

## AN EVALUATION OF PERFORMANCE OF A DOUBLE-LEG CIRCLE ON A POMMEL HORSE, AND A DESIRABLE PERFORMANCE PROPOSAL

Motoyuki Nawa<sup>1</sup>, Kazuie Nishiwaki<sup>2</sup>, Kyoji Yamawaki<sup>3</sup>, Yosuke Ikegami<sup>4</sup>,  
Yoshihiko Nakamura<sup>4</sup>, Akihiko Murai<sup>5</sup>, Ko Ayusawa<sup>6</sup>, and Taiga Yamasaki<sup>7</sup>

Rakusho Gymnastics Club, Ikoma, Japan<sup>1</sup>  
Research Organization of Science and Technology, Ritsumeikan University,  
Kusatsu, Japan<sup>2</sup>

Faculty of Education, Gifu University, Gifu, Japan<sup>3</sup>

Department of Mechano-Informatics, University of Tokyo, Tokyo, Japan<sup>4</sup>

Human Informatics Research Institute, AIST, Tokyo, Japan<sup>5</sup>

Intelligent Systems Research Institute, AIST, Tsukuba, Japan<sup>6</sup>

Faculty of Computer Science and Systems Engineering

Okayama Prefectural University, Soja, Japan<sup>7</sup>

For the evaluation of the performance of a double-leg circle on a pommel horse, we focused on the relation between the horizontal rotation of a body about the vertical axis in the center of a pommel horse and the hip rotation about the longitudinal axis of a body. Several gymnasts having different levels of skill were examined by using a motion capture system. The analysis shows that the horizontal rotation and the hip rotation are in good synchronization for the performance of a well-trained gymnast.

**KEY WORDS:** gymnastics, motion analysis, hip rotation

**INTRODUCTION:** A double-leg circle is the most basic technique on a pommel horse. To improve the performance of a double-leg circle is the key to the development of a variety of other techniques on a pommel horse.

For the performance of the circle, the historical transition of the techniques was studied by Mizushima (1998). According to the history, a recent interest is focused on the hip rotation in a flank-out phase. Fujihara et al. (2009) pointed out that the motion of a double-leg circle is composed of two different rotations, one of which is the horizontal rotation of a body around a vertical axis in the center of a pommel horse [hereafter, horizontal body rotation] and the other is the hip rotation around a longitudinal body axis [hereafter, hip rotation].

The previous studies stated above gave the morphological understanding of a double-leg circle and the analytical understanding of its motion. However, what is a good double-leg circle or how its performance can be evaluated has been vague and the instruction to gymnasts in training depends on a coach. From this stand point, we aimed to develop a characteristic diagram that is an objective analysis understandable to both gymnasts and coaches. The characteristic diagram is designed to see especially the flank-in and flank-out phases by showing the relationship between the horizontal body rotation and the hip rotation, using three dimensional coordinate data of the body motion measured with a motion capture system.

**METHODS:** Figure 1(a) shows the movement of a body in a horizontal plain over a pommel horse. In this case, it is a clockwise rotation. Symbols P1 to P8 are assigned to corresponding rotational positions of a body. When we see the body above the head-shown by the hollow arrows in Figure 1(a), a performer's body rotates around its longitudinal axis in the counter-clockwise direction as indicated in Figure 1(b): the hollow half circle indicates face.

To analyse the performance of a double-leg circle, three gymnasts from skilled to well skilled were examined. They are designated by the gymnasts S1, S2, and S3.

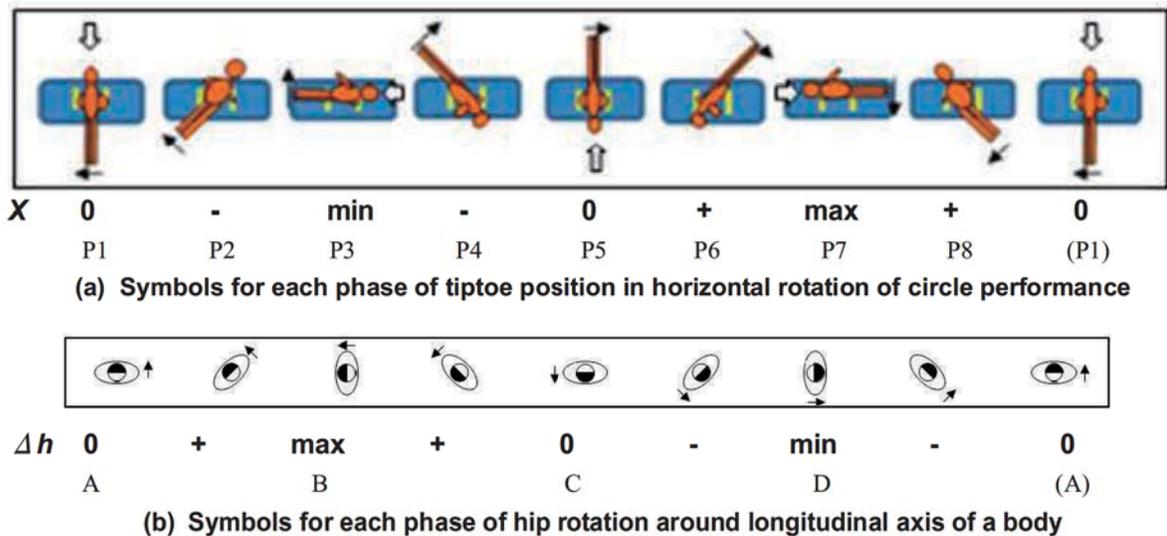


Figure 1: Horizontal rotation and hip rotation

S1 is a university gymnast who is at a skilled level. S2 is a university graduated well skilled gymnast who once won the championship in the pommel horse event at the Society Member Tournament of Gymnastics in Japan. S3 is a high school skilled gymnast who performed well in the pommel horse event in the High-School Tournament in Japan. S3 was trained under the instructions by Yamawaki, one of the co-authors of this paper. He trained S3 to straighten the body without breaking the hips and to make continuous rotation all the way about the longitudinal axis of a body while making the horizontal rotation.

The motion capture measurements were carried out for these gymnasts. We used a motion capture system of Motion Analysis Inc. This system is composed of twelve Eagle and Raptor cameras that capture optical markers at 200 frame/s. The markers are a modified version of the Helen Heyse Hospital marker set where 35 markers were set on typical points on a gymnast's body.

The gymnast made performance three times, each of which includes 10 circles. We chose the best one out of the three performances, and extracted one typical circle from 10 circles for analysis. The tiptoe movement and the hip movements of left and right sides were detected directly by the optical markers put on these positions.

Motion analysis was done using an assumed model with a set of mass properties, which consisted of the mass, the center of mass (or the center of gravity), and the inertia tensor of each segment of the body. There were 51 segments in total. The mass properties were computed from the simplified segment shapes using spheres, cylinders, and cones adopting a constant density. The kinematic model is a tree-structured rigid-body segments connected by spherical joints. For the present analysis only the time dependent coordinates of the center of the gravity of the whole body were used.

**RESULTS & DISCUSSION:** Figure 2(a), (b) and (c) show the relations between the horizontal body rotation and the hip rotation for the three selected performances: S1, S2 and S3, respectively. In the figure, the horizontal axis is the  $x$ -coordinate of the tiptoe position, as indicated in Figure 1(a). The  $x$ -coordinate is in a longitudinal direction of the horse body and its origin is at the center of the upper surface of a pommel horse. The  $x$ -coordinate value represents the horizontal body rotation. The vertical axis is the height difference ( $\Delta h$ ) between left and right hips, as indicated in Figure 1(b). The value of  $\Delta h$  represents the hip rotation. Although angles of rotation indicate directly the horizontal body rotation and the hip rotation, the  $x$ -coordinate and the height difference ( $\Delta h$ ) are used instead for simplicity.

In Figure 1 (a),  $x$  values are shown for each tiptoe position. For example, at P3,  $x$  = minimum value(minus), and at P7,  $x$  = maximum value(plus). In Figure 1 (b),  $\Delta h$  values are shown for each hip rotating position. For example, at B,  $\Delta h$  = maximum value(plus), and at D,  $\Delta h$  = minimum value(minus).

When P1, P3, P5, and P7 coincide in phase with A, B, C, and D, respectively, the horizontal body rotation and the hip rotation can be said to be synchronized and a very smooth performance will be attained. As the synchronization, however, is not always easy, there are a variety of ways of performing the circles depending on the skill levels of gymnasts in competition.

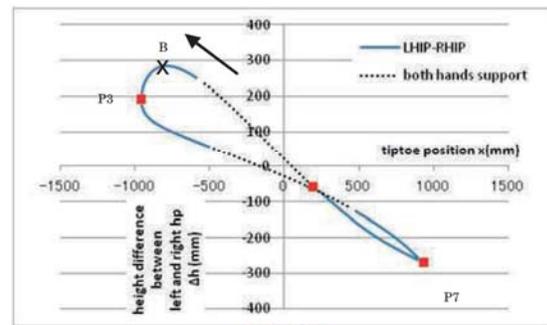
It is a common nature in Figure 2 that the curves for the three gymnasts pass in the close vicinity of the origin. Some differences, however, can be observed between the three gymnasts as described in the following.

As for S1, there is a big bulge in the 2<sup>nd</sup> quadrant. Because of this bulge, P3 phase does not coincide with B phase. As to performance, the hip rotates to vertical position (B) before the tiptoes cross over the horse body (P3). The observation of movies revealed that this gymnast made the posture of breaking hips slightly from P7 to P8. After breaking hips he had to stretch his hips at the rear support phase (P5). In this process, in order to prepare for P5's hip posture earlier, hips became vertical before P3 phase. Moreover this large bulge accompanies the inclination difference in two lines which are connected with bulge. This means that the relation between horizontal body rotation and hip rotation differs before and after bulge. According to these reasons, this circle performance is not a smooth one.

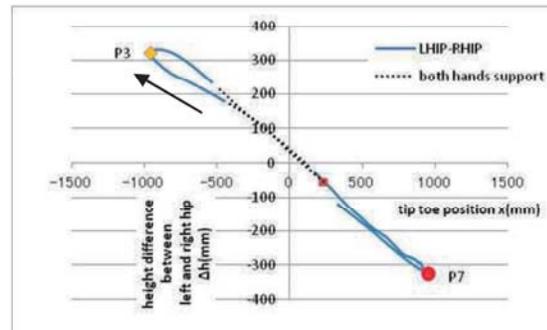
As for S2, there also exists a bulge in the 2<sup>nd</sup> quadrant. Nevertheless, it is seen that the bulge is so small that P3 almost coincide with B and the two bulge curves merge with each other to make nearly a single straight line. It can be said that the horizontal body rotation and the hip rotation are almost in phase, which means the performance is smooth.

As for S3, two bulges appear in the 2<sup>nd</sup> and 4<sup>th</sup> quadrants. However, they are as small as the one shown by S2. It can be said that S3 also exhibits smooth performance.

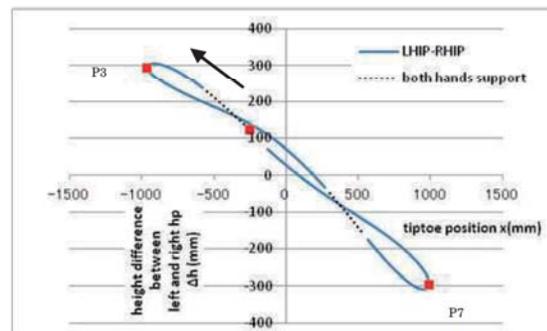
Figure 3 shows the vertical movement of the center of gravity during one circle for each gymnast. Horizontal axis shows the non-dimensional elapsed time for one circle movement. The start position is P1. Vertical axis shows the non-dimensional vertical distance of the center of gravity from the pommel on the basis of the arm length of each gymnast. As is



(a) S1



(b) S2



(c) S3

**Figure 2: Difference in height between left and right hips versus tiptoe movement**

shown, the center of gravity of S2 is higher than S1, and S3 is higher than S2 on average. It is noted that S3 performed with the smallest variation in the height among the three.

Table 1 shows the periods of each gymnast for one circle movement. As shown in this table, S2 is faster than S1, and S3 is faster than S2. S3's period is 93% of S1. From these data, in order to attain higher position of the center of gravity, faster speed seems to be required. The desirable circle from the stand point of grandeur of performance is considered to be the one that exhibits higher center of gravity induced by faster speed. Besides, a smaller variation in the height of the center of gravity is another factor to show a smooth performance. From the stand point of elegance of performance, a desirable circle is considered to be the one in which smooth movement is conducted with no posture drawback. Our evaluation method of checking the coincidence of phasing of the horizontal body rotation and the hip rotation shown by Figure 2 can be a useful tool for training and coaching to develop a smooth performance. As an overall evaluation, both the gymnasts S2 and S3 exhibit a good performance from the stand point of phasing of the two rotations. The higher position and the smaller variation in the height of the center of gravity exhibited by S3 are an additional factor to make an even better performance.

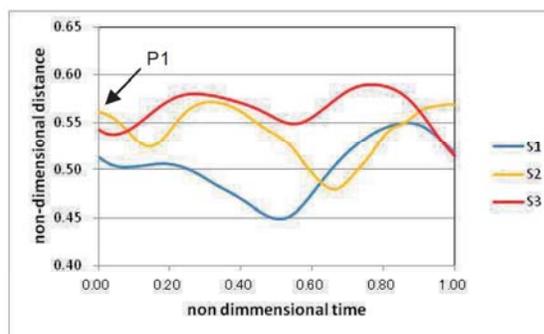


Figure 3: Vertical movement of center of gravity

Table 1 : Periods of one rotation of circle

gymnast	S1	S2	S3
Period[ms]	945	905	880
ratio	1	0.96	0.93

**CONCLUSION:** For the quantitative evaluation of the performance of a double-leg circle, the characteristic diagram has been developed to see whether the horizontal rotation and the hip rotation are well synchronized or not. The diagram shows the relationship between the coordinate of the tiptoe in the longitudinal direction of the pommel horse and the difference in height between the left and right sides of hips, based on the analysis of the data acquired for three gymnasts with the motion capture system.

It is shown that a desirable performance is expressed by an almost straight line with roughly the origin symmetry in the characteristic diagram, which indicates the horizontal rotation and the hip rotation are nearly synchronized.

The diagram is comprehensible to both gymnasts and coaches and will help improve the performance of a double-leg circle.

#### REFERENCES:

- Fujihara, T., Fuchimoto, T. & Gervais, P. (2009). Biomechanical analysis of circles on pommel horse. *Sports Biomechanics*, 8(1), 22-38.  
 Mizushima, K. (1998). Technique of double-leg circle on pommel horse [in Japanese]. *Journal of Gymnastics Research*, 6, 39-55.

#### Acknowledgement

We would like to appreciate late professor Kiyoshi Goto in Okayama Prefectural University for his earnest effort to this analysis.