

Comparison of High & Low Scoring Roche Vaults

The global view and a road to mastery of the vault

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Key words

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INTRODUCTION

At present, the Cuervo vault (handspring with one-half turn and tucked salto backward), Lou Yun vault (handspring and stretched salto forward with one and one-half turns), and Roche vault (handspring and double salto forward tucked) are among the most advanced variations of the handspring category performed in international competitions. In the past, until the 1950's, the handspring was one of the most difficult vaults used in high-level competitions. From the 1950's to the late 1960's, the handspring with full turn (or twist) vault and the handspring and salto forward tucked vault were the most difficult in international competitions (FIG, 1968). Of the above, the Roche vault poses greater challenges and risks to the gymnast than the Cuervo or Lou

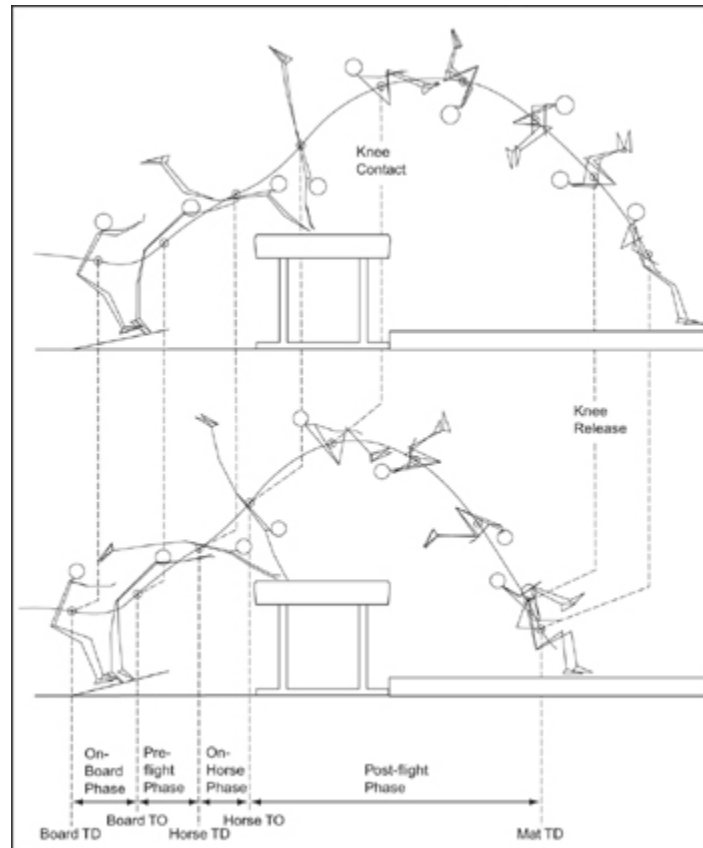


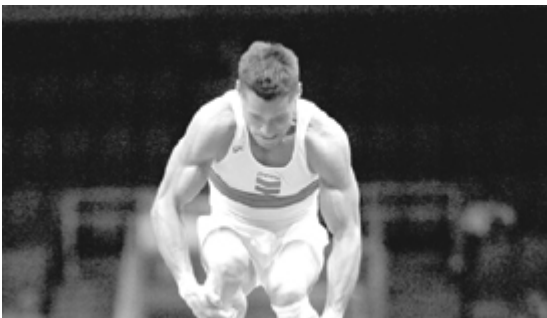
Figure 1 Caption

The five phases of the Roche vault consist of approach (run-up approach followed by a hurdle step onto the take-off board), on-board, pre-flight, on-horse (hand contact on horse in semi-inverted body position, blocking followed by pushing off the horse, to departure from the horse in an inverted position), and post-flight. The vaults shown here illustrate differences in the path of the gymnast's mass center and the body positions at critical instants of the highest scored (upper, 9.800 points) and lowest scored (lower, 9.050 points) Roche vaults from the 2000 Olympic Games.

Yun vault. This is due to the so-called "blind" nature of the landing associated with the vault. Unlike the first two vaults, the Roche does not allow "visual spotting" of the landing area on the mat prior to touchdown. Consequently, the gymnast must control the degree of body rotation "blindly" based on one's own spatial perception or kinesthetic senses, not an easy task when having to complete $2\frac{1}{2}$ forward somersaults in a matter of one second while in flight and simultaneously prepare for landing, as seen in Figure 1.

Due to the heavy emphasis on the aspect of "difficulty" and down-grading of base scores of existing vaults, gymnasts are forced to perform complex vaults, such as the Roche, before mastering the basics to be competitive at the elite level. This approach has made serious joint and spinal injuries more common, often resulting in permanent debilitation as well as expensive lawsuits when gymnasts attempted the Roche and landed in a disastrous manner due to insufficient height or incomplete somersaulting rotation.

A greater understanding of the Roche vault will help coaches develop safer and more effective training strategies. To prepare effectively during the countdown toward the next Olympic Games, the gymnasts must systematically study the techniques used by the world's best gymnasts, identify the elements that make them so successful, and train to attain or exceed their level of performance. One of the ways to achieve this goal is to study the Roche vault by slowing down or stopping the actions and conducting an in-depth analysis through the use of high-speed cinematography. The human eyes are relatively slow in processing images, incapable of resolving motion that occurs in less than $\frac{1}{4}$ second, and estimated to be about 12 frames per second or less when equated to a motion-picture camera. Therefore, it is impossible to "see" the instants of "touchdown onto and take-off from the board and the horse," assess the techniques as they occur in "real-time," and make appropriate judgement and critical decisions for the next trial to achieve success. The high-speed cinematography makes it possible to see the motion "frame by frame," identify joint actions and the muscles involved, and conduct further analysis to determine the mechanical variables that are crucial in achieving successful performance. With special permission given to the authors by the International Olympic Committee, 48 Roche vaults performed during the 2000 Olympic Games were filmed for an in-depth study of the techniques. We wished to identify the differences in techniques which are important in achieving successful performance of the Roche vault. The purpose of the study was to identify the differences in mechanical variables between the 16 highest- and the 16 lowest-scored Roche vaults. Practical application of the results is two fold: (a) to gain insight for improvement of performance and prevention of injuries and (b) to help coaches develop training strategies for effective learning of the Roche vault for the benefit of not only the elite gymnasts but also young gymnasts who aspire to participate in future high-level competitions.



METHODS - *Data Collection*

All 48 Roche vaults performed during the 2000 Olympic Games were filmed using a Locam II DC 16-mm motion picture camera operating at 100 frames per second. A theoretical model, as described by Hay and Reid (1988), was developed to identify mechanical variables that determine the linear and angular motions of the gymnast in

performing the Roche vault, and used to guide the analysis in systematic and logical manner. For each vault analyzed, approximately 85 frames of film were digitized, using a projection head and a digitizer linked on-line to a laboratory microcomputer. The time of contact was defined as the time from the first frame when the gymnast contacted the board or horse to the first frame when he lost contact with the board or horse. The time of flight was defined as the time from the first frame when the gymnast lost contact with the board or horse to the first frame when he contacted the horse or landing mat. The frames depicting the instants of touchdown on and take-off from the board and the horse as well as touchdown on the mat were identified. From these critical instants, the on-board, pre-flight, on-horse, and post-flight phases were defined (Fig.1).

Of the 48 Roche vaults performed by 24 gymnasts from 12 countries during the 2000 Olympic Games, the 16 highest scored vaults (G1) and 16 lowest scored vaults (G2) were selected for comparison. There were four categories of competition with six sessions: Team preliminary (3 sessions on the same day), Team final, Individual all-around final, and Event final. These sessions were held on four different days over a 9-day period during the Games. Analysis of techniques, that is, variability of performance of the Roche, which led to high judges' scores or low scores, regardless of who performed the vault, was the primary focus of this investigation. For this reason, rather than discarding additional trials for the gymnast who performed the Roche in multiple competitions, we considered each performance to be a unique and valuable addition to the data pool. This was based on the fact that the gymnasts who could perform the Roche vault successfully and consistently at the present time are few in number and therefore, achieving necessary number of trials and statistical power are of major concern. The decision was also based on the evidence that gymnasts with multiple trials performed only one Roche vault in one category of competition and the performance of each vault and the judges' score varied widely from competition to competition. For example, a number of gymnasts performed the vault well, showing controlled landing in Team preliminary competition and received high scores, and yet some of them performed rather poorly, showing disastrous landing in subsequent Event finals which took place nine days later.

In G1, five gymnasts had a single trial, four had 2 trials, and one had 3 trials. In G2, twelve gymnasts had a single trial and two had 2 trials. Of these, two gymnasts appeared in both G1 and G2, which indicated large variability of performance from trial to trial, necessitating the inclusion of multiple trials by the same individuals for the analysis. Initially, the means and standard deviations of all the quantifiable variables identified in the deterministic model were computed and subsequently t tests were performed between G1 and G2. A value of $P < .05$ was chosen to indicate statistical significance. It was our belief that setting the alpha at this level would better detect the small but important mechanical differences between the high-and low-scoring Roche vaults that may be useful to coaches and gymnasts. This study was approved by the Institutional Review Board of Northern Illinois University for all procedures.

RESULTS - *On-Board Phase*

The height of body mass center (that is, the point of balance of a body; the point at which the weight of the body may be considered to be concentrated; or the point around which the body rotates freely in space), the horizontal and vertical velocities, the normalized angular momentum (that is, the quantity of the rotational motion or the somersaulting potential of the gymnast adjusted for the difference in physique), and the normalized moment of inertia (that is, the degree of body extension or "stretch" adjusted for the difference in physique) of the gymnast at touchdown on the board were similar between the groups. However, the high-scoring group had greater speed of body mass center at touchdown on the board than the low-scoring group. The high-scoring group, compared to G2, had shorter time of foot contact on the board and greater normalized average braking horizontal force (that is, the backward horizontal force adjusted for the difference in body weight of the gymnast) exerted by the board. The high-scoring group had similar horizontal impulse (that is, horizontal force exerted over time or the product of the average horizontal force

and the time of contact on the board) exerted by the board and similar change in the horizontal velocity and the normalized angular momentum while on the board, and departed from the board with the horizontal velocity, the height of body mass center, and the normalized moment of inertia similar to G2. The high-scoring group had greater normalized average upward vertical force exerted by the board, compared to G2. G1 had similar vertical impulse exerted by the board and greater gain of the vertical velocity while on the board, and departed from the board with greater vertical velocity than G2.

Pre-flight Phase

The high-scoring group had the time, the horizontal and vertical distances traveled by body mass center, the forward somersaulting rotation and average somersaulting speed during the pre-flight comparable to G2. Furthermore, the quantity of rotational motion or the somersaulting potential of the gymnast measured by the normalized angular momentum, and the degree of body extension measured by the normalized average moment of inertia were similar between the two groups. In other words, the mechanical characteristics of the horizontal and vertical motions and the somersaulting motions of the gymnast in the pre-flight phase were nearly identical between the two groups.

On-Horse Phase

The height of body mass center, the horizontal and vertical velocities, the normalized angular momentum, and the normalized moment of inertia of the gymnast at touchdown on the horse were similar between the groups. The high-scoring group had similar time of contact on the horse and similar normalized average backward or "braking" horizontal force exerted by the horse. The low-scoring group, compared to G1, had greater braking horizontal impulse exerted by the horse against the forward motion of the body (in reaction to the forward horizontal impulse the gymnast exerted on the horse). Subsequently, the low-scoring group had greater reduction of the horizontal and resultant velocities while on the horse and departed from the horse with smaller horizontal and resultant velocities than G1. The high-scoring group had similar normalized average upward vertical force and the vertical impulse exerted by the horse (in reaction to the downward vertical force and impulse the gymnast exerted on the horse). As a consequence, the high-scoring group had similar gain in the vertical velocity and similar loss of the normalized angular momentum while on the horse and departed from the horse with the height of body mass center and the normalized angular momentum comparable to G2. However, the high-scoring group had greater normalized moment of inertia and larger vertical velocity at take-off from the horse than G2.

Post-flight Phase

The high-scoring group had greater horizontal distance traveled by body mass center in post-flight than G2. In addition, they had longer horizontal distance measured from the far end of the horse to the heel of the gymnast at touchdown on the mat (that is, the "official distance of post-flight" that the judges seek in awarding a bonus point) than G2. The high-scoring group had greater maximum height of body mass center of post-flight than G2. However, the time of post-flight was similar between the groups. In regard to the angular motion, the forward somersaulting rotation, the average somersaulting angular speed, the quantity of rotational motion or the somersaulting potential, and the degree of body extension of the gymnast in post-flight were all similar between the groups. In other words, the "overall" mechanical characteristics of the forward somersaulting motions of the gymnast in post-flight were nearly identical between the two groups. However, the high-scoring group had larger "relative height of take-off of post-flight" (that is, the height of body mass center at take-off from the horse relative to its height at touchdown on the mat) or smaller downward vertical displacement of body mass center from the horse take-off to mat touchdown than G2. Consequently, the high-scoring group landed on the mat with higher body mass center, more fully extended body position (as reflected in greater normalized moment of inertia), and smaller downward vertical velocity than G2.

DISCUSSION On-Board Performance

In the handspring and salto forward tucked vault performed at the 1988 Olympic Games (Takei, 1991a), the high-scoring group had greater horizontal velocity at touchdown on the board than the low-scoring group. In the present study, however, both the high- and the low-scoring Roche vaults had similar "large" horizontal velocities of the hurdle step onto the board, as stated earlier. This meant that both groups sprinted the approach just as vigorously, departed from the floor into the hurdle step with similar large kinetic energy, and contacted the board with comparable large horizontal velocity. In the handspring and salto forward tucked vault performed at the 1988 Olympic Games (Takei, 1991a), and the handspring with full turn vault performed at the 1992 Olympic Games (Takei et al., 1996), the high-scoring group had greater horizontal velocity (but not vertical velocity) at take-off from the board than the low-scoring group. In the handspring and salto forward tucked vault (Takei, 1991a), the time of contact on the board, the average horizontal and vertical forces and the horizontal and vertical impulses exerted while on the board, and the changes in the horizontal and the vertical velocities on the board were similar between the groups. However, the high-scoring group had greater horizontal velocity at take-off from the board than the low-scoring group. In the present study, the high-scoring group had shorter time of contact (G1 had 0.01s or 9.1% shorter time than G2) on the board, greater normalized average backward horizontal force (0.31 or 12.1% greater) and greater upward vertical force (0.65 or 11.8% greater) exerted by the board (in reaction to the forward horizontal force and the downward vertical force the gymnast exerted on the board), greater increase in the vertical velocity while on the board (0.30 m/s or 6.2% greater), and greater vertical velocity at take-off from the board (0.14 m/s or 3.2% greater) than G2.

These results clearly indicate that the gymnasts performing the high-scoring Roche vaults were more skillful than G2 in converting the large horizontal motion of the hurdle step to large vertical motion of the body while on the board without incurring much loss of the horizontal velocity. This was made possible by the application of large horizontal and vertical forces over a brief duration of time while on the board. Due to the fact that both groups contacted the board with similar horizontal and vertical velocities, conversion of the body motion (from horizontal to the vertical while on the board) was achieved by: initially "blocking" the forward motion of the body and compressing the board through forceful isometric (or static) contraction of the hip, knee, and ankle extensor muscles, followed immediately by the application of vigorous and rapid concentric (or shortening) contraction of the same extensor muscles at these joints timed synchronously with the repulsion of the take-off board for maximum results (that is, large gain of the vertical velocity with a small loss of the horizontal velocity). During this brief period on the take-off board, 1) the gluteus maximus, semimembranosus, semitendinosus, and long head of the biceps femoris at the hip, 2) the vastus medialis, vastus intermedius, vastus lateralis, and rectus femoris at the knee, and 3) the soleus, gastrocnemius, plantaris, tibialis posterior, peroneus longus and brevis, flexor hallucis longus, and flexor digitorum longus at the ankle (which are the extensor muscles of the lower extremity) are recruited and "fired" rapidly in synchronous manner to provide large summation of forces necessary to achieve quick conversion of the body motion from horizontal to vertical.

It should be pointed out that the "soft" take-off board provides greater compression/repulsion range or the greater vertical displacement of its take-off surface and longer time of contact than the "stiff" board and, thereby, providing "trampoline effect" to enable the application of large vertical impulse and large change of vertical velocity while on the board and subsequent large vertical velocity at take-off. However, the large compression/repulsion range and long time of foot contact, simultaneously, cause greater loss of horizontal velocity, greater forward body tilting toward the horse, and greater gain of the forward somersaulting angular momentum than the stiff board during the foot contact. This results in small horizontal velocity and large quantity of rotational motion or somersaulting potential of the gymnast at take-off from the board and possibly "excessive" forward body rotation in pre-flight. Therefore, it is important to choose the take-off board of appropriate stiffness (based on the body weight and the strength of the aforementioned extensor muscles of the lower extremity of the gymnast) to ensure successful on-board performance and depart from the board with optimum combination of the horizontal and vertical velocities and the somersaulting angular momentum to effect successful pre-flight.

Pre-flight Performance

In the handspring and salto forward tucked vault performed at the 1988 Olympic Games (Takei, 1991a), both the high-and the low-scoring groups had similar horizontal and vertical distances traveled by body mass center, normalized angular momentum, forward body rotation, and time of pre-flight. As for the handspring with full turn vault performed at the 1992 Olympic Games, both groups had similar horizontal distance traveled by body mass center in pre-flight. However, the high-scoring group had greater normalized angular momentum, shorter duration of time, smaller vertical distance traveled by body mass center, and smaller forward body rotation in pre-flight than the low-scoring group (Takei et al., 1996). In the present study, however, the linear and angular motions of the gymnasts in pre-flight were nearly identical between the groups, as evidenced by similar duration of time, horizontal and vertical distances traveled by body mass center, forward body rotation, average somersaulting angular speed, quantity of rotational motion or somersaulting potential, and degree of body extension of the gymnast in pre-flight. These results indicate that the pre-flight techniques differ greatly depending upon whether the post-flight requires additional 1½ salto forward, full turn, or 2½ salto forward as in the Roche. In the handspring and full turn vault, short duration of time, small vertical distance traveled by body mass center, and small body rotation of pre-flight are important in achieving success. On the other hand, no particular pre-flight mechanical variables are associated with high judges' score nor crucial in achieving overall success of the vault when the post-flight consists of multiple forward somersaults, as in the handspring and salto forward tucked or the Roche. These differences in pre-flight techniques among the three vaults may be, in part, due to the difference in the blocking/pushing off technique required to achieve necessary changes in the horizontal and vertical velocities and the angular momentum while on the horse, and subsequently to depart from the horse with appropriate body position to ensure successful post-flight performance. In achieving the optimum combination of the velocities, the angular momentum, and the body position at take-off from the horse (to enable the required number of somersaults and/or turns in post-flight), the gymnast must contact the horse with the body angle, velocities, and angular momentum most desirable to bring about the necessary changes in these variables while on the horse. This, in turn, dictates the characteristics of the linear and angular motions of the pre-flight that the gymnast must strive to achieve.

On-Horse Performance

In the handspring and full turn vault (Takei et al., 1996), the high-scoring group had greater horizontal velocity and lower body angle at touchdown on the horse, greater backward horizontal impulse exerted by the horse and greater reduction of the horizontal velocity while on the horse, and similar horizontal velocity and greater vertical velocity at take-off from the horse than the low-scoring group. In the handspring and salto forward tucked vault (Takei, 1991b), the high-scoring group had greater horizontal velocity and similar body angle at touchdown on the horse, greater upward vertical impulse exerted by the horse and greater increase in the vertical velocity while on the horse, and similar horizontal velocity and greater vertical velocity at take-off from the horse than the low-scoring group. In the present study, the high-scoring group had similar large horizontal and vertical velocities at touchdown on the horse, smaller backward horizontal impulse exerted by the horse (20 Ns or 17.2% smaller) and smaller reduction of the horizontal velocity while on the horse (0.26 m/s or 14.1% smaller), and greater horizontal velocity at take-off from the horse (0.28 m/s or 8.2% greater) than G2. The high-scoring group had similar upward vertical force and vertical impulse exerted by the horse, similar increase in the vertical velocity while on the horse, and greater vertical velocity at take-off from the horse (0.16 m/s or 4.3% greater) than G2. Based on the above, it is evident that effective conversion of large horizontal motion of the body at horse touchdown to large vertical motion at take-off is crucial in achieving success, regardless of the type of vault performed. Furthermore, the extent of this conversion is greatly influenced by the performance requirements of post-flight, that is, whether the post-flight consists of additional 1½ salto forward tucked, ½ salto forward stretched with full turn, or 2½ salto forward tucked as in the Roche.

In the present study, both groups had similar body angles at touchdown on the horse (30E

and 28E above horizontal for G1 and G2, respectively) and take-off from the horse (81E and 78E above the horizontal for G1 and G2, respectively). This caused the body mass center to remain "behind and above" the point of hand contact (wrist) throughout the course of blocking and pushing off the horse (Figure 2). A large backward horizontal reaction force exerted on the gymnast by the horse causes reduction of the horizontal velocity while on the horse and decreases the horizontal distance traveled by body mass center in post-flight. This is counterproductive to the goal of fulfilling the post-flight distance requirement. The backward horizontal reaction force simultaneously tends to increase the angular momentum (that is, the forward somersaulting potential of the gymnast) while on the horse. On the other hand, large upward vertical reaction force exerted on the gymnast causes large increase in the vertical velocity on the horse. This enables the gymnast to depart from the horse with greater vertical velocity than before at touchdown on the horse. The large vertical velocity at horse take-off, in turn, brings about great height and long duration of post-flight. However, this upward vertical reaction force simultaneously tends to decrease the angular momentum or the forward somersaulting potential of the gymnast while on the horse (Figure 2).

For the present sample, the effect of this upward reaction force was far greater than that of the backward reaction force exerted by the horse on the gymnast. Consequently, all gymnasts increased the vertical velocity and decreased the forward somersaulting potential of the body while on the horse. Furthermore, it should be pointed out that a large increase of the vertical velocity while on the horse is almost always accompanied by large reduction of both the horizontal velocity and the forward somersaulting potential of the gymnast (Takei 1992; Takei, et al., 1996). Therefore, maximizing the vertical velocity at horse take-off brings about a high "trajectory" of body mass center and aids the gymnast in fulfilling the post-flight height requirement and possibly earn a bonus point. However, this same strategy tends to decrease the horizontal velocity and the forward somersaulting potential of the gymnast and therefore, (a) reducing the horizontal distance of post-flight and possibly increasing the

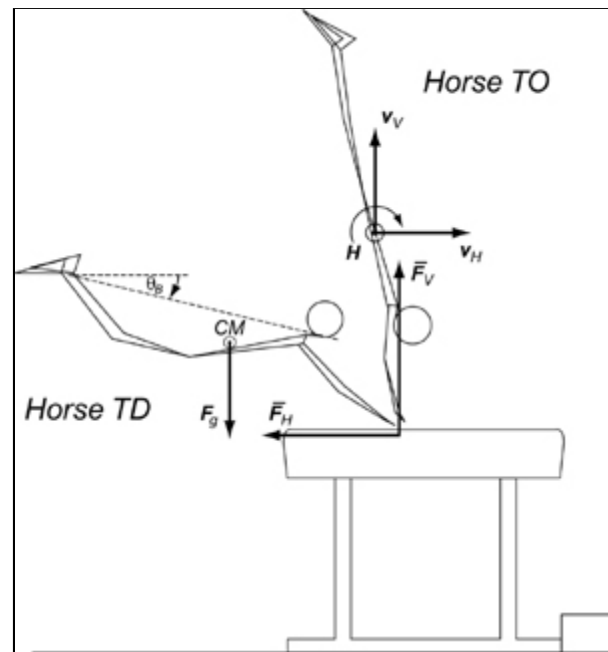


Figure 2 Caption

Forces acting on the gymnast while on horse and velocities and the forward somersaulting potential of the body (forward somersaulting angular momentum) at touchdown (TD) and take-off (TO) from the horse. Because the body's center of mass (CM) remains behind and above the point of hand contact (wrist) throughout the course of blocking and pushing off the horse, upward vertical reaction force (F_V) exerted by the horse tends to increase the gymnast's vertical velocity (v_V) and simultaneously decrease the forward somersaulting angular momentum (H) while on the horse. Similarly, backward horizontal reaction force (F_H) tends to decrease horizontal velocity (v_H) and simultaneously increase forward somersaulting angular momentum while on the horse. Body angle (θ_b) at touchdown was determined by (a) the horizontal reference line extending forward through the lateral malleolus of the gymnast and (b) the line connecting the lateral malleolus and the base of mid neck. It was measured from the horizontal reference. F_g = Force of gravity acting through body mass center (that is, body weight)

chance of failing to meet the post-flight distance requirement and, more importantly, (b) increasing the danger of stalling the forward somersaulting rotation in midair and landing in disastrous manner when performing the handspring and salto forward category vaults including the Roche.

Post-flight Performance

In regard to the linear motion, the high-scoring group, in performing the handspring and salto forward tucked (Takei, 1991a; Takei, 1991b) and the handspring with full turn (Takei et al., 1996) vaults, had greater maximum height, longer horizontal distance, and longer time of post-flight than the low-scoring group. However, in the present study, the high-scoring group had greater maximum height (0.07 m or 2.3% greater), longer horizontal distance (0.30 m or 8.7% longer), and greater "official distance" (0.29 m or 11.6% greater) of post-flight than G2 and yet the time of post-flight was similar between the groups. Furthermore, they had smaller fall or vertical distance traveled by body mass center from the horse take-off to mat touchdown (0.12 m or 9.3% smaller) and landed with higher body mass center (0.14 m or 14.1% higher), more fully extended body position (0.90, or 23.7% greater), and smaller falling vertical velocity (0.11 m/s or 1.8% smaller) than G2. In the handspring and salto forward tucked (Takei, 1991a; Takei, 1991b) and the handspring with full turn (Takei et al., 1996) vaults, the high-scoring group had smaller average angular speed of somersaulting rotation in post-flight, compared to the low-scoring group. This was due to a combination of similar somersaulting rotation and longer time of post-flight for the high-scoring group. In other words, the high-scoring group rotated more slowly than the low-scoring group, as they had more time in the air to complete similar degree of somersaulting rotation. In the present study, however, the angular motion of the gymnasts were nearly identical between the two groups, as evidenced by similar forward somersaulting rotation, similar average somersaulting speed, similar forward somersaulting angular momentum of the body, and comparable "overall" degree of body extension in post-flight.

Finally, if all else is equal, the greater the maximum height of post-flight, the longer the time, the larger the horizontal distance, and the greater the angular distance of the post-flight. This aids the gymnast execute the required somersaults high in mid-air and simultaneously prepare for a controlled "stick" landing that the judges seek in awarding a bonus point. In this regard, the greater maximum height of post-flight in the high-scoring group and yet similar time of post-flight between the groups seemed "odd" with the above mechanical relationship. However, this may be due to the lower body mass center at touchdown on the mat found earlier in the low-scoring group. In fact, some gymnasts in the low-scoring group reached down with the hands and placed them beside the buttocks on the mat as they landed in a deep, squat position to help protect the knee and ankle joints from excessive flexion. This suggests that the low-scoring group had difficulty completing the majority of the required somersaults (approximately 2 somersaults out of the 2½ required) above the height of the horse. Consequently, it is plausible that they had no choice but to hold onto the knees and remain tucked longer until the body was much closer to the landing mat than the high-scoring group to "squeeze in" the remaining ½ somersault and enable "feet-first" landing. Nonetheless, further study is needed to learn more about the aspect of "body control." Follow-up study initially defining the post-flight into sub-phases (based on the critical instants observed on the film such as knee grasp, peak of flight, and knee release), and subsequently quantifying the mechanical variables that determine the linear and angular motions of the body in each sub-phase may reveal useful information on body control for successful performance of the 2½ forward somersaults and landing.

CONCLUSIONS

Based on the results, it was concluded that successful performance of the Roche vault is most likely

when focus is on achieving the following:

- Sprinting the approach to acquire large horizontal motion (i.e., horizontal velocity) of body mass center at touchdown on the board, as true in most vaults.
- Converting the large horizontal motion of the approach to large vertical motion of pre-flight by blocking and pushing off the take-off board rapidly and vigorously downward, achieving a large increase of vertical velocity while on the board, and departing from it with large vertical velocity.
- Reaching forward toward the far end of the horse with the arms and hands immediately after the take-off from the board, thus ensuring near-maximum flexion of the humerus at the shoulder joint and contacting the horse with semi-inverted body position for the blocking on the horse to follow.
- Exerting large downward vertical force and small forward horizontal force by completing the flexion of the humerus (until the arm is fully aligned with the trunk in a straight line) and elevation of the scapula "rapidly and forcefully" from an inverted body position to achieve large gain of vertical velocity and small loss of horizontal velocity while on the horse.
- Departing from the horse with large horizontal and vertical velocities to achieve great maximum height, large horizontal distance, and long time of post-flight (to execute the required 2½ somersaults and simultaneously prepare for a controlled landing), and contacting the mat with high body mass center.

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