Physiological responses that account for the increased power output in speed skating using klapskates

Abstract The present study investigates which physiological sources support the increase in mechanical power output ($W_{out}$) that can be obtained using klapskates in speed skating. It was hypothesized that the increase in $W_{out}$ could be achieved through an increase in gross efficiency or an increase in aerobic power ($W_{aer}$). Six speed skaters performed a submaximal and maximal 1600-m skating test with both klapskates and conventional skates, to measure gross efficiency and maximal $W_{aer}$ during speed skating. The rate of oxygen uptake ($\dot{V}O_2$) and post-exercise blood lactate concentrations ([La]) were measured and video recordings were made. $W_{aer}$ was calculated from $\dot{V}O_2$. $W_{out}$ was derived from the power needed to overcome air and ice friction. Gross efficiency was calculated as the ratio of $W_{out}$ and $W_{aer}$. In the maximal tests, the subjects skated faster with klapskates compared to conventional skates (10.0 vs 9.6 m·s⁻¹). They sustained the resulting maximal $W_{out}$ with klapskates at an equal $\dot{V}O_2$. [La] was, however, 1.7 mmol·L⁻¹ higher when klapskates were used, which might reflect an increase in anaerobic power. During the submaximal tests the skaters generated equal $W_{out}$ with both types of skate. Although not statistically significant, $\dot{V}O_2$ and $W_{aer}$ were, on average, lower when klapskates were used compared to conventional skates [mean (SD) 0.3 (0.43) L·min⁻¹, 105 (143) W]. Despite the lack of a statistically significant difference in $W_{aer}$, gross efficiency was shown to be significantly higher with klapskates compared to conventional skates (16.3% vs 14.8%, $p = 0.02$). We conclude that the increase in $W_{out}$ when the subjects were using klapskates could be explained by an increase in gross efficiency rather than an increase in $W_{aer}$.

Key words Aerobic power · Efficiency · Equipment · Locomotion · Exercise physiology

Introduction

Optimal sports performance relies on both technical and physiological aspects. Analyses of the push-off technique in speed skating (Boer et al. 1986; Ingen Schenau et al. 1983, 1985, 1987; de Koning et al. 1991) have resulted in the recent development of a new type of skate: the klapskate (Ingen Schenau et al. 1996). In the klapskate the rigid connection between the shoe and the blade has been replaced by a hinge mechanism beneath the ball of the foot. The rigid connection between the shoe and the blade of conventional skates placed a constraint on the plantar flexion of the ankle, since it would force the foot to rotate around the front end of the relatively long blade and press the tip of the blade into the ice (Boer and Nilsen 1989; Ingen Schenau et al. 1983, 1985, 1987; de Koning et al. 1991). The hinge of the klapskate allows the skater to plantar flex his foot independent of the blade, which can continue to glide over the ice.

The introduction of the klapskate in international speed skating competition was followed by a remarkable increase in skating performance (Gemser et al. 1999; Ingen Schenau et al. 1996; de Koning et al. 2000). A recent experiment concerning the push-off mechanics in speed skating revealed that work per stroke increased significantly when klapskates were used compared to conventional skates (Houdijk et al. 2000a). Together with a slight increase in stroke frequency, this resulted in an increase in mechanical power output ($W_{out}$) of 25 W, almost 12%, and an increase in skating velocity of more than 5%.

Although studies into push-off mechanics demonstrate that klapskates enhance the work per stroke and the mean $W_{out}$ of a speed skater, these data have not yet

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established how this increase in $W_{\text{out}}$ can be liberated from the available metabolic sources. It should be considered that without affecting physiological sources, the use of the klapskate could not have resulted in an increased $W_{\text{out}}$. In that case, an increase in work per stroke would merely have coincided with a decrease in stroke frequency, as the available $W_{\text{out}}$ dictates the product of work per stroke and stroke frequency. Insight into the underlying physiological changes that result from using klapskates is therefore necessary to fully comprehend the benefits of this skate. Moreover, this knowledge might also contribute to identifying the physiological determinants of an optimal performance in speed skating.

In theory, an increase in $W_{\text{out}}$ can be sustained in two ways. The use of the klapskates should allow for an increase in the liberation of metabolic energy, or it should increase the efficiency at which the available metabolic power is converted into mechanical power. It can be calculated that an increase in $W_{\text{out}}$ of 25 W is equivalent to an absolute increase in gross efficiency of approximately 1%, or an increase in maximal oxygen uptake ($V_{\text{O}_2\text{max}}$) of approximately 0.3 l · min⁻¹.

In a previous study, de Koning et al. (2000) investigated the physiological differences between two matched groups of skaters, one group habituated to conventional skates and one group habituated to klapskates. They showed that skaters with klapskates consumed less oxygen at equal external power levels compared to the conventional skaters. No differences in the $V_{\text{O}_2\text{max}}$ during skating were observed between the two groups. Although these results clearly point to an increase in gross efficiency and an absence of change in aerobic capacity when klapskates are used, a restraint should be made. Matching the two groups on the basis of speed-skating performance may have introduced a selection bias. After all, by accepting the idea that klapskates really improve performance, matching the two groups on skating performance will lead to the potential selection of a group of klapskaters that is of lower level than their conventional counterparts, who skate just as fast but do not yet experience the benefits of the klapskate.

The present study was therefore designed to eliminate a possible selection bias in the study of the physiological differences between skating with conventional and klapskates. The purpose of this study was to clarify the source of $W_{\text{out}}$ enhancement using klapskates compared to conventional skates. For this purpose energy consumption and $W_{\text{out}}$ were measured within a single group of skaters who were experienced in using both klapskates and conventional skates.

### Methods

#### Subjects

Six members of the Dutch national junior speed skating selection [three males and three females; mean (SD) height 1.78 (0.06) m, body mass 71 (6) kg] were selected to participate in this experiment. All six were highly experienced in using both klapskates and conventional skates. Although all of them used klapskates in competition nowadays, they had been brought up with conventional skates and they still regularly use these skates for training purposes. All subjects provided written informed consent to participate.

#### Protocol

On an indoor 400-m ice rink [temperature 4 °C, barometric pressure 1002 hPa (100.2 kN · m⁻²)], each skater performed two sets of two 1600-m skating tests, one set using klapskates and one set using conventional skates. With each type of skate, first a 1600-m test had to be skated at a fixed submaximal velocity, a velocity regularly used by these skaters during endurance training. The second 1600-m test had to be skated as fast as possible, using a constant-velocity strategy. A 30-min rest period was allowed between each test, and the order in which both types of skate were used was alternated from subject to subject. Skaters were coached from the side of the rink by informing them of their lap times. The tests at submaximal effort were designed to estimate skating efficiency. The tests at maximal effort were designed to measure $V_{\text{O}_2\text{max}}$ during skating with each type of skate.

#### Data collection

Aerobic energy consumption was calculated from the oxygen uptake ($V_{\text{O}_2}$) during the final 200 m (approximately 20 s) of each test. Four skaters were tested using portable Douglas bags (de Groot et al. 1983). The volume and composition of the expired air in the Douglas bag were analyzed after the test (oxylyser-capnolyser, Mijnhardt, Germany). From inspiratory volume and air composition, $V_{\text{O}_2}$ and respiratory exchange ratio ($R$) were calculated. For two subjects, a portable breath-by-breath gas exchange measurement system (Cosmed K4b², Cosmed, Italy) was used to continuously record $V_{\text{O}_2}$ during all tests. The final 20 s of these tests were also used for further analysis. Aerobic power ($P_{\text{aer}}$) was calculated from $V_{\text{O}_2}$ using the energy equivalent of oxygen at observed $R$ levels (Garby and Astrup 1987). Three minutes after the skater had finished each test, a blood sample was drawn from the fingertip to allow the analysis of blood lactate concentration ([La]; Dr. de Lange, miniphotometer). Heart rate was recorded throughout each test (Polar Vantage NVTM), and was averaged over the last minute of each test.

In speed skating at a constant velocity, $W_{\text{out}}$ is used predominantly to overcome air and ice friction. Power dissipated to both sources of friction was calculated to obtain the $W_{\text{out}}$ of the skater. Power lost against air friction was calculated according to the model presented by van Ingen Schenau (Ingen Schenau 1982). Average knee angle and trunk angle (angle between trunk and ice surface), the skater’s body length and mass, barometric pressure, altitude and ice friction serve as the input of this model. To obtain knee and trunk angle, video recordings were made using two sVHS camcorders operating at 50 Hz (Panasonic). Both panning cameras were positioned at the inside of the rink, 11-m apart, and could follow the skaters as they passed on the straight part of the rink. Markers were placed on the suit of the skater to indicate the location of the skater’s neck, hip, knee and ankle. Knee and trunk angle were determined during the gliding phase of the stroke, which was defined as the middle 0.2 s of the ice-contact phase of the left leg. For each lap the gliding phase that was closest to both cameras was analyzed. The video images of both cameras were digitized manually and the three-dimensional (3D) coordinates of the body markers were calculated using a method outlined by Yeaden (1989). Mean knee and trunk angle were calculated from these 3D coordinates. Power lost to ice friction was calculated from the skater’s body mass, the coefficient of ice friction and skating velocity (de Koning et al. 1992). It was recently shown that the difference in ice friction between conventional and klapskates is negligible, even when the blade of the conventional skate is pressed into the ice at the end of the stroke (Houdijk et al. 2001). Therefore, a constant friction coefficient of 0.0045 was assumed in all tests.

Gross efficiency was estimated using the ratio of $W_{\text{out}}$ to $P_{\text{aer}}$, obtained from the submaximal 1600-m test. It should be realized,