KJSB

Korean Journal of Sport Biomechanics 2018; 28(2): 69-78
http://dx.doi.org/10.5103/KJSB.2018.28.2.69
http://e-kjsb.org eISSN 2093-9752

ORIGINAL

Feasibility of a New Vault Technique through Kinematic Analysis of Yeo 2 and YANG Hak Seon Vaults

Joo-Ho Song[1], Jong-Hoon Park[2], Jin-Sun Kim[3]

[1]Korea Institute of Sport Science, Seoul, South Korea
[2]Division of Tourism & Sports Leisure, Catholic Kwandong University, Gangwon-do, South Korea
[3]Department of Physical Education, Yonsei University, Seoul, South Korea

Received : 30 January 2018
Revised : 30 April 2018
Accepted : 30 April 2018

Corresponding Author
Jin-Sun Kim
Department of Physical Education, Yonsei University, 50 Yonsei-ro, Seodaemun-gu, Seoul 03722, South Korea
Tel : +82-10-9115-8986
Fax : +82-2-2123-8375
Email : jinsun@yonsei.ac.kr

Objective: The purpose of this study was to investigate the feasibility of a new vault technique through a kinematic comparison of the YANG Hak Seon and Yeo 2 vaults.

Method: The photographic images of the YANG Hak Seon and Yeo 2 vaults were collected using a high-speed camera, and their kinematic characteristics were analyzed using three-dimensional image analysis.

Results: During the post-flight phase of the Yeo 2 and YANG Hak Seon vaults, the time of flight, height of flight, and flight distance were similar. At the peak of the post-flight phase, the trunk rotation angle of the YANG Hak Seon vault rotated 457° more than did the Yeo 2 vault. During the post-flight descending period, the twist velocity of the trunk was much faster with the YANG Hak Seon vault (1,278°/s) than with the Yeo 2 vault (1,016°/s).

Conclusion: To succeed in the new technique, the average twist velocity during post-flight must be maintained at 1,058°/s and the twist velocity must be increased from the ascending phase.

Keywords: YANG Hak Seon vault, Yeo 2 vault, Twist velocity, Flight height

INTRODUCTION

The vault comprises four stages, namely jumping, approach run, somersault, and landing, and it is an event that requires jumping ability, accuracy of somersault, and landing stability (Yoon, Yeo & Kim, 2001). As the vault requires the athlete to perform exact techniques within a short period, it has drawn the interest of researchers for a long time. In particular, ever since the implementation of the motion analysis project that focused on the Division of Sports Medicine of the International Olympic Committee (IOC) following the LA Olympics in 1984, studies on technical analysis have been actively pursued (Yeo, 2003).

By implementing a systematic training program with integration of sports science, the South Korean men's gymnastics team has shown noticeable improvement in their technical skill level, and as a result, Yang Hak Seon became the first South Korean to win a gymnastics gold medal in the 2012 London Olympics by executing his signature move, the Yang Hak Seon vault, which involves a forward handspring and forward straight salto with a 1,080° twist (Park & Kim, 2014). This technique adds an additional 180° twist to the 900° twisting turn in the post-flight stage of the Yeo 2 vault, which allowed Yeo Hong Chul to win a silver medal during the 1996 Atlanta Olympics. As a result, it was recognized at the time as the most difficult technique with the highest difficulty score (D-score) of 7.4 points (Park & Song, 2012).

However, after the London Olympics, the Federation Internationale de Gymnastique (FIG) revised the scoring system in 2013 to create equity in scoring with other events. Consequently, the D-score for the Yang Hak Seon vault performed by Yang Hak Seon was lowered from 7.4 to 6.4 points, while that of the Lopez vault was lowered from 7.0 to 6.0 points (Park & Song, 2015). Moreover, both the Ri Se Gwang and Ri Se Gwang 2 vaults performed by Ri Se Gwang of North Korea, who is a competitor of Yang Hak Seon in vault, were given a D-score of 6.4, which is 0.4 points higher than the Yang Hak Seon vault (Song & Park, 2016). As a result, an upgraded technique with a higher D-score than the Yang Hak Seon vault is needed.

The vault performed by Yang Hak Seon has the same in-flight rotation in the post-flight stage after take-off, except for the handspring forward, forward straight salto, and twist motions. Therefore, the most ideal approach to developing a new technique with a high D-score is to increase the twisting turn in the in-flight rotation (Park & Song, 2015). Accordingly, 180° was added to the twisting turn during the in-flight move of the Lopez vault to develop the so-called Yang Hak Seon 2 vault (forward handspring and forward straight salto with a triple twist), and it was successfully performed during the 2014 Korea Cup. However, because this tournament was not a FIG-sanctioned event, the technique was not registered as an official technique. Subsequently, the Yang Hak Seon 2 vault was given a D-score of 6.4 points in the Nanjing World

Copyright © 2018 Korean Journal of Sport Biomechanics
This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (http://creativecommons.org/licenses/by-nc/3.0/) which permits unrestricted noncommercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

Championship, but the vault could not be successfully executed owing to injuries and poor conditions; thus, the development of a new technique with high probability of execution is needed.

The Yang Hak Seon vault involves forward landing where the landing is executed in the direction of the motion while facing away from the horse. When executing a forward landing, contact is made with the mat while the body is in lying position. Therefore, the center of mass (CoM) is leaning toward the back, compromising stability, which increases the risk of sitting down during the landing. On the other hand, when executing a backward landing, the athlete descends while staring at the mat. As a result, visual stability increases, which makes it easier to control the body and for the ankles to absorb shock (Park & Song, 2012). Therefore, if the in-flight technique is executed with an additional 180° rotation added to the Yang Hak Seon vault, the probability of successfully executing the technique can be increased through stable landing by backward landing.

Therefore, to successfully execute the new technique (so-called Yang Hak Seon 3) with an additional 180° twisting rotation added to the Yang Hak Seon vault, the study aimed to identify the technical kinematic elements needed to execute the new technique by analyzing the motions in the Yang Hak Seon vault (1,080° twist) and Yeo 2 vault (900°) that share similar motions except for the degree of twisting rotation.

METHODS

1. Participant

The participant in the present study was YHS, a gymnast with 17 years' experience and a gold medalist in the vault event in the 2012 London Olympics. His physical characteristics were as follows: height, 159.9 cm; weight, 52.3 kg; and age, 27 years.

2. Procedure

Image data from the Yeo 2 vault performed during competition in July 2017 and the Yang Hak Seon vault performed during the national team competition in April 2010 (T1: right foot one step forward), national team competition in July 2017 (T2: left foot one step backward), and competition in September 2017 (T3: left foot one step forward) were collected. Image analysis was performed on the collected data based on the type of landing. The methods for collection and analysis of the Yang Hak Seon and Yeo 2 vault image data were based on the same settings used in the study by Song, Kim & Park (2016). For image acquisition, 5 high-speed cameras (NEX-FS700, SONY, Tokyo, Japan) were set up as shown in Figure 1, as follows: 15 m to the left and right sides relative to the front of the horse, runway, and board, and the other for panning. To create a global coordinate system, 1- × 1- × 2-m and 1- × 1- × 4-m control points, two of each (Visol, Seoul, Korea), were set up. To capture images of landing motion, 1- × 1- × 4-m control points located on the right of the horse were moved to 1.5 m left of the control points located on the left side of the horse. After capturing the images, the points were removed. The shooting speed of the cameras was set to 120 Hz, while the shutter speed was set to 1/500 sec.

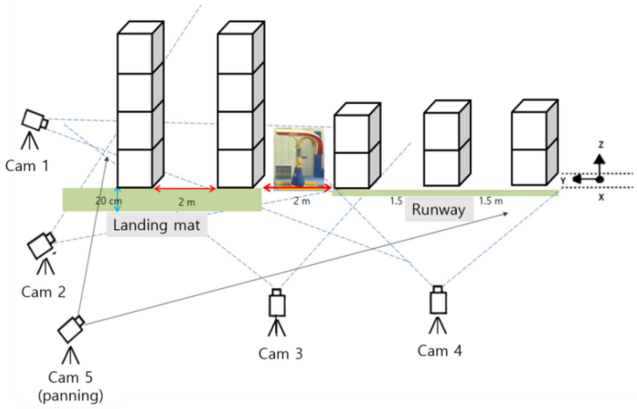

Figure 1. Layout of cameras and control point installation (Song et al., 2016)

3. Data processing

For image data processing, KWON3D version 3.1 (Visol, Seoul, Korea) was used. Data processing involved calculating the actual spatial coordinates by using the control points and deriving the three-dimensional (3-D) coordinates of the body. Here, the left/right direction was defined as the X axis; the forward/backward direction (the direction of motion), as the Y axis; and the up/down direction, as the Z axis. The human body model was defined by the rigid body system connecting 16 body segments based on 21 joint points. The 2-D coordinates obtained from each camera were synchronized using cubic spline interpolation, while the direct linear transformation method developed by Abdel-Aziz and Karara (1971) was used to calculate the 3-D coordinates. Moreover, smoothing was performed using a Butterworth second-order low-pass filter to eliminate errors caused by noise generated by various causes, including digitizing. The cutoff frequency was set to 10 Hz.

1) Events and phases

The events and phases were established as shown in Figure 2, based on the previous studies by Song et al. (2016), Song, Lee, Song, Park and Ha (2011), and Song, Moon, Kim, Kwon and Park (2014).

Events

- Board touchdown (BTD): the point when the feet touch down on the board
- Board takeoff (BTO): the point of takeoff from the board
- Horse touchdown (HTD): the point when the hands touch down on the horse
- Horse takeoff (HTO): the point of takeoff from the horse
- Peak: the highest point the CoM reaches during the in-flight move in the post-flight stage
- Landing (LD): the point when the feet touch down on the mat

Phases

- Board contact (BC): board contact phase, when the feet touch the board

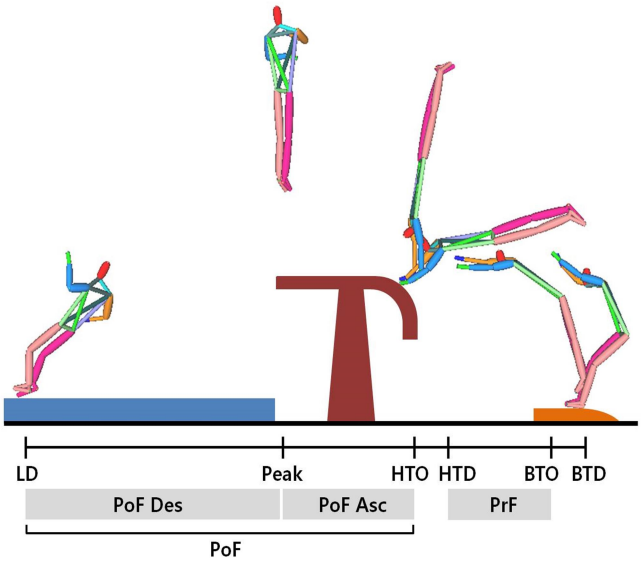

Figure 2. Events and phases of the Yeo 2 and YANG Hak Seon techniques (Song, 2017)

- Pre-flight (PrF): pre-flight phase, from the moment of takeoff from the board to the moment the left hand touches the horse
- Horse contact (HC): horse contact phase, when both hands touch the horse
- Post-flight (PoF): post-flight phase, from the moment the right hand takes off from the horse to the moment the feet touch down on the mat
- Post-flight ascending period (PoF Asc): phase within the post-flight phase, from the moment the right hand takes off from the horse to the moment the CoM reaches the peak
- Post-flight descending period (PoF Des): phase within the post-flight phase, from the moment the CoM reaches the peak to the moment the feet touch down on the mat

2) Variables

On the basis of the previous studies by Song and Park (2016); Park and Song (2015); Takei, Blucker, Hudert, Myers, and Fortney (1996); Takei (2007); and Lee, Park, and Lee (2006), the present study analyzed the phase time, displacement, and velocity of CoM according to phase, changes in the angles of body segments, and changes according to body rotation (Figure 3), and changes in angular velocity.

- Hip joint angle: relative angle between the thigh and the trunk (1)
- Knee joint angle: relative angle between the thigh and the lower leg (2)
- Shoulder joint angle: relative angle between the upper arm and the trunk (3)
- Board touchdown and take-off angles: angle projected on the YZ plane, which represents the vector angle directed from the midpoint of the CoM of two feet relative to the *Y* axis to the CoM (4)
- Horse touchdown and take-off angles: vector angle directed from the midpoint of the CoM of the hands relative to the horizontal axis to the CoM (5)
- Thigh rotation angle: angle of the thigh projected on the YZ plane, the absolute angle formed with the *Y* axis (6)
- Trunk rotation angle: angle of the trunk projected on the YZ plane, the absolute angle formed with the *Y* axis (7)
- Trunk twist angle: angle of the trunk projected on the XY plane, the absolute angle formed with the *X* axis

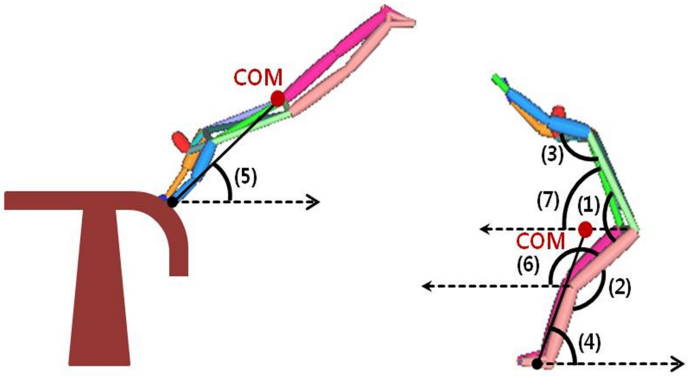

Figure 3. Definition of angles (Song, 2017)

RESULTS

1. Phase time

In the phase times shown in Table 1, the Yeo 2 and Yang Hak Seon techniques showed the same results in the BC, HC, and PoF phases, and similar results in the PrF, PoF Asc, and PoF Des phases and total vaulting time with differences of only 0.01~0.02 sec.

In the Yang Hak Seon technique, T1 showed the shortest time in the BC phase, while both T1 and T2 showed a similarly short time in the HC phase. Meanwhile, the vaulting time and PoF Asc and PoF Des times were longest in T1.

2. Displacement

Table 2 shows the horizontal and vertical displacements of the CoM. With respect to the horizontal displacement of the CoM, the Yeo 2 technique contacted the horse at a position 0.1 m farther and further moved 0.2 m at peak and LD as compared with the Yang Hak Seon technique. However, the horizontal displacement in the PoF phase was similar between the two techniques, with a difference of only 0.1 m.

In the Yang Hak Seon technique, the highest horizontal displacement at peak and LD was found at T1 and T2, while the highest horizontal displacement at PoF Des was found in T1. With respect to the vertical displacement, the Yeo 2 and Yang Hak Seon techniques showed the same post-flight height, while the vertical position at LD was 0.1 m lower in the Yeo 2 technique.

In the Yang Hak Seon technique, T2 showed the highest vertical position at HTO, while T1 showed the highest post-flight height.

Table 1. Phase time (unit: sec)

		BC	PrF	HC	PoF	PoF Asc	PoF Des	Vaulting time
Yeo 2		0.10	0.13	0.13	1.05	0.40	0.65	1.41
Yang Hak Seon	T1	0.09	0.11	0.13	1.08	0.43	0.65	1.41
	T2	0.10	0.11	0.13	1.05	0.42	0.63	1.39
	T3	0.10	0.10	0.17	1.03	0.38	0.65	1.40
	Mean (SD)	0.10 (0.01)	0.11 (0.01)	0.14 (0.02)	1.05 (0.03)	0.41 (0.03)	0.64 (0.01)	1.40 (0.01)

Table 2. Horizontal and vertical displacements of the center of mass (unit: m)

		Horizontal								Vertical							
								Displacement								Displacement	
		BTD	BTO	HTD	HTO	Peak	LD	PrF	PoF	BTD	BTO	HTD	HTO	Peak	LD	PoF Asc	PoF Des
Yeo 2		0.0	0.6	1.3	1.9	3.2	5.2	0.7	3.4	0.9	1.1	1.7	2.2	3.0	0.9	0.8	2.1
Yang Hak Seon	T1	0.0	0.6	1.2	1.7	3.1	5.1	0.6	3.4	0.9	1.1	1.6	2.1	3.1	1.1	1.0	1.9
	T2	0.0	0.6	1.2	1.8	3.1	5.1	0.6	3.3	0.9	1.1	1.6	2.2	3.0	0.9	0.8	2.1
	T3	0.0	0.6	1.2	1.8	2.9	4.9	0.6	3.1	0.9	1.1	1.5	2.1	3.0	1.1	0.9	1.9
	Mean (SD)	0.0 (0.0)	0.6 (0.0)	1.2 (0.0)	1.8 (0.1)	3.0 (0.1)	5.0 (0.1)	0.6 (0.0)	3.3 (0.2)	0.9 (0.0)	1.1 (0.0)	1.6 (0.1)	2.1 (0.1)	3.0 (0.1)	1.0 (0.1)	0.9 (0.1)	2.0 (0.1)

Table 3. Horizontal and vertical velocities of the center of mass (unit: m/s)

		Horizontal							Vertical				
		BC			HC			Po Mean					
		BTD	BTO	ΔV	HTD	HTO	ΔV		BTD	BTO	HTD	HTO	LD
Yeo 2		7.6	5.5	-2.1	4.9	3.1	-1.8	3.2	-0.3	4.3	3.3	4.0	-5.1
Yang Hak Seon	T1	7.9	5.4	-2.5	5.1	3.1	-2.0	3.2	-0.2	4.0	3.7	4.1	-5.3
	T2	7.6	5.1	-2.5	4.9	3.0	-1.9	3.1	-0.3	4.1	3.6	3.6	-5.3
	T3	7.5	5.4	-2.1	5.1	2.6	-2.5	3.0	-0.4	3.9	3.5	3.8	-5.8
	Mean (SD)	7.7 (0.2)	5.3 (0.2)	-2.4 (0.2)	5.0 (0.1)	2.9 (0.3)	-2.1 (0.3)	3.1 (0.1)	-0.3 (0.1)	4.0 (0.1)	3.6 (0.1)	3.8 (0.3)	-5.5 (0.3)

3. Velocity

Table 3 shows the horizontal and vertical velocities of the CoM. With respect to the horizontal velocity of the CoM, the Yang Hak Seon technique, as compared with the Yeo 2 technique, showed that the amount of change in horizontal velocity of the CoM was higher by 0.3 m/s at BTD and HC. At BC and HC, the Yang Hak Seon technique showed faster velocity by 0.1 m/s, while the Yeo 2 technique showed faster velocity by 0.2 m/s at BTO and HTO.

In Yang Hak Seon, T1 showed the fastest horizontal velocity in approaching the board, while the fastest horizontal velocity at BTO and HC was found at T1 and T3. The amount of change in horizontal velocity while touching down on the board was large at T1 and T2, while the amount of change while touching down on the horse was largest at T3.

With respect to the vertical velocity of CoM, the vertical velocities of Yeo 2 in BTO and HTO were faster by 0.3 and 0.2 m/s, respectively, than those of the Yang Hak Seon technique. Meanwhile, the Yang Hak Seon technique showed results faster by 0.3 and 0.2 m/s at HC and LD, respectively.

In the Yang Hak Seon technique, T2 showed the fastest velocity at BTD, while T1 showed the fastest velocity at HTD and HTO. At LD, T3 showed

Table 4. Change in hip, knee, and shoulder joint angles (unit: degrees)

				BTD	BTO	HTD	HTO	Peak	LD
Hip	Yeo 2			90.9	129.8	180.1	159.5	175.4	119.2
	Yang Hak Seon	T1		105.3	135.8	181.5	194.9	177.7	182.1
		T2		105.9	141.8	182.9	175.0	179.6	166.7
		T3		116.2	152.9	196.4	196.5	199.3	195.9
		Mean (SD)		109.1 (6.1)	143.5 (8.7)	186.9 (8.2)	188.8 (12.0)	185.5 (12.0)	181.6 (14.6)
Knee	Yeo 2			134.6	162.8	166.3	165.0	167.7	157.1
	Yang Hak Seon	T1		150.7	170.3	170.4	171.5	170.5	147.5
		T2		146.5	169.7	162.8	172.0	174.1	118.6
		T3		144.8	164.3	173.2	176.3	169.8	138.7
		Mean (SD)		147.3 (3.0)	168.1 (3.3)	168.8 (5.4)	173.3 (2.6)	171.5 (2.3)	134.9 (14.8)
Shoulder	Yeo 2		L	132.8	134.9	130.8	161.7	38.5	94.9
			R	124.5	134.5	139.4	153.6	75.6	90.8
	Yang Hak Seon	T1	L	126.3	132.2	127.0	152.0	25.1	120.7
			R	120.9	130.8	128.6	157.0	61.2	62.1
		T2	L	132.8	137.5	136.9	154.7	34.3	73.5
			R	113.0	141.6	137.0	157.7	65.3	47.2
		T3	L	119.0	113.2	101.6	133.5	29.3	105.5
			R	109.6	127.3	110.5	133.8	66.8	49.9
		Mean (SD)	L	126.0 (6.9)	127.6 (12.8)	121.8 (18.2)	146.7 (11.5)	29.6 (4.6)	99.9 (24.1)
			R	114.5 (5.8)	133.2 (7.5)	125.4 (13.5)	149.5 (13.6)	64.4 (2.9)	53.1 (7.9)

the fastest vertical velocity.

4. Angles

Table 4 and Figures 4 and 5 show the changes in hip, knee, and shoulder joint angles.

When performing the Yang Hak Seon technique, hip joint hyperextension angles of 6.9°, 8.8°, and 5.5° were found at HTD, HTO, and peak. In the Yeo 2 technique, a hip joint extension angle of 180.1° was found at HTD and flexion angles of 20.5° and 4.6° were found at HTO and peak, respectively.

In the Yang Hak Seon technique, T1 and T2 showed hyperextension of 1.5° and 2.9° at HTD, respectively, while T3 showed greater hyperextension of 16.5°. At HTO, T1 and T3 showed hyperextension of 14.9° and 16.5°, respectively, whereas T2 showed flexion of 5°. At peak, T3 showed hyperextension of 19.3°, whereas T1 and T2 showed angles close to 180°.

The knee joint showed similar angles between the two techniques at HTD. However, the knee extension angles were >8.3° and 3.8° at HTO

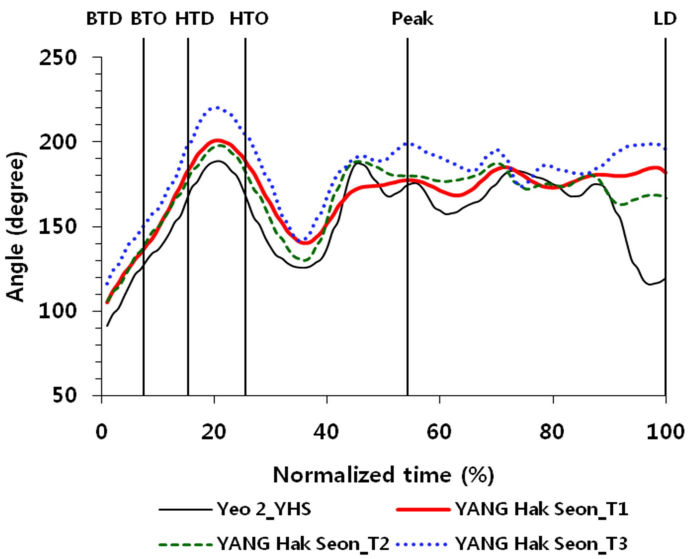

Figure 4. Change in hip joint angle

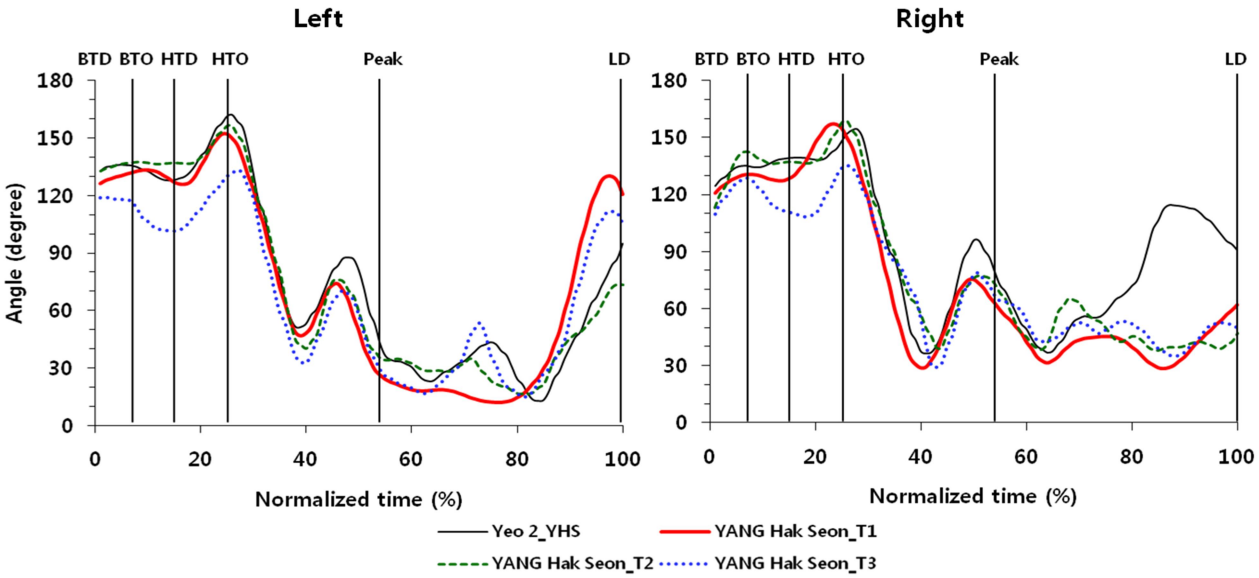

Figure 5. Change in left and right shoulder joint angles

Table 5. Touchdown and take-off angles of the board and horse landing angles (unit: degrees)

		BC		HC		LD
		BTD	BTO	HTD	HTO	
Yeo 2		65.4	113.3	32.6	90.0	77.4
Yang Hak Seon	T1	61.6	99.1	22.0	70.2	53.7
	T2	64.1	111.7	27.5	86.4	47.0
	T3	64.6	107.2	22.6	88.4	62.0
	Mean (SD)	63.4 (1.6)	106.0 (6.4)	24.0 (3.0)	81.7 (10.0)	54.2 (7.5)

and peak, respectively, when performing the Yang Hak Seon technique.

In the Yang Hak Seon technique, T3 showed the biggest knee joint angle at HTD, while T2 showed the biggest knee joint angle at peak. T1 maintained a similar angle from BTO to peak.

With respect to the shoulder joint, the joint angle in both shoulders was bigger in the Yeo 2 technique. In the Yang Hak Seon technique, the left and right shoulder joints showed flexion closer to the trunk by 8.9° and 11.2° at peak, respectively, while the left shoulder showed greater extension by 5° at LD. In the Yang Hak Seon technique, the differences in joint angles of both shoulders at HTD and HTO were similar with 3.6° and 2.8°, respectively, whereas the Yeo 2 technique showed a relatively greater differences of 8.6° and 8.1°, respectively.

In the Yang Hak Seon technique, T2 showed the biggest shoulder joint angles at HTD and HTO, while T1 showed the smallest angle at peak. At LD, the left shoulder at T1 showed the widest extension. At HTD, the differences in both shoulder joints at T1 and T2 were similar with 1.6° and 0.1°, respectively, whereas T3 showed a relatively large value of 8.9°. At HTO, T1, T2, and T3 showed differences of 5°, 3°, and 0.3°, respectively.

Table 5 shows the changes in touchdown and take-off angles of the board and horse, along with the landing angle. Both techniques showed similar BTD angles, while the Yang Hak Seon technique showed a horse approach angle smaller by 8.6°.

In the Yang Hak Seon technique, T3 showed the biggest board approaching angle, while T1 showed the smallest HTD angle. Meanwhile, T2 showed the smallest LD angle, while T3 showed the biggest TD angle.

Table 6 shows the thigh and trunk rotation angles. The Yeo 2 technique showed a bigger thigh rotation angle by 17.6° at HTD, but the Yang Hak Seon technique showed a bigger thigh rotation angle by 8.2° at HTO and by 4.9° at peak. Meanwhile, the Yeo 2 technique showed a bigger trunk rotation angle by 17.9° at HTD and by 15.8° at HTO, whereas the Yang Hak Seon technique showed a bigger trunk rotation angle by 9.7° at peak.

In the Yang Hak Seon technique, the biggest thigh rotation angles were shown at T2 in HTD, T3 in HTO, and T1 in peak. Meanwhile, the biggest trunk rotation angle was shown at T2 in both HTD and HTO, and at T3 in the peak.

Table 7 shows the trunk twist angles. In the Yang Hak Seon technique, touchdown on the horse had a negative twist angle and then take-off had a similar angle, whereas in the Yeo 2 technique, touchdown on the horse had a positive twist and then take-off had at a twist angle of 24.5° in the negative direction. At peak, the Yang Hak Seon technique showed a bigger twist angle by 14.6° and landing occurs after executing a twisting turn bigger by 175°.

In the Yang Hak Seon technique, at T1, T2, and T3, the horse is approached with a twist in the negative direction, with T3 showing the biggest negative twist angle and T1 showing the smallest negative twist angle. Relative to the angle when approaching the horse, at T1, T2, and T3, take-off from the horse occurs by twisting at an angle of -2.4°, 8.8°, and 1.7°, respectively. For the twist angle at the peak, T2 showed the

Table 6. Rotation angles of the thigh and trunk (unit: degrees)

			BTD	BTO	HTD	HTO	Peak	LD
Thigh	Yeo 2		33.2	97.8	206.0	253.0	450.6	812.6
	Yang Hak Seon	T1	39.7	92.7	182.6	256.4	461.4	770.4
		T2	39.7	108.6	193.3	257.0	454.0	755.2
		T3	47.1	114.1	189.2	270.2	451.0	784.4
		Mean (SD)	42.2 (4.3)	105.1 (11.1)	188.4 (5.4)	261.2 (7.8)	455.5 (5.4)	770.0 (14.6)
Trunk	Yeo 2		120.3	149.3	197.8	266.3	448.1	747.7
	Yang Hak Seon	T1	114.9	137.2	180.6	239.4	456.4	766.0
		T2	113.5	146.3	188.4	260.4	451.8	765.1
		T3	109.7	139.7	170.7	251.6	465.1	768.3
		Mean (SD)	112.7 (2.7)	141.1 (4.7)	179.9 (8.9)	250.5 (10.5)	457.8 (6.8)	766.5 (1.7)

Table 7. Twist angle of the trunk (unit: degrees)

		BTD	BTO	HTD	HTO	Peak	LD
Yeo 2		3.2	2.2	2.1	-22.4	208.2	874.5
Yang Hak Seon	T1	12.6	3.6	-7.3	-9.7	225.0	1046.9
	T2	-11.3	-6.9	-15.5	-6.7	238.6	1054.5
	T3	-9.5	-18.0	-19.5	-17.8	204.8	1047.2
	Mean (SD)	-2.7 (13.3)	-7.1 (10.8)	-14.1 (6.2)	-11.4 (5.7)	222.8 (17.0)	1049.5 (4.3)

biggest angle and T3 showed the smallest angle, while for twist angle at LD, T2 showed the biggest angle and T1 showed the smallest angle.

5. Angular velocity

Table 8 shows the angular velocities of thigh rotation, trunk rotation, and trunk twist. With respect to the thigh rotation angular velocity, the Yang Hak Seon technique showed faster rotation velocity than the Yeo 2 technique at BTO, HTD, and HTO, faster by 16.9°/s in the PrF phase and by 92.3°/s in the HC phase. Meanwhile, the Yeo 2 technique showed faster velocity by 25.6°/s at the PoF Asc phase and by 55.7°/s at the PoF Des phase.

In the Yang Hak Seon technique, T1 showed the fastest rotation velocity at BTO and HTO, while T3 showed the fastest velocity at HTD. Meanwhile, the fastest rotation velocity in PrF, HC, and PoF Asc phases was observed at T1, while that in the PoF Des phase was observed T3.

With respect to trunk rotation velocity, angular velocity was similar between the two techniques in the BC phase, while the Yeo 2 technique showed faster rotation by 37.2°/s in HC phase. In the PoF Asc phase, the Yang Hak Seon technique showed faster rotation by 46.8°/s.

In the Yang Hak Seon technique, the fastest velocity in HC phase was observed at T2, while the fastest velocity in the HC and PoF Asc phases was observed at T3. With respect to trunk twist velocity, the Yang Hak Seon technique showed a negative angular velocity at HTO, while the Yeo 2 technique showed a positive angular velocity. The Yang Hak Seon technique also showed a faster angular velocity by 63.3°/s at peak and by 587.1°/s at LD. The two techniques showed similar velocities in the PoF Asc phase, but the Yang Hak Seon technique showed a faster velocity by 262°/s in the PoF Des phase.

In the Yang Hak Seon technique, T3 showed the fastest angular velocity at peak and LD, while T1 showed the slowest angular velocity. In the PoF Asc phase, T2 showed the fastest angular velocity, while in the PoF Desc phase, T3 showed the fastest angular velocity.

DISCUSSION

The present study aimed to examine the feasibility of the so-called Yang Hak Seon 3 technique (forward handspring and forward straight salto with a three-and-a-half twist), which added a half full twisting turn to the Yong Hak Seon technique (forward handspring and forward straight salto with a triple twist). Accordingly, in the present study, a comparative analysis of the major variables was conducted between the Yeo 2 technique (forward handspring and forward straight salto with a two-and-a half twist) and the Yang Hak Seon technique for presenting

Table 8. Angular velocities of the thigh and trunk (unit: degrees/s)

			BTO	HTD	HTO	Peak	LD	BC	PrF	HC	PoF	PoF Asc	PoF Des
Thigh rotation	Yeo 2		722.3	735.8	113.1	–	386.3	–	742.7	402.7	–	495.7	541.5
	Yang Hak Seon	T1	780.1	754.8	349.8	–	116.6	–	800.1	–	–	473.4	474.4
		T2	771.5	682.5	150.8	–	216.5	–	726.4	424.1	–	466.5	471.5
		T3	724.0	788.5	193.6	–	303.8	–	752.3	485.7	–	470.4	511.6
		Mean (SD)	758.5 (30.2)	741.9 (54.2)	231.4 (104.7)	–	212.3 (93.7)	–	759.6 (37.4)	495.0 (75.9)	–	470.1 (3.5)	485.8 (22.4)
Trunk rotation	Yeo 2		–	380.5	572.2	–	481.8	274.2	369.9	508.3	–	–	461.8
	Yang Hak Seon	T1	–	302.5	557.7	–	402.7	249.0	387.8	–	–	503.1	477.7
		T2	–	325.1	523.2	–	464.3	306.4	361.2	473.8	–	461.3	493.9
		T3	–	280.2	612.2	–	460.6	276.0	317.3	481.8	–	555.2	467.7
		Mean (SD)	–	302.6 (22.5)	564.4 (44.9)	–	442.5 (34.5)	277.1 (28.7)	355.4 (35.6)	471.1 (12.3)	–	506.5 (47.0)	479.8 (13.2)
Trunk twist	Yeo 2		–	–	118.8	1245.5	97.1	–	–	–	842.0	579.3	1016.2
	Yang Hak Seon	T1	–	–	-136.1	1177.6	481.7	–	–	–	972.4	543.0	1262.8
		T2	–	–	-120.0	1334.4	727.3	–	–	–	999.8	590.8	1281.0
		T3	–	–	-15.0	1414.3	843.6	–	–	–	1021.0	587.8	1290.7
		Mean (SD)	–	–	-90.4 (65.8)	1308.8 (120.4)	684.2 (184.8)	–	–	–	997.7 (24.4)	573.9 (26.8)	1278.2 (14.2)

quantitative data on the kinematic factors required for completing the Yang Hak Seon 3 technique.

The Yang Hak Seon 3 technique, the feasibility of which was examined in the present study, shares the same physical posture as the Yang Hak Seon and Yeo 2 techniques in the handspring and post-flight phases, but it requires a greater amount of twisting. The findings in the present study showed that the Yeo 2 and Yang Hak Seon techniques had similar or same post-flight duration, height, and distance, indicating a similar flight pattern. However, the Yang Hak Seon technique showed a trunk rotation angle prior to the PoF Peak of 457° (97°), whereby an aerial rotation distance longer than that in the Yeo 2 technique was secured with the body extending beyond a completely vertical position. Moreover, the trunk twist in the PoF Asc phase did not show significant differences, with results ranging from 543° and 590°/s, but in PoF Des phase, the twist velocity in the Yang Hak Seon technique (1,278°/s) was much faster than that in the Yeo 2 technique (1,016°/s).

On the basis of these results, we can conclude that if an athlete is capable of executing the Yeo 2 technique, the athlete should be able to complete the Yang Hak Seon technique with a higher degree of difficulty by simply increasing the amount of twist by increasing the twist velocity in the PoF phase. However, in the Yang Hak Seon technique, in which the athlete lands facing away from the horse, landing that is as stable as that in the Yeo 2 technique, in which the athlete lands facing toward the horse, is difficult to expect (Park & Song, 2012). Moreover, the Yang Hak Seon technique maintains a very fast twist velocity (684°/s) up to the moment of landing. This requires both arms to stay tucked right up to the landing, not allowing the athlete to extend the arms to control the twist velocity in preparing for a stable landing (Park & Kim, 2014). Moreover, inertia from twisting increases the likelihood of the body falling to the side, which causes further landing instability.

However, the Yang Hak Seon 3 technique uses landing while facing the horse, just as in the kinematic analysis of the Yang Hak Seon 2 technique (Tsukahara stretched with a three-and-a-half twist) reported by Park and Song (2015). Although the Yang Hak Seon 2 technique is a Tsukahara-type technique (side dismount), it shares the same kinematics as the Yang Hak Seon 3 technique in the PoF phase. The technique for successfully executing the Yang Hak Seon 2 vault showed a similar in-flight height and duration in the PoF phase as the Yang Hak Seon technique, but the total twist in the PoF phase was 1,056°, which is twisting more by approximately 10° as compared with the Yang Hak Seon technique. Moreover, the average twist velocity in the PoF phase was 1,058°/s, while that in the PoF Asc and PoF Des phases were 727°/s and 1,250°/s, respectively. Therefore, a slightly faster twisting motion was executed in the PoF phase, as compared with the Yang Hak Seon technique, while a relatively much faster twisting motion was executed during the PoF Asc phase. Therefore, to successfully execute the Yang Hak Seon 3 technique, the same twist velocity as the Yang Hak Seon 2 technique, which uses the same type of landing, should be maintained while finding ways to increase the in-flight duration in the PoF phase. For this, the study compared three techniques that use different types

of landing when the Yang Hak Seon technique was used, to investigate the determining factors associated with increased flight height so that the findings can present the kinematic factors required to complete the new technique.

In the Yang Hak Seon technique, the T1 technique, which involved taking one step forward during landing, had a flight duration of 1.08 sec and a flight height of 3.1 m in the PoF phase, which was longer and higher than those in the T2 and T3 techniques. This may be attributed to maintaining a fast thigh rotation velocity when taking off from the horse while generating the fastest vertical and horizontal velocities of the body, which affects the vertical height and horizontal distance during the PoF phase (Kim & Park, 1994). Moreover, the T1 technique involved executing a vertically centered PrF motion with a short BTD, but the hands were placed quickly on the horse to maintain a low horse contact angle. During the hand contact phase, a fast back kick speed was maintained and shoulder push (extension) motion was executed with a high-level force to induce a higher take-off height.

Both the T2 and T3 techniques showed slightly lower flight height than the T1 technique, but the Yang Hak Seon vault was completed without any major problems. The T2 technique generated a large body rotation starting from BTO, and the trunk rotation at HC was performed at a very high velocity. Moreover, the vault was successfully executed because enough twists had been completed prior to reaching the peak (Park & Song, 2012).

The T3 technique attempted a horizontally centered HTD, and by executing a forceful push-up technique during HC, the technique strengthened the rotational motion of the trunk starting from HTO, which generated a very fast twisting motion in the PoF phase.

On the basis of the characteristics required to complete the technique in each phase of the Yang Hak Seon vault, the variables required to successfully execute the new technique were determined to include the following.

On the basis of the PoF motion of the T3 technique that completed the Yang Hak Seon vault despite having the shortest in-flight time and assuming that the twist velocity in the PoF phase of the Yang Hak Seon 2 technique reported in a previous study can be maintained, the flight duration and height required to add another 180° twist were as follows: As the T3 technique showed a total twist distance of 1,047° with an average twist velocity of 1,021°/s, which required 1.03 sec of flight duration, adding an additional 180° of twist to execute the new technique would require a total twist distance of approximately 1,227°, which would require approximately 1.2 sec of flight duration. However, if 1,227° of twist is executed by an average twist velocity of 1,058°/s used to execute the Yang Hak Seon 2 vault in the previous study, the flight duration required to successfully execute the technique would be approximately 1.15 sec. This would require the flight duration in the PoF phase to be increased by >0.1 sec from the existing Yang Hak Seon technique.

Such increase in flight duration may appear to be somewhat difficult, but considering that the flight duration in PoF phase was 1.14 sec in the study by Song et al. (2014) that analyzed the Yang Hak Seon 2 technique and 1.12 sec in the study by Song and Park (2016) that analyzed that Yang Hak Seon technique, such increase may be quite feasible if the flight height can be increased through changes in the take-off motion.

In the T3 technique, the flight duration in PoF was 1.03 sec, while the CoM took off front the horse at a height of 2.1 m and ascended up to 3 m. In other words, the CoM showed an increase in height of 0.9 m over 0.38 sec. Moreover, a height of 1.1 m was maintained from the point of descending from the peak to landing, which indicated a descent of 1.9 m over 0.65 sec. As the flight duration in the PoF phase required to successfully execute the Yang Hak Seon 3 technique is 1.15 sec, an increase of 0.12 sec is necessary.

The T1 technique of the Yang Hak Seon vault showed the CoM maintaining a vertical velocity of 4.1 m/s at HTO, which was much faster than that in the T3 technique. The ascent time was 0.43 sec, which was 0.05 sec longer than that in the T3 technique. Thus, if 0.07 sec is added to the PoF Des phase to maintain the total descent time at 0.72 sec, such added time would be enough to allow the new technique to be successfully executed. The new technique requires landing while facing the horse, in which case, a landing height of even 0.7 m would allow execution of a stable landing technique. Therefore, as the vertical descent distance from the peak height to 0.72 sec after free fall would be 2.5 m, maintaining a flight height in the PoF phase of 3.2 m would allow the athlete to complete the twisting motion in the PoF phase of the Yang Hak Seon 3 technique without any problem.

CONCLUSION

First, to successfully execute the new technique (Yang Hak Seon 3), the average twist velocity in the PoF phase must be maintained at 1,058°/s; for this, the athlete must attempt to increase the twist rotation velocity from the start of the PoF Asc phase. Moreover, the flight height should be increased to 3.2 m, and the flight duration should be maintained for >1.15 sec by increasing the vertical velocity at HTO to ≥4.1 m/s.

Second, to secure the required twist velocity in the PoF phase, the vertical velocity at HTO, and the flight height and duration, the lowest possible body angle should be maintained at HTD and the back kick should be performed quickly as the hands touch down, so that the leg back kick velocity can be maintained starting from HTO.

Third, the BTD time should be short and the body should be erect when taking off from the board in a vertically centered manner. Meanwhile, the shoulder joints should be closed rapidly to quickly perform HC to reduce the horse-blocking angle. During HC, the fast horizontal velocity must be maintained and performed using a forceful push-up technique by quickly extending the tucked shoulders, which can be helpful in increasing the vertical ascent velocity and allowing the twist motion during ascent to be performed more easily.

REFERENCES

Abdel-Aziz, Y. I. & Karara, H. M. (1971). Direct linear transformation from comparator coordinates in object-space coordinates in close range photogrammetry. *Proceedings of the ASP Symposium of Close-Range Photogrammetry*. Urbana: University of Illinois.

Kim, S. K. & Park, Y. J. (1994). A Kinematic Analysis of Cuervo and Cuervo Full - turn Motions of Gymnastics. *Korean Journal of Physical Education*, *33*(2), 133-143.

Lee, S. H., Park, J. H. & Lee, J. H. (2006). Kinematic Analysis of Acopian in Vault. *Korean Journal of Sport Biomechanics*, *16*(1), 89-99.

Park, C. H. & Kim, Y. K. (2014). Kinematic Comparisons between Yang-1 and Yang-2 Vaults in Men's Artistic Gymnastics. *Korean Journal of Sport Biomechanics*, *24*(4), 317-327.

Park, J. H. & Song, J. H. (2012). The Kinematic Analysis of YANG Hak Seon Vault. *Korean Journal of Sport Science*, *23*(3), 702-717.

Park, J. H. & Song, J. H. (2015). The Kinematic Analysis of Tsukahara Stretched with 7/2 Turn (YANG Hak Seon 2) in Vault. *Korean Journal of Sport Science*, *26*(2), 413-429.

Song, J. H. (2017). A Study of the Possibility of New Technique in Vault for the 2020 Olympic Games in Tokyo. *Korea Institute of Sport Science.*

Song, J. H., Kim, K. J. & Park, J. H. (2016). A Study on the Optimization of YANG Hak Seon Vault for the 2016 Liu Olympic Games. *Korea Institute of Sport Science*.

Song, J. H., Lee, S. H., Song, H. S., Park, J. H. & Ha, C. S. (2011). Analysis to improve the completeness of new technique (handspring forward and salto forward straight with triple twist) in vault. *Korea Institute of Sport Science.*

Song, J. H., Moon, Y. J., Kim, K. J., Kwon, Y. H. & Park, J. H. (2014). A study to improve the completeness of new technique (tsukahara stretched with 7/2 turn) in vault. *Korea Institute of Sport Science.*

Song, J. H. & Park, J. H. (2016). A Comparative Study of Kinematic Characteristics of Ri Se Gwang Motion in Vault. *Korean Journal of Sport Science*, *27*(3), 644-655.

Takei, Y., Blucker, E. P., Hudert, D. J., Myers, S. A. & Fortney, V. L. (1996). A Three-dimensional analysis of the men's compulsory vault performed at the 1992 Olympic Games. *Journal of Applied Biomechanics*, *12*, 237-257.

Takei, Y. (2007). The Roche Vault Performed by Elite Gymnasts: Somersaulting Technique, Deterministic Model and Judges' Scores. *Journal of Applied Biomechanics*, *23*, 1-11.

Yeo, H. C. (2003). Kinematic Analysis of Yeo Motion at Horse Vaulting. *Korean Journal of Sport Biomechanics*, *13*(1), 39-50.

Yoon, H. J., Yeo, H. C. & Kim, T. S. (2001). The Kinematical Analysis of Yeo2 Motion in Vault. *Korean Journal of Sport Biomechanics*, *11*(1), 41-52.