plane. The position data were low-pass filtered (Butterworth 4th-order zero-lag filter with a cutoff frequency of 20 Hz), and velocities and accelerations were obtained with a 5-point differentiating filter.

The push-off force and its point of application were recorded by means of special skates equipped with strain gauges between the shoe and the blade of the skate (Jobse, Schuurhof, Cserh, Schreurs, & de Koning, 1990). The force signals were sampled (500 Hz) and digitally stored in a portable computer carried on the skater's back. Telemetered pulses from the force measuring device were given on the edge of the film for the synchronization of cine film, push-off force data, and EMG.

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Figure 1 — (a) Positions of the marks on the speed skater; (b) angles between segments and horizontal: upper body ($\theta_1$), upper leg ($\theta_2$), lower leg ($\theta_3$), and foot ($\theta_4$); (c) definition of angles in hip ($\theta_h$), knee ($\theta_k$), and ankle ($\theta_a$).
Power Calculations

**Link Segment Model.** Anthropometrical data combined with data from Clauser, McConville, and Young (1969) provided the body segment parameters. A rigid-link segment model (Elftman, 1939) was used to obtain instantaneous net moments at the hip, knee, and ankle joints. Moments having a hip extending, knee extending, and plantar flexing influence were defined as positive.

Net power output about the joints was calculated by multiplication of net joint moments and joint angular velocities. The work per stroke of each leg was determined from the sum of the net joint power produced at the ankle, knee, and hip joints. The average external power output (joint power $P_j$) was calculated from the work per stroke of each leg and the stroke durations.

**Geometrical Model of Speed Skating the Curves.** In order to determine the external power output necessary for following the curve, de Boer et al. (1988) developed a geometric model. In the model, the power output is dependent on mean speed in the curve ($v_c$), stroke frequency ($f$), and radius ($R$) of the curve. The external power in the curve ($P_c$) is given by the following equation:

$$P_c = \frac{v_c^4}{2fR^2}$$

$P_c$ is expressed in W kg$^{-1}$ body weight (for the deduction of the equation, see de Boer et al., 1988).

**Frictional Losses.** In speed skating, the frictional losses $P_f$ can be divided into losses due to air and ice friction. Ingen Schenau (1982) calculated the power associated with air friction, based on wind tunnel experiments. The power necessary to overcome ice friction was calculated with the coefficient of ice friction as determined by de Koning, Jobse, Cserep, Ingen Schenau, and de Groot (1989a).

**Electromyography**

Electromyographical activity was recorded from the semitendinosus, biceps femoris caput longum, gluteus maximus, rectus femoris, vastus lateralis, vastus medialis, gastrocnemius lateralis, gastrocnemius medialis, soleus, and tibialis anterior muscles of both legs. The anatomical locations of these muscles are shown in Figure 2.

After standard skin preparation techniques (Basmajian, 1978), pairs of surface Ag/AgCl electrodes with a diameter of 1.5 cm (Sentry Medical Products, Santa Ana, CA) were positioned at the approximate geometrical center of the muscle belly. The center-to-center electrode distance was 4 cm. The inter-electrode resistance was less than 10 kΩ. The electrical signals were preamplified (1,000 times) and transmitted telemetrically (Biomes 80, Glonner Electronics GmbH, Munich, Germany) to a multitrack portable data recorder (Teac SR-70, Teac Corp., Tokyo) and stored on tape (Teac DT-400, Teac Corp., Tokyo). For synchronization of the EMG signals with film and force data, synchronization pulses at the instant where the push-off force dropped to zero were received from the portable computer of the push-off force equipment.

After the experiments, the EMG signals were band-pass filtered with a bandwidth of 5 to 100 Hz to avoid movement artifacts and aliasing effects. Subsequently, the signals were full-wave rectified and analog-to-digital converted (sample frequency of 400 Hz). The data were time-averaged with a window of
Figure 2 — Position of leg muscles. The raw myoelectric signals were rectified, filtered, and averaged with a window of 25 ms.

25 ms and the resulting values of EMG level were expressed in percentages of the maximum value attained during the stroke (Gregor, Cavanagh, & Lafortune, 1985, Figure 2). For each subject, EMG patterns were averaged over a number of trials for each leg separately. Subsequently, mean EMG patterns for each leg were obtained by averaging the mean individual curves over subjects.

In interpreting the EMG patterns in combination with kinetic data, the delay between EMG and the mechanical output of the muscles should be taken into account. The literature reports values of 80 to 130 ms for leg muscles (Cavanagh & Komi, 1979; Vos, Mullender, & Ingen Schenau, 1990). In this study a value of 100 ms was chosen in processing the raw EMG data.

**Data Treatment**

From each trial, the stroke that was most perpendicular to the sagittal camera was used for analysis. At least five strokes of the right and five strokes of the left leg were analyzed for each subject. The strokes were divided into two parts, a gliding phase and a push-off phase. The onset of the push-off phase was defined as the time from which the knee angular velocity is continuously rising, approximately 200 ms before the end of push-off. The end of the push-off, defined as the instant the push-off force drops to zero, was used for synchronizing EMG, force, and cinematographical data and for synchronizing the individual curves before averaging. Differences in variables between both legs were tested with a two tailed t test (level of significance ≤ 0.05).
Speed Skating the Curves

Figure 3 — Position of the body when skating the curve.

Results

When skating the curves, the push-offs of both legs are directed to the right (Figure 3). The body leans over to the left and the angle $\varphi$ between the leg and the vertical is always positive for both legs (Figure 4). The data shown in Figures 4 through 9 cover part of the gliding phase and the entire push-off phase. In the figures, time is expressed relative to the end of push-off ($t=0$). The mean patterns for angles and angular velocities of the hip, knee, and ankle joints for both legs are shown in Figure 5. The extension of the hip, knee, and ankle joints of the left leg occurs over a longer period of time and the extension velocities reach higher values earlier compared to the right leg.

The patterns of velocity difference between ankle and hip ($V_{a-h}$) and between the ankle and the mass center of the body ($V_{a-meb}$) also differ between right and left (Figure 6). The right leg shows a rise in these velocity differences only during the push-off phase, as is the case when skating the straights (de Koning et al., 1991). For the left leg as well, a rise is observed in the velocity difference during the middle of the stroke.

Figure 7 shows patterns of averaged surface myoelectrical signals of 10 leg muscles during the stroke of each leg. The differences in kinematics between right and left are reflected by differences in the EMG patterns of left and right leg muscles. Distinct differences in timing between right and left are seen in the patterns of gastrocnemius lateralis, semitendinosus, and rectus femoris muscles.

Mean plots of net joint moments at the hip, knee, and ankle are shown in
Figure 4 — Angle $\varphi$ between the push-off leg and the vertical. This angle is presented for the right leg (-----) and the left leg (——).

Figure 5 — (top) Mean angles of hip (——), knee (-----), and ankle (-----); (bottom) mean angular velocities of hip (——), knee (-----), and ankle (-----). The push-off begins at $\pm -0.2$ sec.
Figure 6 — (top) Mean velocity differences between segment endpoints in a direction perpendicular to the horizontal, induced by rotation of the trunk (---), upper leg (-----), and lower leg (-----); (bottom) mean velocity difference between ankle and hip ($V_{a-h}$) (-----) and between ankle and mass center of the body ($V_{a-meb}$) (-----).

Figure 8. There is a striking difference in the net moments between the two legs, the net moments of the left leg being larger for the hip and ankle joints. The differences in net joint moments and angular velocities of the hip, knee, and ankle joints result in different net joint power patterns for each leg, as shown in Figure 8. The sum of the net power output at the hip, knee, and ankle joints gives the instantaneous external power output $P_j$. Figure 9 presents the power output of each leg. For comparison, power output during speed skating the straights (calculated with data from de Koning et al., 1991) is also shown.

The mean external power output $P_j$ and work per stroke when skating the curves and the straightaway calculated from the joint powers are given in Table 2. The mean external power $P_c$ and work calculated with the geometrical model for the curves and the mean external power output $P_f$ calculated with the friction model are also presented. The mean summed joint power $P_j$ and work per stroke in the curve does not differ significantly from the power $P_f$ and work calculated with the friction model. $P_c$ differs significantly from $P_f$ and $P_j$. 
Figure 7 — Averaged EMG levels of the muscles of the right (-----) and left (—) leg. The electromechanical delay is included in these patterns. Time = 0 indicates push-off.

Discussion

The Calculation of Mean Power

Since the pioneer work of Fenn (1930a, 1930b), there have been many attempts to assess external power in human locomotion (see Aleshinsky, 1986a, 1986b; Ingen Schenau & Cavanagh, 1990; Williams & Cavanagh, 1983; for an extensive discussion of this topic). For speed skating the curves, it is possible to calculate power output along three lines. Ignoring power associated with the swing phase and assuming that the skaters did not show a substantial change of their velocity while skating the curve, the different estimates of power should have about the same magnitude. Table 2 shows that the mean external power as calculated from the summed joint powers \( P_j \) is 3.69 ± 0.72 W kg\(^{-1}\) is in good agreement with the power necessary to overcome air and ice friction \( P_i \) is 3.60 ± 0.51 W kg\(^{-1}\). However, \( P_c \) appears to be significantly larger than \( P_j \) and \( P_i \).
Figure 8 — (top) Mean net moment at the hip (—), knee (-----), and ankle (·····); (bottom) mean net power output about the hip (—), knee (-----), and ankle (·····) joints.

Figure 9 — External power output calculated by the summation of the net joint power output when speed skating the curve for the right leg (·····) and for the left leg (-----). For comparison, skating the straightaway (—, for both legs) is also shown.
Table 2
External Mean Power Output and Work per Stroke Calculated With Different Methods

<table>
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<tr>
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<th>Power W kg(^{-1})</th>
<th>SD</th>
<th>Work J kg(^{-1})</th>
<th>SD</th>
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<tbody>
<tr>
<td>Curve, left leg</td>
<td>(P_j)</td>
<td>4.38</td>
<td>0.48</td>
<td>2.79</td>
</tr>
<tr>
<td>Curve, right leg</td>
<td>(P_j)</td>
<td>3.00</td>
<td>0.63</td>
<td>1.91</td>
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<tr>
<td>Curve mean</td>
<td>(P_j)</td>
<td>3.69</td>
<td>2.35</td>
<td></td>
</tr>
<tr>
<td>Straight</td>
<td>(P_j)</td>
<td>3.94</td>
<td>0.72</td>
<td>2.51</td>
</tr>
<tr>
<td>Geometrical model</td>
<td>(P_c)</td>
<td>4.68</td>
<td>0.69</td>
<td>2.98</td>
</tr>
<tr>
<td>Friction model</td>
<td>(P_f)</td>
<td>3.60</td>
<td>0.51</td>
<td>2.29</td>
</tr>
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</table>

It should be noted that the calculation of these three powers can be judged as entirely independent, which means that a comparison of the three models can shed light on the reliability of the model predictions. However, with the presented results it is not possible to conclude which is the most reliable method because we have no information about the real external power of the speed skater, as we do, for instance, in ergometer cycling (Ingen Schenau, Woensel, Boots, Snackers, & de Groot, 1990). Our choice to use the power liberated in the joints to calculate the external power output is based on the assumptions underlying this model (see Ingen Schenau & Cavanagh, 1990, for an extensive review).

The origin of the difference between the summation of joint power and the frictional power, and the external power calculated with the geometrical model, calls for an explanation. In the deduction of the geometrical model (de Boer et al., 1988), it was assumed that the push-off skate describes a straight line during the entire stroke. If the strokes would slightly follow the curve, the geometrical model would overestimate the external power since the change of direction of the center of mass would no longer be entirely due to the push-off. The frontal film showed that a curved trajectory of the skate indeed seemed to occur, which may have considerable influence on the skating kinetics.

An advantage of this technique might be that it introduces an inertial force that allows the skater to develop higher extension moments and joint power during the push-off when compared to skating straight strokes. Since the total force on the mass center of the body is increased, the average push-off force and the joint moments must be larger than if this force is not present (straight strokes). A second advantage might be that this force allows the skater to push off in a more horizontal direction (larger angle \(\phi\)). The angle \(\phi\) at the end of the push-off has been defined as the effectiveness of the push-off (Ingen Schenau, de Groot, & de Boer, 1985), and it has been shown that this effectiveness is one of the most important technical aspects of speed skating (de Boer & Nilsen, 1989; Ingen Schenau et al., 1985; de Koning, de Groot, & Ingen Schenau, 1989b). Clearly, the influence of the curvature of the stroke on joint power and effectiveness deserves further attention in our future three-dimensional analysis.
As already stated, speed skating the curves shows an asymmetrical movement pattern of the legs. Figure 9 shows remarkable differences between the patterns of instantaneous summed joint power output $P_j$ of each leg.

These differences result from different patterns in the individual joint powers of each leg (Figure 8). The origin of the observed differences in power output must be reflected in the way in which the muscles are activated and by the resulting net moments about the ankle, knee, and hip joints. The net joint moments are the sum of all the moments exerted by muscles and passive structures crossing the joint.

In EMG activity patterns (Figure 7) some differences are observed between the two legs. Relative to the maximum activation level during the stroke, the patterns of the left leg muscles show higher activation during the middle of the stroke. The most striking differences can be seen in the semitendinosus, rectus femoris, and gastrocnemius lateralis muscles. The pattern of the semitendinosus muscle can be explained by its role in the adduction of the left leg, which is necessary for performing a push-off to the right. The resulting net joint moments in hip, knee, and ankle are different for both legs (Figure 8). The largest difference in magnitude is observed in the hip and ankle joints. The hip joint moment of the right leg decreases continuously while the left hip joint moment decreases only during the last 250 ms of the stroke. The opposite holds true for the knee joint moment. The moment of the left leg decreases continuously while that of the right leg decreases only during the last 150 ms.

The explanation for these patterns can be based in part on the activity patterns of the muscles. The knee extensor muscles (vastii) of the left leg show a more uniform activity pattern during the stroke than those of the right leg, while the left gastrocnemius lateralis and soleus muscles have higher levels of activity earlier. The decreasing net knee joint moment and the increasing net ankle joint moment occurs for the left leg, therefore earlier in the stroke than for the right leg. The smaller angle in the left knee joint relative to the right, due to a more horizontal position of the left upper leg during the complete stroke, requires higher muscular force levels of hip and knee extensors. These larger forces obviously contribute to larger net joint moments.

In de Koning et al. (1991) it was shown that when speed skating the straight, the capacity to maintain a more horizontal position of the upper leg should be judged as a major prerequisite for high performance speed skating. In this study it is shown that when speed skating the curves, the leg with the smallest knee angle at the start of push-off, the left leg, produces much higher net moments. These high net joint moments contribute to the observed high net joint powers in the hip, knee, and ankle joints.

Differences in net joint power outputs of both legs are reflected by the external power output $P_j$ of each leg. The right and left leg show a mean power output of 3.00 ± 0.63 and 4.38 ± 0.48 W kg⁻¹, respectively (Table 2). In a previous study it was found that the external power $P_j$ of a comparable population of speed skaters when skating the straights (de Koning et al., 1991) at approximately the same velocity (10.3 m s⁻¹) was 3.94 ± 0.72 W kg⁻¹. This value lies between the values found for each leg, but it is larger than the averaged external power $P_j$ for left and right when skating the curve (3.69 W kg⁻¹).
The pattern of the instantaneous power production at the straights (Figure 9) lies between the patterns for each leg. The observed difference in power output of the right and left leg when skating the curves indicates that the maximal power production during a movement like speed skating is obviously constrained by how the movement is executed. This specific movement pattern most likely has a large influence on the amount of work that can be done in one cycle. Due to the positions of the body and the legs when skating the curves (Figure 3), the left leg is forced to produce more work than the right leg compared to when skating the straights. Skaters often indicate that fatigue occurs sooner in the left leg than in the right. This might point to an early accumulation of lactate due to the high force level at which the left leg must operate in the curves.

In the study on intermuscular coordination of speed skating the straight-away, de Koning et al. (1991) indicated that a sequential pattern in the movements of the trunk, upper leg, lower leg, and foot in the proximodistal direction was advantageous in meeting the anatomical and geometrical constraints in transferring joint rotations to the velocity of the mass center of the body relative to the skate. These constraints (Ingen Schenau, 1989a, 1989b), and the need to maintain the trunk and the skate in a horizontal position, influence the velocity pattern of the mass center of the body with respect to the ankle of the push-off leg ($V_{a-mcb}$).

This velocity pattern (Figure 6) shows a peak 50 ms before the end of the push-off. The velocity difference between the mass center of the body and the ankle depends on movements of three segments: lower leg, upper leg, and trunk. In the contribution of these segments to $V_{a-mcb}$ (Figure 6), a sequence can be observed. It is most pronounced in the contributions of the upper and lower legs. Particularly, the lower leg contributes later to $V_{a-mcb}$ than does the upper leg. With such a temporal sequence in movements, it is possible to delay the termination of the push-off, which implies better use of the muscular work capacity (Bobbert & Ingen Schenau, 1988).

There are some remarkable differences in the velocity profiles of each leg. In contrast to the right leg, the left leg shows a considerable difference in velocity between the mass center of the body and the ankle, in the middle of the stroke (from 500 to 250 ms before the push-off). This velocity results from the early onset of the push-off of the left leg due to a shorter gliding phase. Most likely the early onset of the push-off of the right leg has to do with the smaller angle $\phi$ (Figure 4) of the left leg at the onset of the stroke. The higher level in velocity can be ascribed entirely to the contribution to $V_{a-mcb}$ of the upper leg. The rotation of the upper leg results from the activity of hip and knee extensors and can also be observed in the higher power output levels of the hip and knee joints for the left leg compared to the right in this phase of the stroke. The velocity profiles show a large similarity with the patterns of external power output (Figure 9).

The sequence from proximal to distal when skating the straight (de Koning et al., 1991) is less pronounced for the left leg than for the right. A clear sequence is seen in the contribution of upper and lower leg to rotation, and consequently to the velocity difference between the mass center of the body and the ankle. The increase in velocity due to the upper leg begins earlier than the one due to the rotation of the lower leg. In addition to a higher velocity value during the pre-push-off phase, the left leg shows no clear sequence during the push-off. In hip, knee, and ankle angular velocity (Figure 4) this phenomenon is also observed.

These patterns are reflected by the EMG activities. For the right leg, the peak in activation of the hip extensors is followed by maximum values in the knee extensor muscles. The simultaneous decrease in semitendinosus activity,
and the increase in rectus femoris activity followed by the increase in plantar flexor activity, seems to fit well in the proximodistal power transport mechanism reported for jumping (Bobbert and Ingen Schenau, 1988). For the left leg, the hip extensors reach their peak activation prior to maximum activity of the knee extensors, but there is no proximodistal sequence between the knee extensors and plantar flexors.

The gastrocnemius lateralis reaches its peak in activation even before the knee extensors do. The reason is probably due to the position of the left leg during the stroke. The knee angle is considerably smaller and the leg is forced to push off while the skate is gliding to the medial side of the body. It seems that the specific position of the left leg prevents a proximodistal sequence in joint extension and muscle activation, as observed in less constrained movements.

The absence of a sequential pattern during the push-off of the left leg has consequences for that push-off. It was stated that a sequential pattern in the proximodistal direction delays the end of the push-off, which implies that the muscular shortening possibilities can be used better. The results of this study show that a sequential pattern is only observed in the right leg. Consequently, the push-off of the right leg terminates at larger knee angles compared to that of the left leg, as can be seen in Figure 5. These results support this beneficial effect of a sequential timing of muscular activation found earlier (Bobbert & Ingen Schenau, 1988). However, it is clear that the more pronounced proximodistal sequence and the larger knee angles at the end of the push-off of the right leg do not result in a higher work output, since this work output was higher in the left leg. In this respect, this specific movement exemplifies the statement made by Newell, Emmerik, & McDonald (1989) toward our previous work, that other constraints may influence the proximodistal formulation.

References


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