THE RELATIONSHIP BETWEEN THE MECHANICAL PARAMETERS IN THE TAKE-OFF OF A VAULT AND THE DROP JUMP ABILITY

Yoshie Motoshima [1], Junichi Kitagawa, Akira Maeda [2]

[1] Graduate School of Physical Education, National Institute of Fitness and Sports in Kanoya, Kanoya, Japan
[2] National Institute of Fitness and Sports in Kanoya, Kanoya, Japan

Original article

Abstract

In the vault in gymnastics, the take-off motion is important to the success of the vault and to perform more difficult vaults. Vaulting ability has been studied by motion analysis, but this method is not effective for easy evaluation. Therefore, the purpose of this study was to investigate the relationship between the mechanical parameters in the take-off of a vault and the drop jump ability, by focusing on the rebound drop jump index (RDJ index) calculated from the two variables of contact time and flight time. Male gymnasts performed the Kasamatsu vault, and their vaulting motion was captured using the 3-dimensional optical motion capture system MAC3D. In addition, they performed a drop jump from a height of 0.4 m without arm swing under two conditions (vault board and non-spring floor), and the RDJ index was calculated. As a result of calculating the regression equation for estimating the vertical impulse of the Kasamatsu vault by using the RDJ index of the drop jump, a significant regression equation was obtained in the RDJ index of the drop jump on the vault board ($y = 0.290x + 5.368$, $p < 0.05$). This result suggests the possibility that the vertical impulse of the take-off on the vault board can be evaluated by measurement under conditions whose characteristics are similar to those of actual vaulting, such as a drop jump on a vault board, in high-level gymnasts.

Keywords: *vault, vertical impulse, drop jump, RDJ index.*

INTRODUCTION

The drop jump is used as one of the methods of evaluating the ability of a stretch-shortening cycle performed in a very short time, producing an estimated rebound drop jump index (RDJ index) (Zushi, Takamatsu, & Kotoh, 1993). RDJ index is an index that indicates the spring characteristics of the lower limbs, and is calculated by dividing the jumping height by the contact time. There are two drop jump techniques: “counter movement drop jump,” which has a long contact time, and “bounce drop jump,” which has a short contact time (Bobbert, Huijing, & van Ingen Schenau, 1987). It is said that gymnasts use the latter technique (Marina, Jemni, Rodríguez, & Jimenez, 2012). When we consider the sports characteristics of the jump ability among different sports, we can use the drop jump as an effective evaluation method. However, as sprint performance is correlated with the drop jump height (Holm, Stalbom, Keogh, & Cronin, 2008; Barr & Nolte, 2011), if we want to target a specific athlete, results consistent with the actual sports performance are required. Therefore, this study focused on the vault, in which jumping motion has a major impact on the performance among the gymnastics events.

In the vault in gymnastics, the take-off motion is important for the success of the vault (Prassas, 1999). Takei, Dunn, & Blucker (2003) compared high-scoring and low-scoring Roche (the handspring with 5/2 tucked forward somersaults) vaults. As a result, they were clarified that high-scoring group obtain larger vertical force in take-off than low-scoring group, and reported the importance of the force obtaining from vault board. Furthermore, it has been reported that the correlation is observed between the judges' score and the variables in the post-flight (Takei, 2007). From these, we thought that the judges' score is related to the mechanical parameters in the take-off.

As the characteristic of take-off motion in the vault, it is mentioned to be SSC exercises performed in a short time of 0.10 to 0.14 seconds (Cheetham, 1983; Dillman, Cheetham, & Smith, 1985; Takei, 1988; Takei, 1991; Bradshaw, Hume, Calton, & Aisbett, 2010; Farana, Uchytil, Jandačka, Zahradník, & Vaverka, 2014), to convert the horizontal velocity to the vertical velocity of the center of mass and product the angular momentum (Brüggemann, 1987; Takei, 1988; Takei, 1991; Takei et al., 2003; Irwin & Kerwin, 2009), and to be performed on an instrument that is highly elastic with springs. To date, vaulting ability, including take-off motion and mechanical parameters, has been investigated by performing motion analysis. From the take-off motion in the vault and the drop jump is similar in a point being SSC exercise performed in a short time, we thought that consideration of the relationship between the mechanical parameters measured by motion analysis and the drop jump ability is useful when performing training and evaluation. Furthermore, Coventry, Sands, & Smith (2006) have investigated about the relationship between the behavior of the vault board and the foot placement on the vault board. Sano, Ikegami, Nunome, Apriantono, & Sakurai (2007) have established the method of measuring the force applied from the vault board to the gymnast during the board contact. Thus, because it is considered that the effective use of the vault board leads to performance in the vault, the research focusing on the vault board has been conducted. Considering the principles of the training (the principle of specificity), when targeting gymnasts, we thought that not only measuring the drop jump on a non-spring surface, as performed in a number of studies, but also measuring the drop jump on a vault board is effective. Therefore, the purpose of this study was to investigate the relationship between the mechanical parameters in the take-off of a vault and the drop jump ability on a take-off surface with two different conditions. This study's hypothesis was that the drop jump on a vault board would be valid to evaluate the mechanical take-off parameters.

METHODS

Subjects

Seven collegiate male gymnasts (age 19.9 ± 1.5 years, height 1.64 ± 0.04 m, body mass 59.4 ± 3.5 kg, competition history 10.9 ± 2.7 years) volunteered to participate in this study. All gymnasts could perform the Kasamatsu vault (Figure 1) or a vaulting technique of a higher degree of difficulty of the sideways handspring vault type. Two gymnasts could perform the Kasamatsu vault (difficulty (D)-score 4.4, FIG, 2013), 2 gymnasts could perform the Kasamatsu vault with half a turn (D-score 4.8, FIG, 2013), 2 gymnasts could perform the Kasamatsu vault with a whole turn (Akopian, D-score 5.2, FIG, 2013), and one gymnast could perform the Kasamatsu vault with one and a half turns (Driggs, D-score 5.6, FIG, 2013).

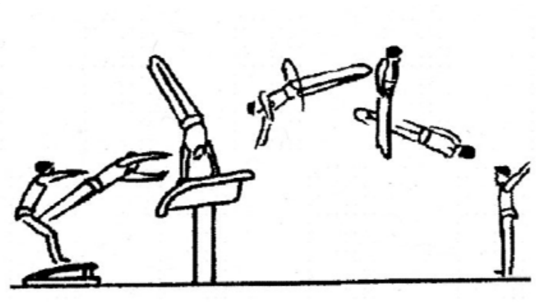

Figure 1. Kasamatsu vault (D-Score 4.4, FIG, 2013).

Before carrying out the experiments, informed consent was obtained from each subject. This study was conducted in accordance with the Declaration of Helsinki and approved by the ethics committee of the National Institute of Fitness and Sports in Kanoya.

Measurement of vaults

Subjects were instructed to perform a Kasamatsu vault twice in experimental condition. A certified judge of the Japan Gymnastics Association scored all vaults' execution (E) score, which evaluated the quality of the vault. All trials were recorded using the 3-dimensional optical motion capture system MAC3D (Motion Analysis, USA; 400 Hz).

A reflective marker with a diameter of 18 mm, which was attached to the body of the subject, was captured by synchronized Raptor-12 cameras, and the 3-dimensional coordinates were measured using Cortex 3.1.1 (Motion Analysis, USA) key software. The reflective markers were attached to the parietal, front head, rear head, acromion (left and right), lateral epicondyle of the humerus (left and right), ulnar styloid process (left and right), third metacarpal bone (left and right), offset, sacrum, lower rib (left and right), anterior superior iliac spine (left and right), greater trochanter (left and right), lateral epicondyle of the femur (left and right), heel bone (left and right), external condyle fibula (left and right), and third metatarsal bone (left and right) (Figure 2). The coordinate system was set to a static coordinate system consisting of the X-axis vector in the horizontal direction with respect to the advancing direction, Y-axis vector in the advancing direction, and Z-axis vector in the vertical direction.

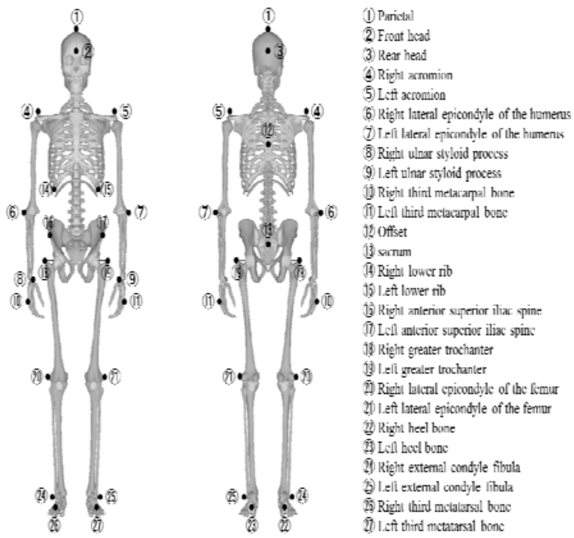

Figure 2. Marker set.

The 3-dimensional coordinate values obtained by MAC3D were smoothed using a fourth-order low-pass Butterworth filter with 8.2 - 19.5 Hz cut-off frequency calculated by residual analysis (Winter, 2009). On the basis of the smoothed three-dimensional coordinates, the body was regarded as a rigid body composed of 15 segments, and the acceleration of the center of mass was calculated using the inertia coefficient of the body segments in Japanese athletes (Ae, Tang, & Yokoi, 1992). The vertical impulse in the take-off phase was calculated from the acceleration of the center of mass (Takei, 1988) and was normalized by dividing by the mass of the subject. When considering the relationship between the vertical impulse and E-score of the Kasamatsu vault, two trials for each subject were used. And when considering the relationship between the vertical impulse of the Kasamatsu vault and the measured value of the drop jump or D-score when gymnasts performed the vault in competition, the vertical impulse was set as the mean value of the two trials for each subject.

Measurement of drop jumps

The subjects performed drop jumps from a height of 0.4 m without arm swing under two conditions (vault board and non-spring floor, Figure 3). In the measurement of drop jumps, a vault board (AJ0700; Senoh, Japan) certified by the International Gymnastics Federation was used and the vault board was the same in the measurement of the vaults. The number of trials was set to 3 times for each condition, and we selected the trial in which the RDJ index was the highest. The instruction given to the subjects was "jump as high and fast as you can." The drop jump on the non-spring floor was performed on a force platform (Kistler, Switzerland; 1000 Hz), and the data were recorded through an A/D converter (Powerlab; ADInstruments, Japan). The drop jump on the vault board was recorded with a high-speed camera (EX-FH25; Casio, Japan; 240 fps). RDJ index (Zushi et al., 1993) was calculated as follows:

$$\text{RDJ index (m/s)} = (1 / 8 \cdot g \cdot t_a^2) / t_c,$$

where 't_c' is take-off time, 't_a' is flight time, and 'g' is acceleration due to gravity.

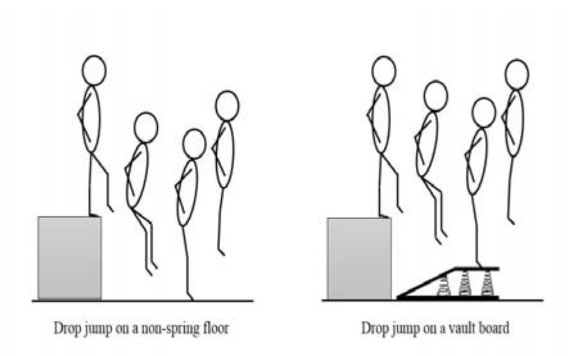

Figure 3. Drop jumps.

Statistical analysis

The relationship between the vertical impulse of the Kasamatsu vault and the D-score (FIG, 2013) of the vault performed in competition was investigated using Spearman's rank correlation coefficient, and the relationship between the vertical impulse and the E-score of the Kasamatsu vault and between the RDJ index of the drop jump in both conditions was investigated using Pearson's product-moment correlation coefficient. To investigate the relationship between the vertical impulse of the Kasamatsu vault and RDJ index of the drop jump, regression analysis was performed for each item, as the dependent variable was the vertical impulse and the independent variable was the RDJ index of the drop jump in each condition. This statistical analysis was performed using SPSS 15.0J for Windows software package (SPSS, Japan) and the significance level was set at $p < 0.05$.

RESULTS

In the Kasamatsu vault, the E-score used to evaluate the quality of the vault was 8.0 points or more (8.6 ± 0.3 points) in all trials. No correlation was observed between the vertical impulse and the E-score of the Kasamatsu vault (Figure 4); on the other hand, a positive correlation was observed between the vertical impulse of the Kasamatsu vault and the D-score of the vault performed in competition ($r = 0.899$, $p < 0.01$; Figure 5).

Figure 6 shows the results of regression analysis to predict the vertical impulse of the Kasamatsu vault from the RDJ index of the drop jump in each condition. A significant regression equation was obtained for the RDJ index of the drop jump on a vault board ($y = 0.290x + 5.368$, $p < 0.05$), and the standard error of the estimate (SEE) by this regression equation was 0.097 Ns/kg. On the other hand, in the RDJ index of the drop jump on the non-spring floor, no significant regression equation was obtained. Furthermore, no correlation observed between the RDJ index of the drop jump in both conditions (Figure 7).

DISCUSSION

Gymnastics performances are scored by the sum of the D-score, indicating the difficulty of the technique, and the E-score, indicating the quality of the performance (FIG, 2013). The D-score is determined for each vault and may be considered to represent the quality of gymnasts' vaults. A positive correlation was observed between the vertical impulse of the Kasamatsu vault and the D-score of the vault that they performed in competition (Figure 5). In the vault, the take-off motion is important to the success of the vault and for practicing more difficult vaults (Prassas, 1999). It has been shown to be one of the most important factors in the take-off motion for obtaining greater force from the vault board (Takei et al., 2003), which is in agreement with our results. From this, it is suggested that it is important to obtain a larger vertical impulse on take-off in order to perform more difficult vaults. On the other hand, a correlation was not observed between the vertical impulse and the E-score of the Kasamatsu vault (Figure 4). Takei (2007) was considered the relationship between the judges' score and some parameters of the post-flight targeting the Roche vault performed during the 2000 Olympic Games. As a result, he has reported the relationship between the judges' score and the normalized horizontal displacement of body center of mass from the knee grasp to peak of post-flight or the horizontal distance of the post-flight. However, a deduction item of E-score in the present study was about the leg separations in the vault contact phase and landing rather than the height or distance in the post flight phase, which is important for performing the rotation and twisting in post flight, this is considered to be influenced the result.

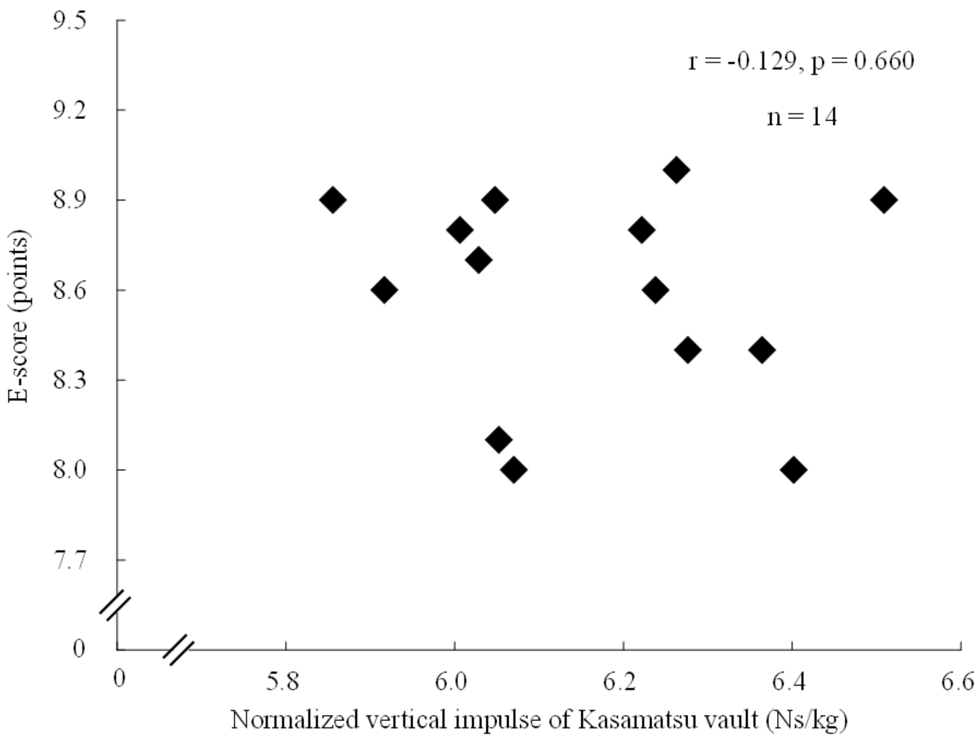

Figure 4. Relationship between vertical impulse and E-score of Kasamatsu vault.

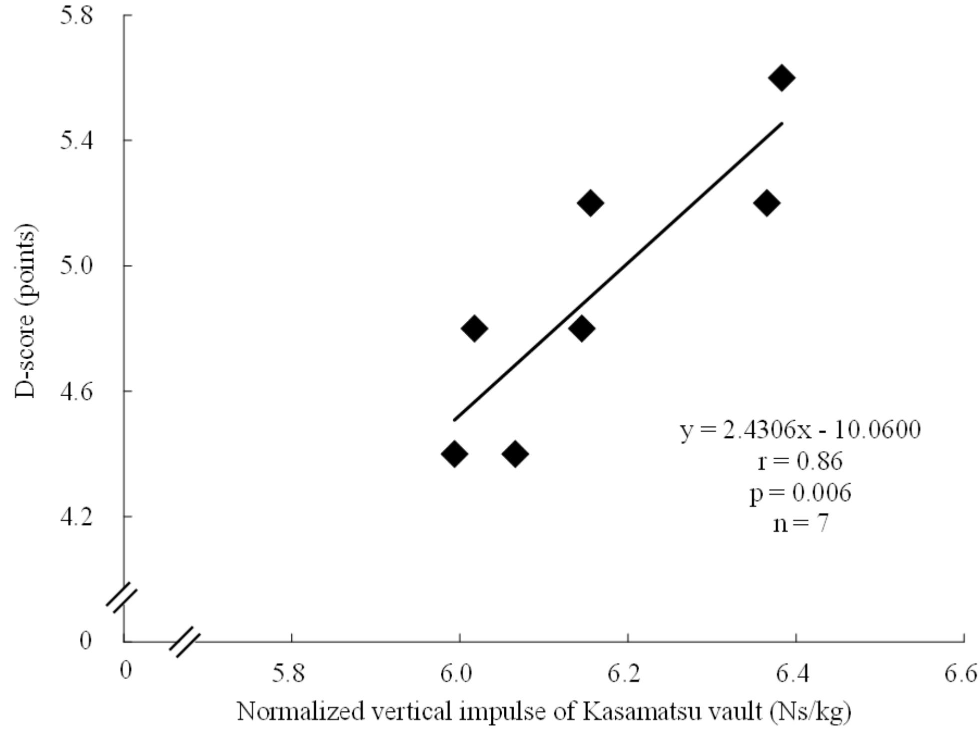

Figure 5. Relationship between vertical impulse of Kasamatsu vault and D-score of vault performed in competition.

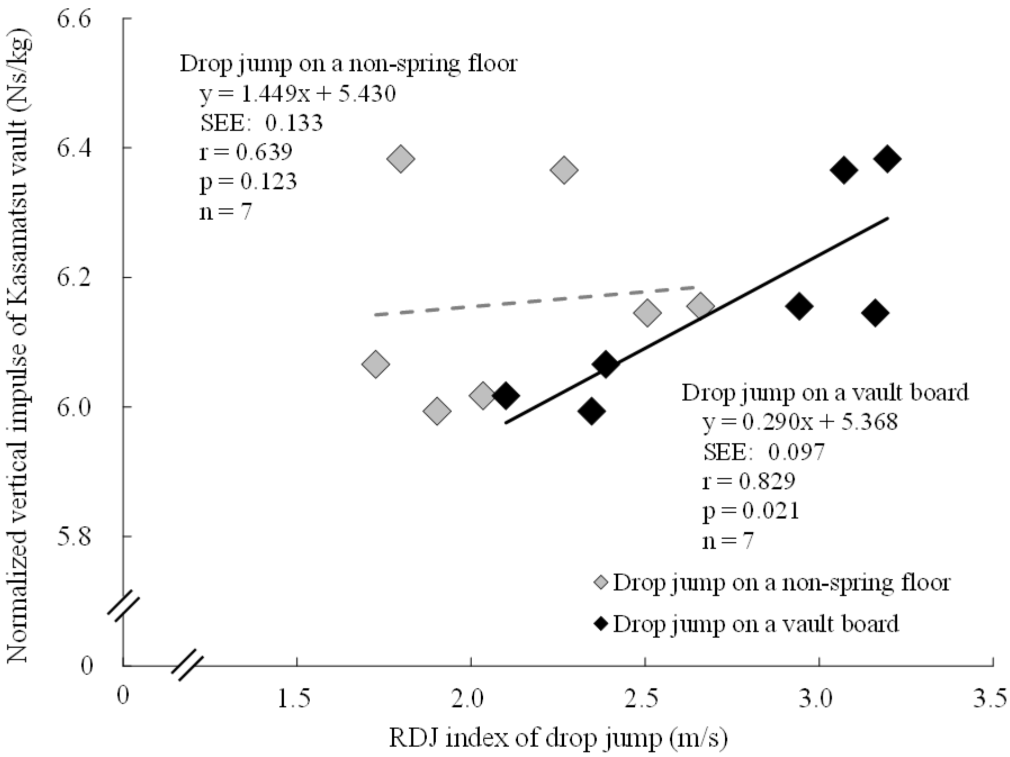

Figure 6. Relationship between RDJ index of drop jump and vertical impulse of Kasamatsu vault.

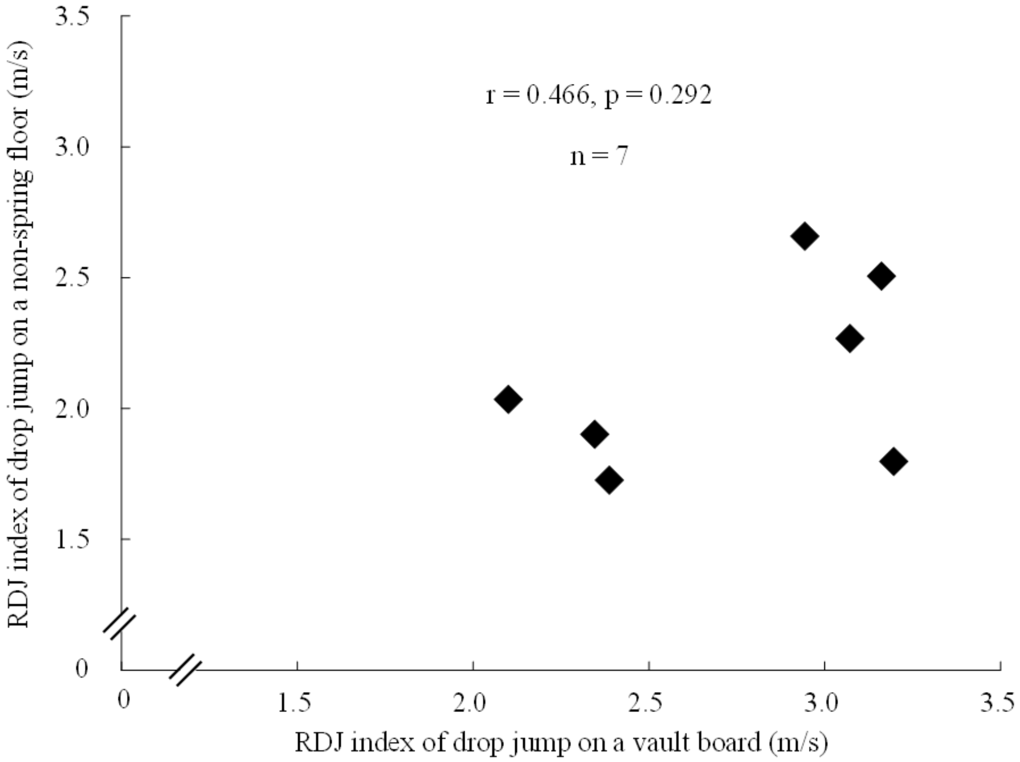

Figure 7. Relationship between RDJ index of drop jump in both conditions.

As a result of examining the relationship between the vertical impulse of the Kasamatsu vault and the drop jump measurement, a significant regression equation was obtained for the RDJ index of the drop jump on a vault board (Figure 6). It has been reported that the function of the neuromuscular system and the biomechanical characteristics of drop jump are affected by the training background (Komi & Bosco, 1978; Kyröläinen & Komi, 1995a; Kyröläinen & Komi, 1995b). In a non-spring surface, in order to increase the jumping performance, it is effective to use the bending and stretching motion of the lower limbs. On the other hand, in an instrument provided with springs, in order to store large elastic energy, it is effective to increase the leg stiffness. In addition, in the vault, it has been reported that gymnasts perform vaults making maximum use of the elasticity of the vault board (Sano, Ikegami, Nunome, & Sakurai, 2011). Gymnasts often perform jumping motion on an instrument provided with springs, and they have mastered the motion required to make use of the spring in the surface effectively. This is considered to be a factor behind the results obtained in the drop jump on a vault board. This study targeted gymnasts who can perform the Kasamatsu vault. In gymnastics, the important factors are not only acquiring height and distance of the second flight phase, but also adding somersaults and twists. In other words, gymnasts need to obtain not only the jumping height but also the angular momentum, and individuals who have high ability at simple jumping may not be able to perform high-difficulty vaults. Therefore, the results obtained in this study indicate that it is necessary to increase the RDJ index in order for high-level gymnasts to perform higher-difficulty vaults. Furthermore, from the regression equation obtained for the drop jump on a vault board (Figure 6), it is considered that increasing the RDJ index for a vault board is likely to lead to the acquisition of more effective take-off motion on a vault board, so it appears necessary to consider the drop jump motion in the future.

As limitations of this study, the results are only from a small number of subjects and trials, and a different measurement method in each condition was used in the drop jump measurement. In terms of this different measurement method, we used a digital video camera because we thought that measurement would be difficult using only a force platform. On the other hand, we used a force platform as a surface with as high stiffness as possible and for convenient measurement. It is considered possible that this difference in the measurement method affected the result. Therefore, we need to consider these points further. However, in the drop jump measurement for a vault board, the use of a digital video camera is reasonable, and it is believed that the result obtained in the vault board condition in this study constitutes an effective index. In the take-off of vault, it is considered that the arm swing has an important role. However, how to use the arm is different by gymnasts. Therefore, because there is a possibility that the arm swing during the take-off of vault does not match the arm swing during the take-off of drop jump, it was performed drop jumps without arm swing in this study, but we need to consider these points again.

CONCLUSIONS

In high-level gymnasts, it was clarified that the mechanical parameters of the take-off from a vault are strongly related to the RDJ index of the drop jump on a vault board. From this, in the evaluation and plyometric training, it is considered that it is effective to be performed on an instrument that is highly elastic with springs under conditions with characteristics similar to those of actual vaulting.

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Corresponding author:

Akira Maeda
National Institute of Fitness and Sports in Kanoya
1 Shiromizu, Kanoya, Kagoshima 891-2393, Japan Telephone and fax number: +81-994-46-4945
E-mail address: amaeda@nifs-k.ac.jp