Push-Off Force in Speed Skating

Jos J. de Koning, Ruud W. de Boer, Gert de Groot, and Gerrit Jan van Ingen Schenau

In speed skating, performance is related to the product of the amount of work per stroke and the stroke frequency. Work per stroke is dependent on the component of the push-off force in the direction perpendicular to the gliding direction of the skate. The push-off force at different velocities was measured in three trained speed skaters. The results showed that the peak push-off force and mean force do not change at different velocities, and that the stroke time was decreased at higher velocities. It can be concluded that these speed skaters regulate their velocity not by changing the push-off force but by changing their stroke time. The shape of push-off-time curves is dependent on push-off technique and differs during straight lane and curve skating.

Performance in speed skating is closely related to the external power $P_0$, the athlete uses to overcome air and ice friction (Ingen Schenau, 1982). External power $P_0$ is equal to the product of the amount of external work per stroke $A$ and stroke frequency $f$. This external work per stroke $(A)$ is determined by lateral component $F_x$ of push-off force $F$, which is directed at right angles to gliding direction $y$ (Figure 1). Ingen Schenau, de Groot, and de Boer (1985) showed that speed skaters control the different speeds at different distances mainly by changing their stroke frequency, not by changing the amount of work per stroke $A$. But at the same distance, the relative small interindividual differences in performance level appeared to be related to differences in push-off mechanics. This study aimed to investigate the dependency of push-off force $F$ on skating speed and to investigate differences in force between straight lane and curve skating.

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Figure 1 — In the proper gliding technique the skate continues to glide during push-off. As a consequence, push-off force $F$ lies in a plane $(x-z)$ at right angles to gliding direction $y$ of the skate.

**Methods**

Three male speed skaters of different performance levels served as subjects for this study. Their data are presented in Table 1. Measurement was done with specially developed skates provided with two strain gauge-measuring elements between the shoe and the skate blade to register push-off force $F$ (technical note
Table 1

Subjects' Performance Levels

<table>
<thead>
<tr>
<th>Subject</th>
<th>BW (kg)</th>
<th>Best seasonal time 85/86</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1500 m</td>
</tr>
<tr>
<td>A</td>
<td>71</td>
<td>2'18.2''</td>
</tr>
<tr>
<td>B</td>
<td>71</td>
<td>2'10.5''</td>
</tr>
<tr>
<td>C</td>
<td>75</td>
<td>2'14.0''</td>
</tr>
</tbody>
</table>

in preparation). During the strokes, the force signal was sampled (500Hz) and digitally stored in a portable computer carried on each skater's back. The stored data were then transferred to a microcomputer after the exercise. The onset of the stroke was defined as the time at which the push-off force attained 100 N. The end of the stroke was defined as the time at which the push-off force fell to 0 N. Skating speed is determined from 100-m times. The push-off forces were normalized to percentages of total weight of body, clothes, and apparatus (7750 gram). The time is normalized in units of stroke time T.

A few days before the tests, the skaters were familiarized with the experimental equipment and protocol. Each skater generated data for several strokes over a range of different speeds. After the measurements, the maximal push-off force, mean push-off force, and normalized push-off force–time curves were calculated, and Pearson correlation coefficients between mean push-off force and peak push-off force on the one hand and skating velocity on the other hand were calculated.

Results

Figure 2a–2c presents the normalized push-off forces (mean ± SE of 10 strokes) of the subjects when skating the straight lane, with a velocity of 9 ms⁻¹. A remarkable similarity in all registrations occurs at the interval during which the force on the skate is lower than body weight. Moreover, all registrations show an increase of force during push-off at the end of the stroke.

Figure 3 shows the normalized push-off force (mean ± SE of 10 strokes) at a velocity of 9 ms⁻¹ that subject C generated while skating the curve. The main difference with respect to the straight lane push-off force is the absence of an interval during the stroke when the push-off force is less than gravity, and the absence of an increase of force at the end of the stroke.

Figure 4a–4c illustrates that at higher velocities (v) stroke time T decreases, while the normalized force does not change. Figure 5 shows the relation between skating speed and absolute push-off force. Both mean force and peak push-off force are independent of skating speed. (Individual correlation coefficients are approximately $r = 0.08$ and $r = -0.13$, respectively.)
Figure 2 — Push-off force during the straight lane, measured on the right skate with a velocity of 9 ms⁻¹. The force (F%) is expressed in percentage of total weight of body, clothes, and apparatus, and the time is normalized in units of stroke time T. Shown are means (n = 10) (solid lines) and standard deviations (dotted lines). A is subject A, B is subject B, C is subject C.

Figure 3 — Push-off force during skating a curve, measured on the right skate of subject C, with a velocity of 9 ms⁻¹. The force (F%) is expressed in percentage of total weight of body, clothes, and apparatus, and the time is normalized in units of stroke time T. Shown is mean (n = 10) (solid line) and standard deviation (dotted line).
Figure 4 — Normalized push-off forces (F%) at different velocities. Data for all 3 subjects expressed in ms⁻¹. (A) Subject A: --- 9.3, --- 8.3, ---- 7.3. (B) Subject B: ---- 10.0, ---- 9.7, --- 8.2. (C) Subject C: ---- 10.7, --- 9.0, ---- 7.7.

Figure 5 — The relationship between skating velocity (v) and absolute mean push-off force (F): A = △, B = ○, C = □ and absolute peak push-off force (F): A = △, B = ●, C = ■.
Discussion

In speed skating, the force–time curves during each stroke show two maxima with a maximum between them (Figure 2a–c). The first maximum can be ascribed to the need to counteract the weight of the body during transfer of body weight from the push-off leg to the new supporting leg. Then during the gliding phase the skater rotates around a y-axis through S in plane x–z (Figure 1). This can be seen as an inverse pendulum movement under the influence of gravity, which causes the minimum and which is followed by a short intensive push-off (second maximum).

The minimum in the middle of the gliding phase is caused by a centrifugal force \( F_{cf} \) in the direction opposite the push-off force. The magnitude of this force can be approximated by \( F_{cf} = m \alpha^2 r \), where \( m \) is body mass, \( \alpha \) is angular velocity, and \( r \) is the distance between the skate and the center of gravity. Since at first approximation \( \alpha \) is the change of \( \alpha \) during the stroke divided by stroke time (T), the centrifugal force will increase when skating speed increases and thus stroke time decreases. At moderate velocity this force will be approximately 15% of body weight (estimated from data of de Boer, Schermerhorn, Gademann, de Groot, & van Ingen Schenau, 1986). The patterns of subject A (Figure 5) provide the best illustration of this concept.

In skating curves, the force–time curves are quite different from force–time curves on the straight part. The main differences with the forces during the straight part are the lower peak forces at the end of push-off and the absence of a phase in the middle of the stroke during which the push-off is smaller than gravity. The latter can be explained by the fact that, in the curves, skaters do not rotate from the lateral to the medial side of the skate as they do on the straight part, and therefore the supposed centrifugal force is not present. During weight transfer from one leg to the other, the angle between the push-off leg and the ice surface is such that the center of gravity projection is positioned at the medial side of the right skate and the lateral side of the left skate. In comparison with the straight lane, one might say that the first part of the gliding phase is bypassed and there is an earlier extension of the knee and hip joint (de Boer, Ettema, van Gorkum, de Groot, & van Ingen Schenau, 1987).

Ingen Schenau et al. (1985) showed that in speed skating, lateral component \( F_x \) of push-off force \( F \) determines the amount of useful work per stroke, \( A = \int F_x v_x \, dt \), and that interindividual differences in performance (speed) are related to differences in push-off mechanics (i.e., in \( A \)). This study shows that the skaters with the best seasonal times on 1500 m and 3000 m (subjects B and C, Table 1) do not have the highest peak push-off force or mean force (Figures 2 and 5). Obviously, the magnitude of \( F \) does not discriminate between the skaters, while work per stroke, \( A \), does. Previous studies (de Boer et al., 1986; Ingen Schenau et al., 1985) showed that the better skaters demonstrate a more explosive and effectively directed push-off (small angle in this study). This results in high values of \( A \), up to 2500 Watt (de Groot, de Boer, & van Ingen Schenau, 1985) at relative low values of the peak push-off force (120%–150% of body weight).
Figure 4a–4c shows that the speed skaters in this study regulate their differences in velocity almost entirely by stroke time $T$, while their mean absolute push-off force and absolute peak push-off force (Figure 5) shows little difference at different velocities. This agrees with the findings of Ingen Schenau et al. (1985), who found that female speed skaters regulated difference in velocity at different distances entirely by their stroke frequency, while the amount of work per stroke did not change. These data also support the results of other studies on endurance sports, which showed that changes in power, and thus velocity, are mainly regulated by stroke frequency (Farfel, 1977).

References


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