Changes in Blade Reaction Forces During the Curve Phase Due to Fatigue in Long Distance Speed Skating

Jun Yuda*, Masahiro Yuki**, Toru Aoyanagi***, Norihisa Fujii**** and Michiyoshi Ae*****

*Graduate School of Comprehensive Human Sciences, University of Tsukuba (Research Student)
1-1-1 Tennodai, Tsukuba, Ibaraki 305-8574 Japan
yuda@lasbim.taiiku.tsukuba.ac.jp
**Faculty of Education, Shinshu University
Roku-ro Nishinagano, Nagano, Nagano 380-8544 Japan
***Japan Skating Federation
1-1-1 Jinnan, Shibuya-ku, Tokyo 150-8050 Japan
****Institute of Health and Sport Sciences, University of Tsukuba
1-1-1 Tennodai, Tsukuba, Ibaraki 305-8574 Japan
[Received May 19, 2004 ; Accepted October 5, 2004]

The kinetic factors to maintain the curve skating velocity of long distance speed skaters were investigated by measuring the changes in blade reaction forces due to fatigue. Eight male long distance speed skaters performed 4000 m skating at maximal effort with an instrumented sensor klapskate. The skaters were videotaped with two synchronized video cameras (60 fields/s) in the mid portion of the curve by using a panning DLT technique. Push-off forces of the left leg and three-dimensional coordinates of the segment endpoints and blades during the left stroke over the 4000 m distance were measured at two points: 650 m and 3450 m. The blade reaction forces (BRF) were defined as the vertical and horizontal components in the coordinate system fixed on the ice, and used to calculate impulse. There were no significant differences in the peak value and impulse of the vertical component of the BRF between the measurements taken at the above two points while those of the horizontal component in the first half were larger than those of the second half. There were significant positive relationships between the peak value and impulse of the horizontal component and the velocity of the center of mass \( r=0.721; 0.677, p<0.01 \). These results indicate that minimizing the decrease in the horizontal impulse of the BRF during the left stroke could be one of important factors to maintain the skating velocity in the curve.

Keywords: klapskates, panning DLT method, fatigue, maintaining the skating speed

1. Introduction

Since the reaction force generated through exerting power externally becomes a driving force in locomotion, information essential to clarify the mechanism of locomotion is obtained by measuring the reaction force during movement.

In research so far, blade reaction forces have been measured by using skates attached with a strain gauge, because the reaction force during skating cannot be measured by using a force platform. De Koning et al. (1987) measured the force of the vertical direction operating on a skate during the straight phase of skating, performed by three expert skaters at three different speeds. They reported that skating velocity could be determined by the stroke frequency, judging from the result that no significant relation was observed between either the peak or average values of force exerted through a stroke and skating velocity. Several studies also measured force during skating using similar specially designed skates (de Boer et al., 1987a; de Koning et al., 1989; de Koning et al., 1991) but they have not conducted adequate examination on the relation between force and skating velocity. The positive relation between push-off force and performance has not been found yet. Yuki et al. (1996) have measured the force operating horizontally on the blade as well as the vertically operating force, considering the reason of inadequate examination on the relation between push-off force and performance...
was because these studies mentioned above measured only a compressive force operating vertically on the blade. They converted two component forces (vertical and horizontal) operating on the blade to a coordinate system fixed on the ice and examined them by defining them as the vertical and horizontal blade reaction forces. As a result, they reported that world-record holders were characteristically fast in giving rise to horizontal blade reaction forces and their peak values were small. Then in 1997, klapskates in which the blade separates from the boot at the heel began to be used. The modification of equipment improved the record of skating achievement enormously. Van Ingen Schenau et al. (1996) speculated that the plantar flexion which was restricted in conventional skates would increase the power output of the skater by 15%, which is supported by other studies (de Koning et al., 2000; Houdijk et al., 2000; Houdijk et al., 2001). Moreover, there are some studies concerning the difference between the skating motions of the klapskates and conventional skates (de Koning et al., 2000; Houdijk et al., 2000). When the great difference between the two types of skates is considered, it is questionable that the knowledge of studies on blade reaction forces using conventional skates (de Koning et al., 1987; de Boer et al., 1987a; de Koning et al., 1989; de Koning et al., 1991; Yuki et al., 1996) could be applied to klapskates. However, Yuki et al. (2000) suggested that there was little difference in the impulse between conventional and klapskates because push-off force operated effectively for about 0.06 seconds with the blade separated from the boot, and that push-off force was markedly small in the case of klapskates. Given this, it can be supposed that the characteristics of blade reaction forces obtained by Yuki et al. (1996) is rationally applied to the klapskates as well.

As referred to above, the relation between push-off force and skating velocity has been examined in respect to the straight phase of skating and knowledge relating to rational skating movement has been acquired. In contrast, although the level of technical difficulty is higher during the curve phase of skating since the skater always exerts push-off force to the right, tilting the body to the inside of the skating rink in order to resist the centrifugal force (de Boer et al., 1987b), studies have yet been rarely conducted on push-off force during the curve phase of skating. Therefore, it is meaningful to measure push-off force during the curve phase of skating and to examine the relation between the obtained values and skating velocity in order to find out the rational skating movement during the curve phase and to acquire the knowledge helpful for improving performance.

In respect to the curve phase of skating, de Koning et al. (1991) pointed out that the load on the left leg was greater, indicating that the average power output of the skater during skating was 4.38±0.48 W/kg on the left leg and 3.00±0.63 W/kg on the right leg in the curve phase of skating while 3.94±0.72 W/kg in the straight phase of skating. This seems to be caused by the characteristic motion of the left leg at a curve, pushing off to the right with the outer edge of the left blade with the right leg crossed in front of it, while tilting the body to the inside of the skating rink. Moreover, Yuda et al. (2001) conducted a three-dimensional analysis on the skating movement of world elite athletes at the curve phase in the 5000 m race. They reported that the gliding phase of a left stroke (from the moment the left skate blade lands on the ice until the moment the support leg is rapidly extended) was significantly longer for a group with a greater decreasing rate in velocity at the latter half of the race. Considering the importance of push-off motion of the left leg during the curve phase as mentioned above, it is necessary to focus on a left stroke concerning blade reaction forces. The helpful knowledge for the training of long distance speed skating would be acquired by examining the changes due to fatigue.

The purpose of this study was to clarify the relation between blade reaction forces and the continuation of skating velocity during the curve phase by measuring the horizontal and vertical components of blade reaction forces during the curve phase in long distance speed skating, and examining the characteristics and changes due to fatigue in relation to skating velocity.

2. Methods

2.1. Subjects

The subjects of this study are 8 males who major long distance speed skating, including 3 high school students, 4 college students and 1 adult (age: 19.4±2.4, height: 1.70±0.05 m, weight: 63.4±5.9 kg, the best time at 5000 m: 7m12s88±20s01)
2.2. Sensor-equipped klapskates

In order to measure push-off force during skating, we produced and used a klapskate equipped with two quartz voltage miniature sensors which measure three components (Kistler, 9251A, 24×24×10 mm, weight: 32 g) at the heel and toe between the boot and the arm of the klapskate (Figure 1). Blades and springs were fabricated from Viking products (blade length: 410 mm, spring diameter: 1.9 mm), with the curvature radius of roundness at the blade bottom being 23 m. Each subject used the same sensor-equipped klapskate specially produced in this study. Blade position was adjusted according to each subject so that every subject would have a similar sense during skating as usual.

2.3. VTR filming and force measurement

Each subject was asked to wear a sensor-equipped klapskate on the left leg and to skate 10 laps (4000 m) around an oval rink of 400 m circuit. Subjects were made to skate on the inside lane only (single-lane track) at the speed to finish at exhaustion.

A measuring range of 5 m in width, 18 m in length and 1.7 m in height was set at the center of the second incurve. Subjects were filmed three-dimensionally from the sides (panning) and from behind (fixed) by two video cameras (SONY, DCR-VX2000) (Figure 2; filming speed 60 filed/s, shutter speed 1/1000 s).

The two cameras were synchronized by capturing an optical signal from a light-emitting diode with both cameras. Signals from the sensor-equipped skates were amplified by a special amplifier (Kistler, 5037B), sampled by an A/D converter card (Keyence, NR-110) at 500 Hz and scanned in a compact laptop computer (SONY, PCG-C1XF). This measuring equipment (3.3kg in total) was put on the back of each subject, carefully placed so as not to disturb skating. The data of each round was collected when the subject pushed a trigger button held in the left hand upon entering the measuring zone. In addition, an LED lamp attached to the head of each subject was turned on at the same moment as the trigger input in order to synchronize the signal from the sensor-equipped skate with the VTR screen image.

Test performance at about the 650 m passing point (the second round) and at about the 3450 m passing point (the ninth round) were analyzed based on the data of each round as a rule. We define a left stroke as the phase from the moment the right blade starts to separate from the boot until the moment the left blade starts separating from the boot. The analysis was conducted on the left leg which becomes the support leg in this phase.

2.4. Measured items and measuring method

Twenty-one body segments, 4 edges of the
Figure 3 Transformation of the blade reaction forces from the blade coordinate system to the global coordinate system fixed on ice.

blade and 1 reference point (26 points in total) were digitized by using a VTR digitizer (DKH, Frame-Dias II) based on the obtained VTR data. Three-dimensional coordinates of the 25 analysis points were calculated according to the Panning DLT method (Takamatsu et al., 1997). These three-dimensional coordinates were then determined for optimal cut-off frequency according to the residual error method (Winter, 1990) and smoothed using a fourth-order Butterworth low-pass digital filter. A cut-off frequency of 2.4~8.4 Hz was applied.

Coordinates of the center of gravity of the body were determined by using the body segment parameter of Ae et al. (1992), and the displacement was calculated. The displacement data thus obtained was numerically differentiated to calculate the velocity, and the horizontal velocity of the center of gravity was calculated by combining velocity components of X direction and Y direction in the coordinate system on the ice. The average value during a stroke was applied as the horizontal velocity of the center of gravity during the curve phase in this study, and the inverse number of the time required for a stroke as the stroke frequency.

The output from the sensor-equipped klapskate was calibrated by weighting the front and rear sensors toward the compression direction and the horizontal direction respectively before the experiment. Then a coefficient to convert the output of the digital signal from the sensor into force on the skate blade (blade coordinate system) was fixed. This study did not calculate anterior-posterior direction forces in the blade coordinate system because the anterior-posterior direction force on the blade during skating is 10 N at most and below 1 % of the compression force (de Koning et al., 1992), and Houdijk et al. (2000) report that this force during skating can be ignored.

Figure 3 shows a skate blade during skating seen from behind. Digital signals recorded in the compact laptop computer during 4000 m skating were converted to forces in the blade coordinate system using a calibrating coefficient. After that, following the method of Yuki et al. (1996) which utilizes an equation (1), the horizontal and vertical components \( F_{\text{blade}x}, F_{\text{blade}z} \) of forces on the skate blade in the blade coordinate system were converted to a force coordinate system \((F_x, F_z)\) defined on the ice. the method of Yuhki et al. (1996) which utilizes an equation (1), the horizontal and vertical components \( F_{\text{blade}x}, F_{\text{blade}z} \) of forces on the skate blade in the blade coordinate system were converted to a force coordinate system at rest \((F_x, F_z)\) defined on the ice

\[
\begin{bmatrix}
  F_x \\
  F_z
\end{bmatrix} = 
\begin{bmatrix}
  \cos \theta & \sin \theta \\
  -\sin \theta & \cos \theta
\end{bmatrix}
\begin{bmatrix}
  F_{\text{blade}x} \\
  F_{\text{blade}z}
\end{bmatrix}
\]

(1)

Here \( \theta \) is the blade tilt angle, and the tilt toward the negative direction of the X-axis (left side in Figure 3) in the force coordinate system was defined as the inside tilt and positive. In fact, the blade tilt angle was calculated as an angle of the cross product of vectors, one from the ankle joint center to the rear edge of the skate blade and another from the ankle joint center toward the front edge of the skate blade, with the X-axis of the force coordinate system. Then forces calculated at the two front and rear sensors were summed up and determined as the horizontal and vertical blade reaction forces. In addition, the horizontal and vertical blade reaction forces were numerically differentiated to determine the impulse.

While the horizontal and vertical blade reaction forces calculated in the force coordinate system would show negative values (left side in Figure 3) during the curve phase, we showed it as positive in results and considerations, corresponding to the feeling of the skater and to facilitate comprehension.
2.5. Standardization of data and statistical analysis

Longitudinal data calculated in this study was standardized by the time taken to a stroke, and averaged in the first and second halves of the 4000 m skating period respectively to be averaged patterns. Blade reaction forces and the impulse were standardized by the body weight ('bw' in this study) of each subject.

In order to evaluate the difference between the first and second halves of 4000 m skating in measured results, a paired t-test was conducted. Moreover, the correlation coefficient was calculated to examine the relation of two parameters. The significance level of these values was determined to be below 5 %.

3. Results

Figure 4 shows average values of the horizontal velocity of the center of gravity and the stroke frequency during the curve phase in the first and second halves of 4000 m skating. The horizontal velocity of the center of gravity was significantly greater in the first half of 4000 m skating (11.41±0.65 m/s) than in the second (10.63±0.40 m/s) \( (p<0.01) \), whereas no significant difference in the stroke frequency was observed between the first half of 4000 m skating (1.71±0.18 stroke/s) and the second (1.71±0.16 stroke/s).

Figure 5 shows average values and the standard deviation of the vertical and horizontal components of blade reaction forces in the first and second halves of 4000 m skating. The horizontal components operating at the inner curve are shown as positive here. The vertical components ran up to the body weight level as soon as a stroke started and increased rapidly at around 60 % stroke in both the first and second halves of 4000 m skating. After arriving at the peak at around 80 % stroke, they rapidly decreased until the end of the stroke. The peak value was 1.99±0.48 N/bw at 82 % stroke the first half of 4000 m skating and 1.88±0.41 N/bw at 81 % stroke of the second half. No significant difference was observed between them. The horizontal components slowly increased after a stroke started both in the first and second halves of 4000 m skating, arrived at the peak at around 80 % stroke and then rapidly decreased toward the end of the stroke. The peak value showed a tendency to be greater \( (p=0.093) \) in the first half of 4000 m skating (0.66±0.22 N/bw at 77 % stroke) than in the second half (0.55±0.22 N/bw at 85 % stroke).

The average value of impulse of the vertical and horizontal components of blade reaction forces in the first and second halves of 4000 m skating is shown...
No significant difference in the impulse of the vertical components was observed between the first half (0.81±0.14 Ns/bw) and the second half (0.79±0.16 Ns/bw) of 4000 m skating. In contrast, the values of impulse in respect to the horizontal components were greater in the first half of 4000 m skating (0.28±0.06 Ns/bw) than in the second half (0.24±0.07 Ns/bw) \((p=0.109)\).

The changes in the blade tilt angle are shown as average values and standard deviations in Figure 7. The blade tilt angle was greater in the first half of 4000 m skating (25.8±3.8 deg) than in the second half (23.7±5.1 deg), which means the blade tilted more in the first half. Both in the first and second halves of 4000 m skating, the tilt angle increased gradually from the start of a stroke to around 40 % stroke, and the value was greater in the first half of 4000 m skating. After around 40 % stroke, the value rapidly increased until the stroke finished in both the first and second halves of 4000 m skating.

Figure 8 shows correlation coefficients between the impulse of the horizontal blade reaction forces and the blade tilt angle at every moment of a stroke (each 1 % of a stroke). In addition, data on the first and second halves of 4000 m skating were used collectively to calculate correlation coefficients. A significant positive correlation was observed between the impulse of the horizontal blade reaction forces and the blade tilt angle at the former part of a stroke \((p<0.05~0.01)\).

4. Discussion

4.1. Characteristics of blade reaction forces during the curve phase

Here we examine the characteristics of blade reaction forces during the curve phase in the first half of 4000 m skating, where the horizontal velocity of the center of gravity was greater, compared with the results of previous research on the straight phase.

Values of the vertical components ran up to the body weight level as soon as a stroke started, and increased rapidly at the latter part of the stroke (Figure 5). The peak value reached about double the skater’s body weight at the final part of a stroke (82 % stroke). Yuki et al. (1996) obtain a result that the vertical blade reaction forces ran up sharply until 20 % stroke during the straight phase of high speed skating, then constantly kept below the body weight (approximately 0.8 N/bw) until around 70 %
stroke, and the peak value appeared at 85 % stroke. Skating velocity when the data on the curve phase was obtained was similar to that of the straight phase, being 11.41±0.65 m/s and 11.51±0.84 m/s respectively. This indicates that greater power was always exerted during a stroke in the curve phase than in the straight phase, even at the same skating velocity. Considering this together with the fact that the peak value at the final part of a stroke was greater in the curve phase (1.99±0.48 N/bw) than in the straight phase (1.38±0.14 N/bw), it is assumed that the load on the leg is greater in the curve phase than in the straight phase.

The horizontal components gradually increased after a stroke started and the values were about half the skater’s body weight during the stroke (Figure 5). Comparing this with the result of Yuki et al. (1996), the values of the horizontal components were markedly small until around 40 % stroke in the straight phase, whereas greater horizontal blade reaction forces already operated toward the inside of the curve at the starting moment of a stroke in the curve phase. Therefore, it can be stated that comparatively larger horizontal blade reaction forces characteristically appear even at the former part of a stroke in the curve phase. Moreover, the stroke frequency was greater in the curve phase than in the straight phase, 1.71±0.18 stroke/s in the curve phase while 1.20±0.17 stroke/s in the straight phase. These results are considered to support the report of de Boer et al. (1987b) that the first part of a stroke is shortened in the curve phase, which leads the stroke frequency to become higher compared to the straight phase. As with the stroke frequency which is characteristically high in the curve phase as seen here, it is assumed that the load on the leg is greater. The peak values of the horizontal components in the curve phase and the straight phase were 0.66±0.22 N/bw and 0.81±0.12 N/bw respectively, and the difference is smaller than that of the vertical components mentioned above. Thus, peak values of the horizontal components are supposed to vary little between them.

Since this study utilized the data on the straight phase obtained by Yuki et al. (1996) in comparing with the data on the curve phase, the subjects are not identical. However, all subjects of both studies passed the level A in the badge test (a system to show the degree of skill level by the skating time) accredited by the Japan Skating Federation, and both groups can be regarded to have little difference in technique and skating level. Therefore, it can be assumed that the characteristics described above are not caused by attributes of the subjects but of the curve phase itself.

As explained so far, the curve phase can be regarded to have the characteristics that both the vertical and horizontal components of blade reaction forces are greater at the former part of a stroke and the peak values of the vertical components are markedly greater at the final part of a stroke, compared to the straight phase.

4.2. Relation between blade reaction forces and skating velocity during the curve phase

The horizontal velocity of the center of gravity declined more significantly in the second half of 4000 m skating than in the first half (Figure 4), which is considered to be due to fatigue. Therefore, valuable knowledge on the continuation of skating velocity would be obtained by comparing the data of both the first and second halves of 4000 m skating in this study.

When comparing blade reaction forces in the first half of 4000 m skating with that of the second half, no significant difference was observed in the peak value and impulse of the vertical components. In contrast, the peak value and impulse of the horizontal components were greater in the first half of 4000 m skating than in the second half (Figure 5 and Figure 6). This result suggests that the decrease of blade reaction forces due to fatigue was greater in the horizontal components than in the vertical components. Next the relation between blade reaction forces and skating velocity was examined. No significant correlation was observed in the peak value and impulse (r=0.307, 0.085 respectively) of the vertical components with the horizontal velocity of the center of gravity, while a significant positive correlation was observed in both the horizontal components (r=0.721, 0.677 respectively; p<0.01). Therefore, in order to achieve the higher skating velocity in the curve phase, it seems essential to gain greater horizontal components of blade reaction forces. Given these, the horizontal components of blade reaction forces are considered to have a great influence on skating velocity in the curve. Thus it is assumed to be necessary to maintain the peak value
and impulse of the horizontal components in order to keep constant skating velocity in spite of exhaustion. According to the report on the straight phase by Yuki et al. (1996), a significant positive correlation was observed between either the peak value or the average force and skating velocity (r=0.53, p<0.05; r=0.68, p<0.01, respectively) in respect to the horizontal components of blade reaction forces. This result is similar to the result concerning the curve phase in this study. Yuki et al. (1996) indicate that the changing pattern of horizontal blade reaction forces, whose values run up quickly and whose peak value is small, has the advantage of a smaller load on muscles and on slowdown during a stroke. The changing pattern of horizontal blade reaction forces during the curve phase in this study (Figure 5) shows that the difference between the first and second halves of 4000 m skating starts to increase at 20 % stroke, and the force rises up slowly at the second half of 4000 m skating. Considering these, it seems necessary to achieve a greater impulse by not being slow in raising the force at the former part of a stroke rather than to gain the greater peak value of the horizontal components, in order to keep constant skating velocity even in exhaustion.

In speed skating, a skate blade with a particular curvature performs a curvilinear motion, drawing a circular arc on the ice. Consequently, the horizontal blade reaction forces can be perceived as the sum of the horizontal components of the skater’s push-off force and centripetal force components in a curvilinear motion. Thus it seems important to increase the horizontal components of push-off force in order to gain horizontal blade reaction force. When gaining greater horizontal blade reaction force, the blade tilt angle which determines the direction of force in addition to the compressive force vertically operating on the blade are considered to work as key factors. The blade tilt angle at the former part of a stroke is smaller and the blade is more upright in the second half of 4000 m skating than in the first half (Figure 7). Furthermore, a significant positive correlation was observed between the blade tilt angle and the impulse of the horizontal blade reaction forces at the former part of a stroke (Figure 8). Thus when increasing the impulse of the horizontal blade reaction forces, it is considered to be essential to tilt the blade as much as possible in the former part of a stroke. The fact that the centripetal force decreases responding to the decrease of centrifugal force operating on the skater when skating velocity decreases, can be listed as one of the reasons which causes the blade to become upright at the former part of a stroke in the second half of 4000 m skating. However, the blade tilt angle became large only at the former part of a stroke in the second half of 4000 m skating and no major difference was observed between the first and second halves of 4000 m skating in respect to the latter part of a stroke (Figure 7). Considering this, the fact that the blade is more upright at the former part of a stroke in the second half of 4000 m skating may be influenced more by the change in skating motion due to fatigue rather than to the decrease of skating velocity as mentioned above. The influence of skating motion can not be referred to here on the basis of the data obtained in this study, and remains to be examined in future.

With these considerations, the fact that the blade did not tilt enough at the former part of a stroke is listed as one of the reasons which caused the horizontal blade reaction forces to rise up slowly and the impulse to be small in the second half of 4000 m skating. Relating to the tilt during the curve phase, Yuda et al. (2003) suggest that it is necessary to tilt the leg toward the inside at the start of a left stroke in order to perform the push-off effectively, which our result also supports.

Following these, it becomes clear that the peak value and impulse mainly in the horizontal components of blade reaction forces decline due to fatigue during the curve phase. In addition, it is necessary to restrict the impulse decrease by trying not to slow the rise up of the horizontal blade reaction forces in order to keep constant skating velocity. To that end, the adequate tilt of the left blade at the former part of a left stroke appears effective.

5. Conclusion

The purpose of this study was to measure the horizontal and vertical components of blade reaction forces during the curve phase in long distance speed skating, and to clarify the relation between blade reaction forces and the continuation of skating velocity during the curve phase by examining the characteristics and the change due to fatigue in relation to skating velocity. The results of this study obtained from measuring blade reaction forces on a left stroke during the curve phase are compiled as follows.
1) Compared with the data on the straight phase by a previous study, both the vertical and horizontal components of blade reaction forces were greater at the former part of a stroke, and the peak value of the vertical components at the final part of a stroke was greater in the curve phase.

2) No significant difference was observed in both the peak value and the impulse of the vertical components of blade reaction forces between the first and second halves of 4000 m skating. The peak value and the impulse of the horizontal components were greater in the first half of 4000 m skating. A significant positive correlation was observed between either the peak value or the impulse of the horizontal components and the horizontal velocity of the center of gravity.

3) The horizontal blade reaction forces showed smaller values after around 20% stroke in the second half of 4000 m skating than in the first half.

4) The blade tilt angle at the former part of a stroke was smaller and the blade was more upright in the second half of 4000 m skating than in the first half. In addition, a significant positive correlation was observed between the blade tilt angle and the impulse of blade reaction forces at the former part of a stroke.

In consequence, it becomes clear that the increase of the horizontal blade reaction forces at the former part of a stroke is necessary to achieve higher skating velocity during the curve phase. Furthermore, in order to keep constant skating velocity in a curve, it is necessary to restrict the decline of impulse by trying not to slow the rise up of the horizontal blade reaction forces. For that purpose, it seems to be effective to tilt the left blade adequately at the former part of a left stroke.

Acknowledgment

The data of this study were accumulated with the cooperation of the Japan Skating Federation and the Gunma Prefectural Boards of Education. M-WAVE Co., Ltd. provided agreeably the place of experiment with great understanding of the import of this study. Skating athletes belonging to Tsumagoi High School, Nippon Sport Science University and Hachinohe Plaza Hotel agreeably cooperated with this experiment as subjects. We sincerely express our gratitude to those people.

References


Name: Jun Yuda

Affiliation: Graduate School of Comprehensive Human Sciences, University of Tsukuba (Research Student)

Address: 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8574 Japan

Brief Biographical History:
1995- Master’s Program in Health and Physical Education, University of Tsukuba
1999- Doctoral Program in Health and Sport Sciences, University of Tsukuba

Main Works:
• “A biomechanical investigation of the skating technique in the curve for elite and junior long distance speed skaters.” The Japan Journal of Sport Methodology, 16 (1), 1-11, (2003).

Membership in Learned Societies:
• International Society of Biomechanics
• International Society of Biomechanics in Sports
• Japan Society of Physical Education, Health and Sport Sciences
• Japanese Society of Biomechanics
• The Japan Society of Sport Methodology
• Japan Society of Training Science for Exercise and Sport