A Comparative Case Study of Roche Vaults Performed by Elite Male Gymnasts

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Introduction

The Roche is a vault in which the gymnast performs a handspring followed by two forward somersaults. The gymnast faces great challenge and risk when performing this vault due to the so-called "blind" nature of the landing. Visual spotting of the landing is not possible due to the combination of rapid body rotation and the gymnast's view of the mat being obstructed by the knees. Therefore the degree of body rotation must be controlled "blindly," based on the gymnast's spatial perception and kinesthetic awareness.

Kinematic analyses have been conducted to compare the techniques between high and low scoring vaults, identify mechanical variables that result in a successful vault, and investigate relationships of pre- and post-flight mechanical variables. Takei et al. (2003) compared the 16 highest scored Roche vaults at the 2000 Olympic Games with those receiving the 16 lowest scores. The high scoring group displayed **(a)** shorter time of board support, greater normalized average upward change in the vertical velocity while on the board, and greater vertical velocity at board take-off, **(b)** comparable linear and angular motions in pre-flight, **(c)** smaller backward horizontal impulse exerted by the table, smaller loss of horizontal velocity while on the table, and greater horizontal and vertical velocities at table take-off, **(d)** greater height and larger horizontal distance of post flight, **(e)** higher body mass center at knee release prior to landing, and **(f)** higher mass center at mat touchdown.

The research described here was conducted as a comparative case study with the purpose of comparing mechanical variables that identify differences in techniques of a higher scoring (9.5) and lower scoring (8.9) Roche vault performed by 2 elite male gymnasts. It is important to highlight that this comparison is based solely on the gymnast's performance on these particular vaults and may not be representative of the gymnast's overall ability. The purpose of this study was to determine if kinematics (i.e., video and computer analyses) could serve to help coaches identify performance characteristics crucial to this type of vault in two individual athletes. A secondary purpose was to apply Takei's model of performance to specific athletes. Based on Takei's deterministic model, the following hypotheses were developed:

The gymnast with the high scoring vault (G1) when compared to the gymnast with the low scoring vault (G2) would display;

1. Greater horizontal and vertical velocity at board and table take-off
2. Smaller loss of horizontal velocity while on the board and table
3. Greater height, more flight time, and larger horizontal distance of post flight
4. Higher center of mass at mat touchdown

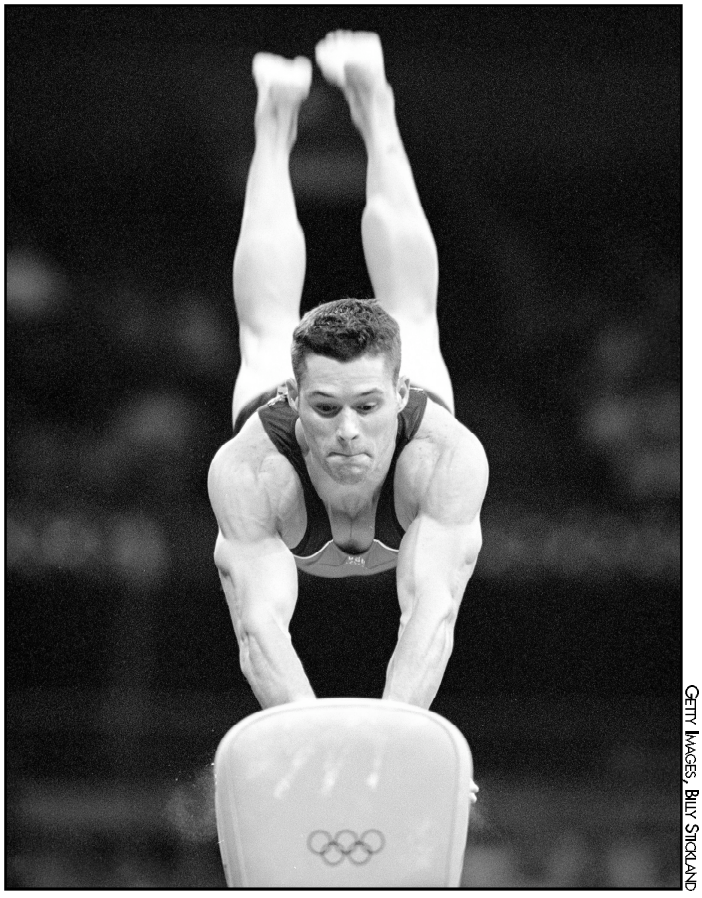
Methods

Data Collection

Two Roche vaults were performed on conventional vault apparatus during the USA Men's Gymnastics Team training camp at the Olympic Training Center in Colorado Springs. These vaults were filmed using two Panasonic digital cameras positioned in line with the table, perpendicular to the direction of the runway. The cameras were positioned so as to capture a specific aspect of the vault; camera one captured the on-table and post-flight phases, while camera two captured the hurdle step, on-board, pre-flight and on-table phases. Using the Peak Motus motion analysis system a (60Hz) two-dimensional coordinate system for each vault was developed, the vaults were digitized and the two views combined into one trial.

The touch down (TD) was defined as the first frame in which the gymnast made contact with the runway, board or table and take off (TO) was defined as the first frame when he lost contact with the particular apparatus. The hurdle step was defined as the last step of the run up prior to board contact. The on-board and on-table phases were defined from TD to TO. The pre-flight and post-flight phases were defined as the time between board TO and table TD and the table TO to landing TD respectively.

Analyses of techniques, which led to the high or low judge's scores, were the focus of this investigation. The vertical and horizontal displacements of the center of mass, linear velocities, flight times, joint angles, speed of rotation, angle of projection and angle of center of mass through the toe/finger with respect to the left horizontal were analyzed for each trial. For more detailed information regarding the research methods contact the author.



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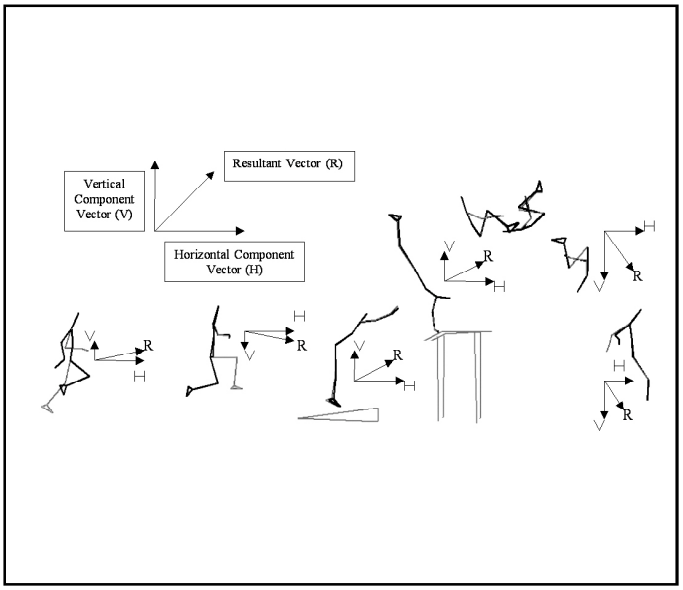

Figure 1. The net velocity of the gymnast at any particular point is the resultant of horizontal and vertical component velocities; this is displayed by resultant vectors. At any one moment the gymnast is producing both horizontal and vertical components movement. The component vectors in the diagram indicate both the magnitude of speed and the direction (horizontal or vertical) of movement. When broken down, the horizontal and vertical components help us in identifying specific movement characteristics in horizontal and vertical directions. These analyses help us determine movement qualities that can then be used to compare superior performances with less superior performances.

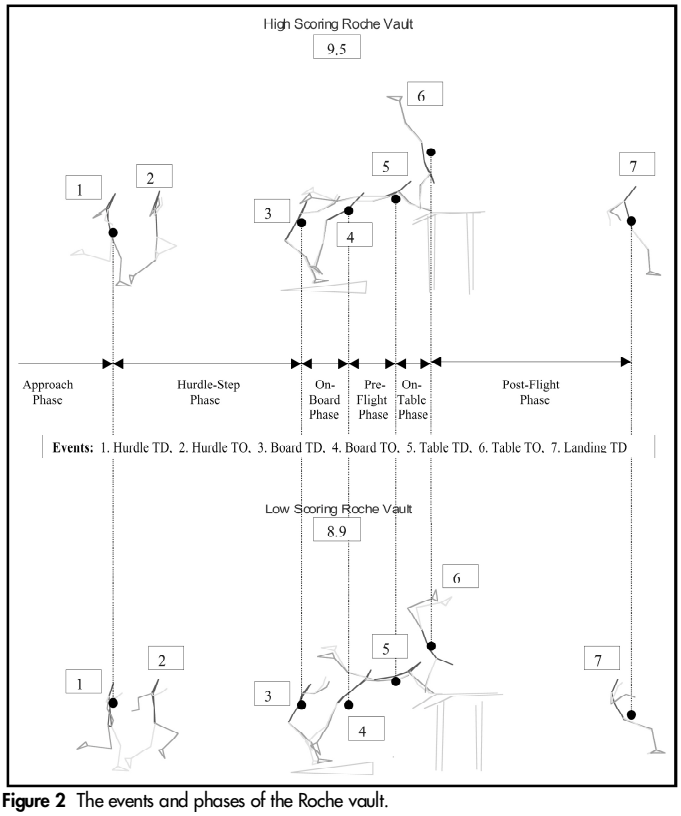

Figure 2 The events and phases of the Roche vault.

Results

When compared to the gymnast who performed the low scoring vault (G2), the gymnast who performed the high scoring vault (G1) displayed:

1. Hurdle-Step Phase
   a. Greater resultant velocity (greater horizontal, lower vertical)
   b. Greater vertical and horizontal displacement
   c. Less time during the hurdle-step phase;
2. On-Board Phase
   a. Greater resultant velocity (greater horizontal, lower vertical)
   b. Smaller decrease in horizontal velocity while on the board
   c. Lower vertical displacement
   d. Less time on the board
   e. Greater knee angle, hip angle and trunk angle (i.e. less bend)
   f. A smaller angle of COM through the toe with respect to the left horizontal (i.e., G1 is leaning closer to the ground)
3. Pre-Flight Phase
   a. Less time in the air
4. On-Table Phase
   a. Greater resultant velocity at TD (greater horizontal, higher vertical)
   b. Lower resultant velocity at TO (lower horizontal, lower vertical)
   c. Greater decrease in horizontal velocity while on the table
   d. Higher vertical displacement at TD
   e. Lower vertical displacement at TO
   f. Longer time on the table
   g. A greater knee angle
   h. A smaller angle of COM through the finger with respect to the left horizontal
5. Post-Flight Phase
   a. Less resultant velocity (lower horizontal, greater vertical)
   b. Greater vertical and horizontal displacement
   c. Longer time in the air
   d. A greater change in knee angle

As hypothesized, G1 displayed a greater horizontal and vertical velocity at board and table take-off, smaller loss of horizontal velocity while on the board, greater height of post flight, more post flight time in air, larger horizontal distance of post flight, and a higher center of mass at mat touchdown. However, G1 displayed a larger decrease in horizontal velocity while on the table. This variable does not support this investigation's hypothesis, is an undesirable value according to Takei's deterministic model and is an area of improvement for G1 on this particular vault. Be that as it may, the variables G1 displays are vital to the successful execution of the Roche vault and are predominant enough to permit some aspects of the performance to be relatively poor.

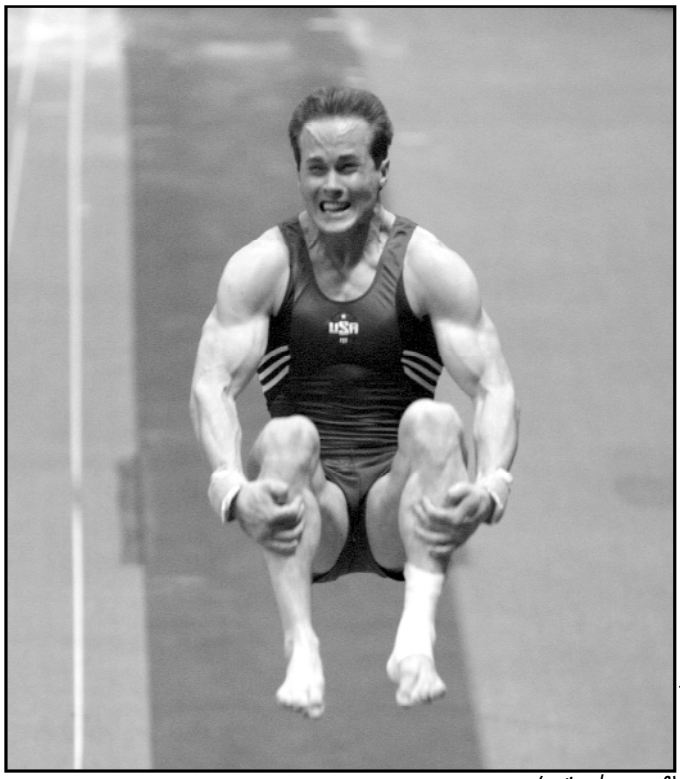

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Table 1 Comparisons of displacements, temporal phases and angle variables in the high scoring and low scoring Roche vaults.

Variables	G1	G2	Difference btw G1 and G2 (with respect to G1	High Scoring Vaults from the 2000 Olympic Games (Takei et al 2003)
				n = 16 M +/- SD
Temporal Phases (COM) (s)				
Hurdle Step	0.25	0.27	-7%	
On Board	0.10	0.12	-17%	0.10 +/- 0.01
Pre-flight	0.10	0.12	-17%	0.15 +/- 0.03
On Table	0.20	0.17	17%	0.15 +/- 0.02
Post-flight	1.00	0.98	2%	1.02 +/- 0.02
Horizontal Displacement (COM) (m)				
Hurdle Step	0.68	0.65	4%	
Pre-flight	0.49	0.54	-11%	0.79 +/- 0.16
Post-flight	3.04	2.83	7%	3.75 +/- 0.16
Vertical Displacement (COM) (m above floor)				
Hurdle TD	1.06	0.99	7%	
Hurdle TO	1.11	1.04	6%	
Board TD	1.04	1.05	-1%	1.03 +/- 0.03
Board TO	1.23	1.33	-8%	1.23 +/- 0.05
Table TD	1.61	1.68	-4%	1.79 +/- 0.08
Table TO	2.32	2.28	2%	2.30 +/- 0.05
Post-Flight Peak	3.08	2.99	3%	3.05 +/- 0.05
Landing TD	1.16	1.10	5%	1.13 +/- 0.05
Angle of Projection (COM) (degrees)				
Board	35.7	37.1	-4%	50.55
Table	52.0	52.9	-2%	40.74
Angle of COM Through 5th Toe (Board)/Finger (Horse) with respect to the Left Horizontal (degrees)				
Board				
Foot TD	60.9	65.4	-7%	
Foot TO	105.2	119.6	-14%	
Table				
Hand TD	16.4	20.3	-24%	30.0
Hand TO	90.8	91.0	-0%	81.0

(continued on page 8)

Discussion

The results of the comparison indicated G1 scored higher due to his greater height of post flight, more post flight time in the air, larger horizontal distance of post flight, as well as the gymnast's higher center of mass at mat touchdown. This is supported by the study's original hypotheses and additionally by Takei et al. (2003), (a) acquiring a large horizontal velocity of the body CM at touchdown on the board by high speed sprinting as well as (b) departing from the table with large horizontal and vertical velocities to achieve great height, large horizontal distance, and long air time of post flight, must be achieved to perform a Roche vault successfully.

After a closer investigation of the variables, the possible reasons for these main differences can be found during the approach, hurdle step and on-board phases. G2 exhibits a greater negative vertical velocity than G1 at board TD. This is a combined result of G2's peak vertical displacement being 3 cm higher during the hurdle step and his body position at board TD (approximately 11o more knee flexion, 3o more hip flexion and 2o more trunk flexion). G2 must accept a greater downward force due to his greater descent distance, which must be arrested and overcome in order to take off from the board. It is hypothesized that G2 may have been fatigued, made a performance error or lacked the leg strength to arrest this downward force while maintaining his horizontal velocity. Consequently, G2 spends more time on the board and loses more horizontal velocity during the on-board phase which is reflected in the subsequent performance data. This on board loss is accentuated by G2's lower horizontal velocity during the hurdle step and at board TD. In comparison with Takei et al. (2003), the high scoring gymnasts display a greater horizontal velocity at board TD and therefore it is speculated that these gymnasts can afford to lose more horizontal velocity while on the board. The resulting lower horizontal velocities during the on-board and on-table phases have a significant impact on G2's performance. Therefore, in order to improve his score on this particular vault, G2 should focus on generating a greater horizontal velocity during the approach phase, using greater leg strength and power to convert the larger negative vertical velocity at board contact into a larger positive vertical velocity during the on board phase, and maintaining a large horizontal velocity throughout the on-board phase.

In addition, both G1 and G2 depart from the table with lower horizontal velocities then gymnasts in Takei et al. (2003), this is an area of improvement for both G1 and G2 on this particular vault.

Coaches often use comparisons among two or more athletes to discern the distinguishing characteristics of winning/better and losing/worse performances. By comparing athletes known to the coaches with information available from more in-depth and broader analyses of many athletes, the sport scientist can assist the coach in emphasizing obvious aspects of performance comparisons and more subtle or perhaps unknown aspects of the performances.

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Table 2 Comparisons of velocities of COM in the high scoring and low scoring Roche vaults.

Variables	G1	G2	Difference btw G1 and G2 (with respect to G1	High Scoring Vaults from the 2000 Olympic Games (Takei et al 2003)
				n = 16 M +/- SD
Resultant Velocity				
Hurdle TD	8.09	7.80	4%	
Hurdle TO	8.22	7.88	4%	
	0.13	0.08	43%	
Board TD	7.25	7.19	1%	8.15 +/- 0.18
Board TO	6.61	6.60	0%	
	-0.64	-0.59	8%	
Table TD	5.27	4.91	7%	
Table TO	4.75	5.03	-6%	5.33 +/- 0.11
	-0.53	0.11	122%	-0.77 +/- 0.16
Landing	5.82	5.83	0%	
Horizontal Velocity				
Hurdle TD	8.09	7.80	4%	
Hurdle TO	8.18	7.83	4%	
	0.09	0.04	56%	
Board TD	7.24	7.18	1%	8.12 +/- 0.19
Board TO	5.36	5.26	2%	5.26 +/- 0.25
	-1.88	-1.92	-2%	-2.86 +/- 0.24
Table TD	4.46	4.04	9%	
Table TO	2.92	3.11	-7%	3.86 +/- 0.18
	-1.54	-0.93	40%	-1.58 +/- 0.25
Landing	2.59	2.98	-15%	
Vertical Velocity				
Hurdle TD	0.04	0.31	-651%	
Hurdle TO	0.84	0.82	2%	
	0.80	0.51	36%	
Board TD	-0.09	-0.19	-101%	-0.63 +/- 0.29
Board TO	3.86	3.98	-3%	4.53 +/- 0.15
	3.95	4.17	-6%	5.15 +/- 0.33
Table TD	2.82	2.79	1%	3.07 +/- 0.31
Table TO	3.74	4.12	-10%	3.85 +/- 0.17
	0.93	1.33	-43%	0.77 +/- 0.38
Landing	-5.22	-5.01	4%	-6.13 +/- 0.09

- The change between the two events named above (i.e., the change in velocity from board TD to board TO)