THREE-DIMENSIONAL ANALYSIS OF YURCHENKO LAYOUT WITH 360° TWIST IN FEMALE VAULTS: MODIFIED DETERMINISTIC MODEL AND JUDGES' SCORES

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The purposes of this study were to identify kinematic variables that govern successful performance and judges' scores and to establish correlative relationships among those variables of Yurchenko layout with a full twist in female vaults. Thirty-two vaults data were collected from national competition by four video cameras (60Hz sampling rate). The obtained scores from judges' decision were mainly affected by post-flight peak height, horse contact time, knee angle at landing, and horse take-off angle. Modified deterministic model showed that round-off entrance and take-off angles and resultant velocity of the CM were the starting variables affecting performance in following kinematic variables. Knee angle at landing, a highly influential variable on the obtained point, was only determined by judges' decision without significant relationship with previous kinematic variables.

KEY WORDS: gymnastic vaults, kinematics, Yurchenko, modified deterministic model, score

INTRODUCTION: Yurchenko vault appeared on 1982 World Cup in Zagreb by Natalia Yurchenko. It consists of round-off entry before board contact and uses back somersault towards horse. In early of 1980s, some athletes were unwilling to perform Yurchenko technique due to the risk of injury as a result of narrow contact zone (transversely located old-fashioned horse). However, Yurchenko currently becomes one of most popular techniques used by female athletes because of the larger contact zone of new-type horse. Previous studies indicate the importance of take-off vertical speed and take-off angle from the horse for successful performance in addition to minimum loss of vertical speed during horse contact (Kwon et al., 1990; Park & Kim, 2016). In order to successfully perform high-scored Yurchenko techniques such as 720° or 900° twist, mastering a full twist Yurchenko (a basic drill) is necessary to athletes.
Deterministic model was originally developed by Hay and Reid (1988) in order to provide qualitative analysis of performance and to find causal relationships between variables. It has been used to identify mechanical variables that govern successful performance of hand-spring, Hetch, and Roche vaults, respectively (Takei, 1998, 2007; Takei et al., 2000). However, there was no study applying deterministic model to Yurchendo vaults.
The purposes of this study were to identify kinematic variables that govern successful performance of female Yurchenko layout vault with a full twist and to investigate the correlative relationships among kinematic latent variables in terms of modified deterministic model.

METHODS: Thirty-two vault data of Yurchenko layout with a full twist were collected from twenty-two subjects (age: 18.64±3.62 years, height: 153.0±6.45 cm, mass: 44.73±7.31kg). Four video cameras (EX-F1, Casio, Japan), having 60Hz of sampling rate, were used to collect data after calibrating area before competition (Figure 1). The obtained scores of athletes' performance were collected according to the electronic scoreboard display and verified by website records of Korea Gymnastic Association.
Motion data, digitized by using Kwon 3D XP (Visol, Korea), were filtered and used to calculate kinematic variables of each phase in Mathlab® (MathWorks Inc., USA). The vault motion was divided in 5 phases such as round-off, board contact, pre-flight, horse contact, and post-flight (Figure 1). Joint angles, joint angular velocities, posture angles on board and horse, linear displacement and velocity of the body center of mass (CM) were calculated and used for statistical analysis. For the correlative relationship with the obtained scores and

kinematic variables, the correlation analysis and regression analysis were performed on SPSS® 20.0 (IBM, USA) with the significance of .05. Deterministic model were modified from Hay and Reid (1988) by locating kinematic variables in a sequence of phases. We want to see how the proceeded kinematic variables (variables in previous phase) affects the current kinematic variables. Finally we assumed the obtained points of athletes was closely associated with the kinematic variables of post-flight.

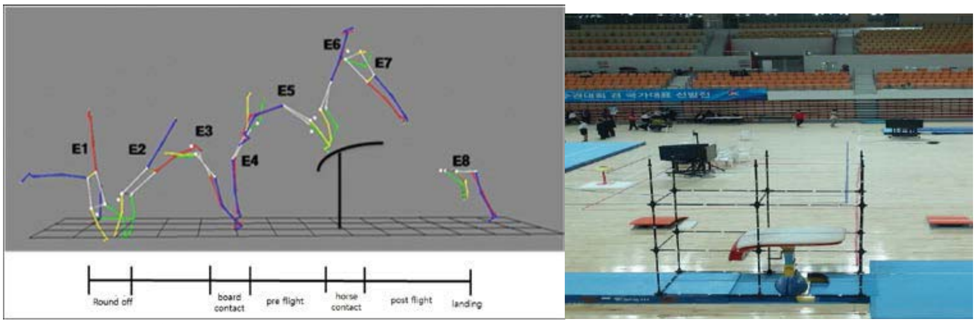

Figure 1: Definition of major events and phases during Yurchenko layout with a full twist and overview of calibration process before competitions

RESULTS: The obtained score (judges' score) were mainly associated with kinematic variables of horse contact and post-flight (Table 1). Phase time, horizontal displacement of the CM, horse take-off angle, and twist angular velocity in horse contact phase significantly gave negative effects on the obtained scores, while resultant linear velocity of the CM, vertical peak height, knee angle at landing during post-flight positively affected the obtained scores.

Table 1
Descriptive statistics and Pearson correlations with judges' score(the obtained score) for kinematic variables of each phase

Variables	Mean±*SD*	Min	Max	*r*
Round-off phase				
Phase time (sec)	0.30±0.03	.23	.40	-.352*
Horizontal displacement of body CM (m)	1.61±0.19	1.22	2.05	-.199
Vertical displacement of body CM (height %)	11±3	4	19	-.325
Board contact phase				
Phase time (sec)	0.13±0.02	.10	.17	-.393*
Horizontal displacement of body CM (m)	0.57±0.08	.41	.73	-.262
Vertical displacement of body CM (height %)	36±5	28	47	-.225
Pre-flight phase				
Phase time (sec)	.12±.02	.10	.17	.081
Horizontal displacement of body CM (m)	.51±.08	.38	.68	.132
Vertical displacement of body CM (height %)	41±6	28	56	.301
Horse contact phase				
Phase time (sec)	0.22±0.02	.20	.27	-.565**
Horizontal displacement of body CM (m)	0.66±0.07	.50	.82	-.486**
Horse takeoff angle (°)	89.05±5.25	79.69	98.75	-.496**
Twist angular velocity (°/s)	72.82±31.13	1.55	121.85	-.442*
Post-flight phase & landing				
Phase time (sec)	0.86±0.05	.77	.97	.105
Horizontal displacement of body CM (m)	2.06±0.22	1.68	2.45	.341

Resultant linear velocity of body CM (m/s)	3.33±0.35	2.56	4.13	.460**
Vertical peak height (height %)	139±5	131	151	.587**
Knee angle at landing (°)	106.13±29.53	65.18	166.16	.516**

* <.05, **<.01

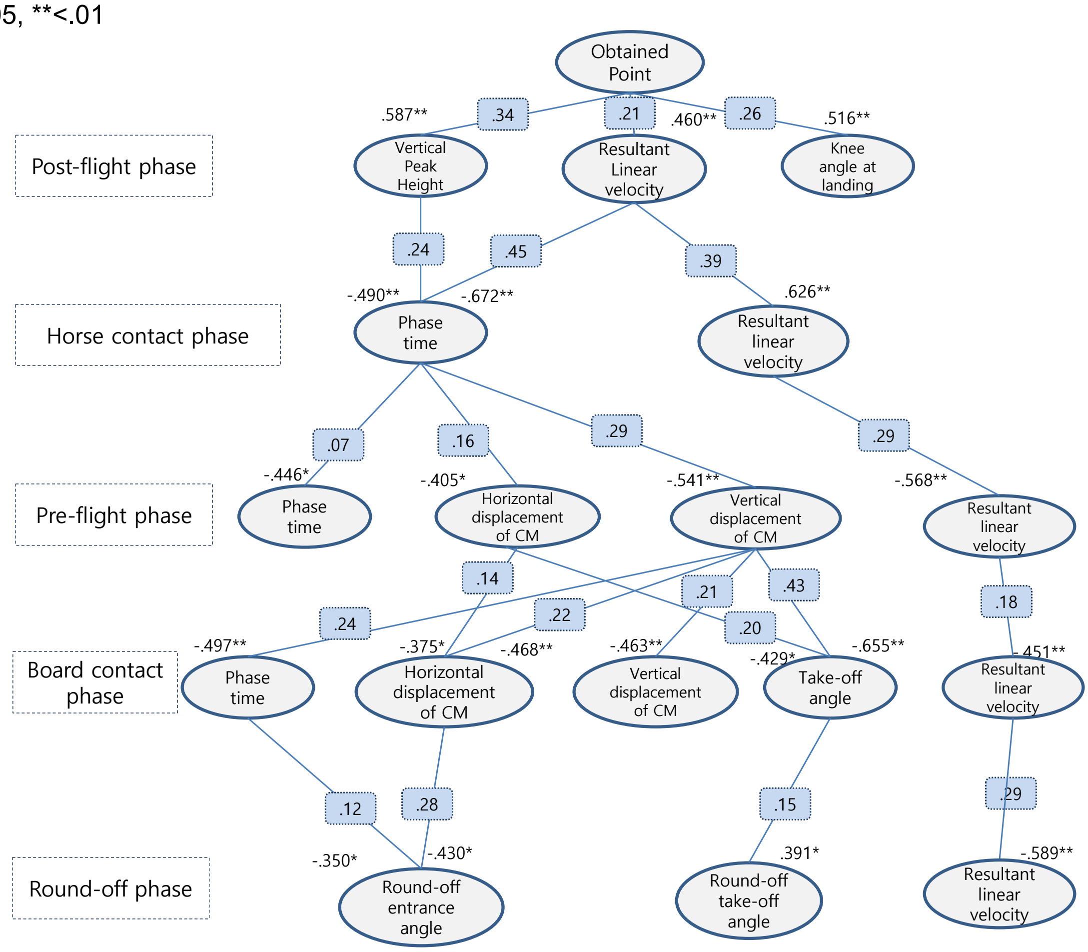

Figure 2: Modified deterministic model for Yurchenko layout with a full twist in female vaults. The number on circle is *r*-value and the number in the box (connecting line) indicated R^2-value.

Figure 2, modified deterministic model, indicated the relationships and strengths among the proceeded kinematic variables (previous phase) and current ones (current phase) in the sequence of phases. The obtained scores were significantly related with vertical peak height, resultant linear velocity of the CM, and knee angle at landing during the post-flight. From the perspective of sequence, round-off entrance and take-off angles and resultant linear velocity of the CM during round-off phase were not correlated with the obtained scores directly in correlation analysis (Table 1). However, those variables were correlated with phase time, linear velocities of the CM, and posture variables of subsequent phases. Knee angle at landing was not affected by the previous variables but only determined by judge's decision.

DISCUSSION: This study indicated the importance of kinematic variables in horse contact and post-flight, affecting successful performance and high obtained scores by the judges. Especially, the shorter horse contact time, shorter horizontal displacement, smaller take-off angle (relative to left horizontal line), and smaller twist angular velocity in horse contact were significant factors to successful performance. These results were supported by Kwon et al. (1990) and Park and Kim (2016). Therefore, the strong blocking during the horse contact by the help of shoulder joints is necessary to achieve higher post-flight and to get high scores. High twist angular velocity (axial rotation) might lose the angular momentum in medial-lateral axis during horse contact (Kwon et al., 1990).

The enough peak height of post-flight allowed more time to prepare landing and consequently induced larger knee angle at landing (Takei, 2007). Good landing posture definitely is associated with high obtained score. Surprisingly, the judge's scores depended on the knee angle at landing but this angle was not related with previous kinematic variables. Thus, it is thought that independent landing training is also necessary to get good results in competitions.
The round-off phase was the precursor affecting kinematic variables of the following phases to the obtained score. Practically it is not easy for an athlete to transfer linear motion of the body (running) to angular motion (round-off entry) in round-off phase. In order to improve this phase performance, repeated trials of establishing the last step proper distance and timing for round-off motion with minimal loss of linear momentum (Takei, 2007).
There are limitations in this study. Since this modified deterministic model listed significant variables of each phase in a sequence of phases, it could not tell the causal relationship directly like Hay and Reid (1988) approach. In addition, the sampling rate (60Hz) and manual digitizing could somewhat affect the quality of accuracy of the motion data.

CONCLUSION: The most influential variables to the obtained scores were post-flight peak height, horse contact time, knee angle at landing, a horse take-off angle. The strong horse blocking technique allowed more vertical height and more chances for stable landing. Modified deterministic model explained correlative relationships among latent variables from the round-off to post-flight phases. Even though the round-off posture (round-off entrance angle and take-off angle) and linear velocity of the CM was not directly associated with the obtained scores, they gave significant effects on kinematic variables of following phases. Therefore, the transition from linear to angular motions (round-off) seems to be the precursor to the subsequent consequences.

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