HEAD-TOE DISTANCE AS A SIMPLE MEASURE TO EVALUATE AMPLITUDE OF CIRCLES ON POMMEL HORSE

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Abstract

To develop scientifically-valid tools to monitor performance in practice, a critical question is what to measure. On pommel horse, the importance of fundamental skills called circles is uncontroversial, and one of the key performance qualities of circles is the amplitude of the movement. Previous studies have used joint angles or the magnitude of a body part's trajectory to evaluate the amplitude, but we hypothesized that the distance between two points, namely a head and toes might be substituted despite its relative simplicity. This study examined the use of Head-Toe Distance (HTD) normalized by the gymnast's body height as a simple variable to potentially evaluate the amplitude of circles. The kinematic data of circles performed by 18 elite gymnasts were collected with a Qualisys motion capture system operating at 100 Hz. HTD and its horizontal component, HTDh, were computed along with their relationships to the outcome scores given by the official judges, as well as the other amplitude variables: the horizontal diameters of shoulder and ankle trajectories; the body flexion angle; and in the rear support position, the shoulder extension angle and the head position. The results supported HTDh, rather than HTD, for its potential usage as a single variable to evaluate the amplitude of circles. The benefits of HTDh compared to the other variables lies in its potential validity despite its relative simplicity in assessment. Because computing HTDh requires only the positional data of the head and toes, it may have greater practical applications as an evaluative tool in gymnastics.

Keywords: *gymnastics, rotation, quality, evaluation, feedback, coaching, judging.*

INTRODUCTION

"Circles" are the most basic skill on pommel horse, and they are fundamental skills due to the fact they are precursors to the development of more complex skills. Coaches focus much attention on the technical quality of the fundamental skill because of its importance in the effective development of successful performance. As George explained in his book (George, 2010), maximising the movement amplitude is one of the keys to optimising technique and successful performance in gymnastics, and this is well applied for circles. The important aspect for the quality of circles is the amplitude of horizontal rotation. Horizontal rotation refers to phase dependent rotation of: rotation of the mass centre about the supporting hands and rotation of the body itself about the mass centre (Fujihara, Fuchimoto and Gervais, 2009). This partially describes the mechanics of horizontal rotation, yet more studies will be helpful to facilitate our understanding of the motion. Among practitioners, however, it would be a clearer agreement that a gymnast should keep his body as straight as possible throughout an exercise (Karácsony & Čuk, 1998; Yoshida & Shiroma, 2001). Figure 1 provides a typical example of higher-quality and lower-quality circles, which have a relatively straight body and bent body, respectively. Kaneko (1974) asserted that ideal circles should show great amplitude characterized by a straight body and maximal possible circular trajectory of his feet. This technical claim are in line with the rules, as the *Code of Points* (International Gymnastics Federation, 2017) states that "ideally circles and flairs must be performed with complete extension. Lack of amplitude in body position is deducted as an individual deduction on for each element. (p. 54)" It should be noted that the *Code of Points* (International Gymnastics Federation, 2017) also states that "circles with a slightly hollow position are permitted. (p.54)" The question here is how slight the position would be considered permissible, and this is likely to rely on judges' subjective perception at least in the current paradigm.

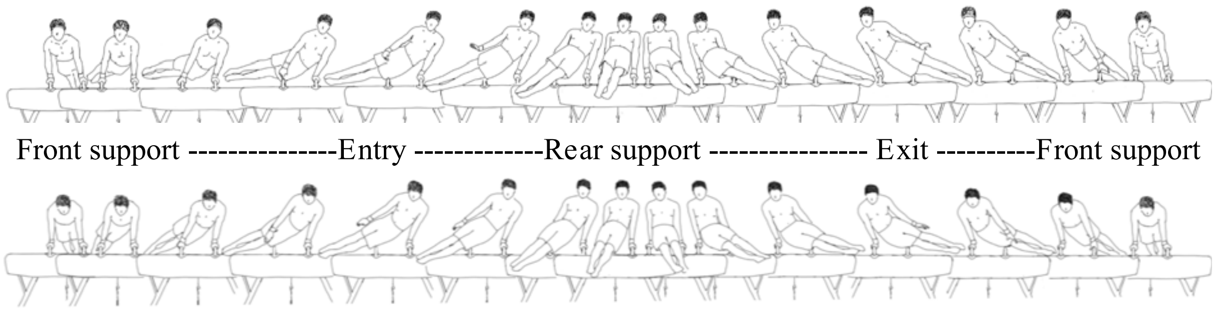

Figure 1. Description of typical higher-quality (top) and lower-quality (bottom) circles and phase definitions. Phases are often divided into four phases based on the relative position of the legs with respect to the pommel horse and the hand release and re-grasp. Front and rear support phases are the double-hand support phases, and entry and exit phases are the single-hand support phases.

In biomechanics, some studies have objectively examined the amplitude of circles. Most common mechanical variables that can discriminate the level of expertise include hip or body angle, and the horizontal diameter of the ankles' excursion (Baudry et al., 2009; Fujihara & Gervais, 2012a). When the hip or body angles were considered, some studies computed the flexion and side flexion separately (e.g. Fujihara and Gervais, 2010). According to Baudry et al. (2009), the horizontal diameter of shoulders' excursion and the shoulder extension angle in the rear support phase (See Figure 1 for the phase definitions) also show significant differences between the skilled and the unskilled gymnasts. These mechanical variables could be helpful to objectively evaluate the quality of circles, but the complexity of computation and a time-consuming data collection procedure may limit a practical application in a daily training.

As a simpler variable, Fujihara and Gervais (2013) pointed out that the head position particularly in the rear support phase is strongly correlated with the scores given by the official gymnastics judges. In fact, this variable showed high correlations with other amplitude variables introduced above: a body flexion angle, the horizontal diameter of shoulders' excursion and the shoulder extension angle in the rear support. Intriguingly, the horizontal diameter of ankles' excursion was the only variable that did not show significant correlation with the head position in the rear support. Because all investigated variables were more or less correlated with the scores by the judges, the motions of head and feet may contain unique information for score prediction whereas other measures such as a body or shoulder angle could be regarded as redundant with the information about the head motion.

Based on these previous studies, we hypothesized that using these two body parts, namely head and feet, or toes in order to differentiate whether or not toes are pointed, might be a plausible method to evaluate the amplitude of circles in a simpler manner. By taking into account the trajectory of the feet in addition to the position of the head segment, which has redundant information on body and shoulder angles, the distance between the head and the centre of the toes (Head-Toe Distance: HTD) can represent much about the quality of circles despite its simplicity (Figure 2). It appeared to be valid from both a practical viewpoint and a theoretical viewpoint of 'straight body' as supported by the previous research. The purpose of this study was to investigate the possible use of HTD as a simple measure for evaluating the amplitude of circles on pommel horse. Such a simple objective measure could be beneficial for evaluation of the performance, assisting coaches and athletes during training and return to best play following injury. Also, this simple measure could potentially provide additional assessment information for judges in a practical setting.

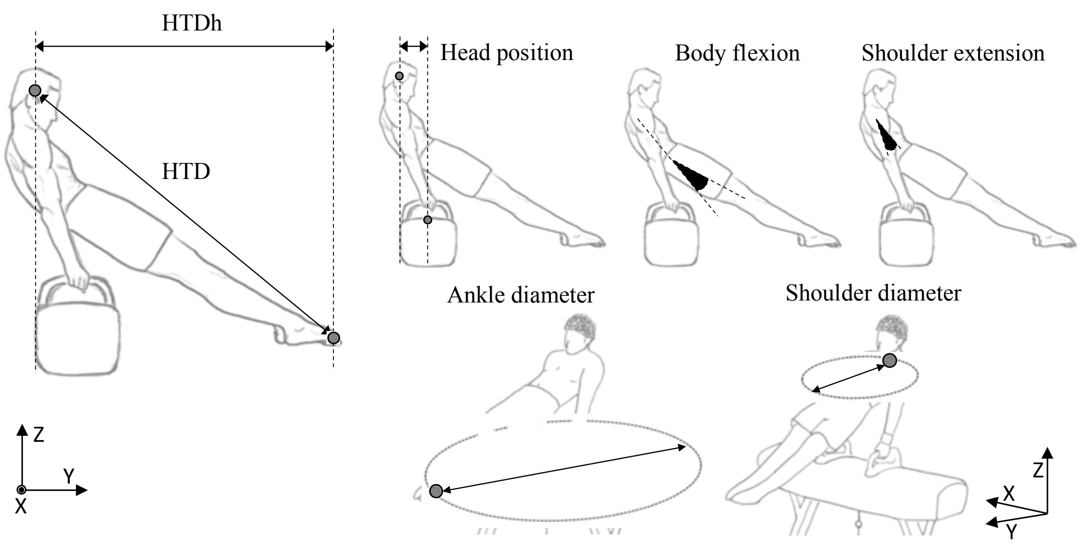

Figure 2. Illustrations of Head-Toe Distance (HTD), its horizontal version (HTDh), and the other amplitude variables computed.

METHODS

Data collected from successful previous studies were employed (Fujihara & Gervais, 2012b) and extended the analysis. Fourteen national-level and four international-level male gymnasts participated in the experiment. All 18 gymnasts were able to consistently perform 20 consecutive circles on two handles of a pommel horse. The mass, height, and ages of the gymnasts were 47.7 ± 10.8 kg, 1.55 ± 0.11 m, and 16.2 ± 3.6 years. They had 9.4 ± 2.9 years of experience in competitive gymnastics and trained 20.3 ± 3.5 hours per week at the time of data collection. Written informed consent was obtained of all the gymnasts and the guardians of under-18 gymnasts. Prior to the start of this project, ethical approval was obtained through the institutional research ethics review board.

A no-leg pommel horse was placed in the laboratory, and the kinematic data were collected using a Qualisys motion capture system with 13 cameras placed around the pommel horse (ProReflex MCU 240, f6 lens, Qualisys AB, Sweden). According to the results of the inter-marker-distance accuracy tests, which were performed before and after each data collection, the standard deviation and the range of the 750.2 mm-wand length were at most 1.3 mm and 8.3 mm, respectively. The centre of the top surface of the pommel horse was defined as the origin of the laboratory coordinate system, and the X-, Y-, and Z-axes were the horizontal lines along the long and short axes of the horse and the vertical line through the origin. The positive directions of the X-, Y-, and Z-axes were rightward, forward, and upward with respect to the direction of the performance (Figure 2).

After general and event-specific warm-ups, the participants were fitted with retro-reflective markers on the anatomical landmarks suggested by de Leva (1996) and performed three sets of 10 circles on the pommel horse. For the full description of the marker placement and the procedure of the anatomical calibrations, please refer to Fujihara and Gervais (2012b). Three-dimensional (3-D) kinematic data were recorded at 100 Hz. For each set of 10 circles, 7 circles (3rd – 9th) were used so that the individual mean data were computed from the data of 21 circles. The 3-D coordinate data were smoothed using a fourth-order Butterworth digital filter at the optimal cut-off frequencies (3.0 Hz – 12.2 Hz) determined by an automatic algorithm (Yokoi & McNitt-Gray, 1990). The head segment was defined as a line from a vertex (top of head) to the centre of right and left gonions, and its mass centre was estimated as a point at 59.76% from the vertex (de Leva, 1996). Hip joint centres were estimated using Halvorsen's algorithm (2003), and all other joint centres were estimated as the centres of two markers attached on the surface of each joint.

HTD was computed as the 3-D distance between the head mass centre and the centre of two markers attached on the right and left acropodions (Figure 2). The head mass centre should reflect the position of the segment better than a vertex. HTD was also computed on a horizontal plane (HTDh), and both HTD and HTDh were normalized by the body height of each gymnast (unit: %BH). As representative kinematic variables for amplitude evaluation of circles, the following variables were also considered: horizontal diameters of shoulder and ankle trajectories (shoulder diameter, ankle diameter), a body flexion angle, a shoulder extension angle in the rear support, and the head position in the rear support position (Fujihara & Gervais, 2012a; b; 2013). The diameters and angles were computed by following Grassi et al. (2005) and Fujihara and Gervais (2010), respectively. The illustrations of these variables are shown in Figure 2, but more detailed computational descriptions can be found in Fujihara and Gervais (2012b).

Four internationally accredited judges

scored the video-recorded circles. A perfect score was set at 10.0 and deductions were applied in step of 0.1 according to technical faults or execution errors. Then, the average of four scores was determined as the final score. The intra-class correlation coefficient, computed as an estimate of the inter-judge reliability, was 0.944. Pearson's product-moment coefficient of correlation was considered among the scores and all computed variables. The normality of the data was checked using the Kolmogorov-Smirnov test. The experiment-wise error rate was set at $p < 0.05$, and the Holm's correction (Holm, 1979) was applied for multiple univariate statistics (Knudson, 2009). The purpose of this study was to explore the possible use of HTD as a simple measure in relation to the quality of circles, instead of to find the best way to predict a score given by the judges participated in this particular study. Therefore, stepwise multiple regression analysis was conducted by a two-block method: first block took HTD and HTDh, and then the second block took the all other variables computed as potential predictors. IBM SPSS statistics v.23 was used for the statistical computations.

RESULTS

Table 1 shows the scores given by the judges and the all computed variables for each individual gymnast. According to the results of the Kolmogorov-Smirnov tests, the distributions of all variables analyzed were not significantly different from a normal distribution. Also, there was no outlier that largely deviated from each variable's mean (< 3 standard deviation). The overall averages of HTD and HTDh for all gymnasts were 88 ± 3 %BH and 75 ± 2 %BH, respectively. The gymnast who had the best score out of 18 gymnasts exhibited the greatest HTD (94 %BH) and HTDh (80 %BH) as the average of 21 circles analysed (Table 1). See Figure 3 for the time-series change in HTD and HTDh during circles for each gymnast. Both HTD and HTDh tended to decrease around the rear support phase where the difference in the head position was found in the previous study (Fujihara & Gervais, 2013). However, the higher-scored gymnasts, who had scores greater than 9.0 out of 10.0, showed less decrease in both HTD and HTDh, maintaining a relatively high value throughout a circle (Figure 3).

The average standard deviation of HTD and HTDh for each gymnast (21 circles) was 0.43 ± 0.16 %BH and 0.56 ± 0.18 %BH, so the intra-gymnast variability was smaller than the inter-gymnast variability. Figure 4 plots the standard deviations of HTD and HTDh for each gymnast against the scores. The higher-scored gymnasts tended to show smaller variability, implying more consistent performance.

Table 2 displays the correlations among the scores and all the amplitude variables computed. The average HTD and HTDh were both significantly correlated with the scores given by the official gymnastics judges, but HTDh showed a stronger correlation than HTD (HTD: $r = 0.556$, $p = 0.017$, HTDh: $r = 0.735$, $p = 0.001$). As a result of the stepwise multiple regression analysis, two models showed statistical significance (Table 3). The first model included HTDh alone as a predictor (adjusted $R^2 = 0.511$). The second model included HTDh and HTD, increasing the adjusted R^2 to 0.662. After these two variables were entered at the first step, no other amplitude variables were entered at a statistically significant level.

Table 1
Scores and the performance variables for each individual gymnast.

Gym -nast	Score	HTD (%BH)	HTDh (%BH)	Head position (m)	Body flexion (°)	Shoulder extension (°)	Shoulder diameter (%BH)	Ankle diameter (%BH)
1	9.675 ± 0.340	94	80	-0.15	2	34	30	101
2	9.575 ± 0.544	91	77	-0.15	-1	26	31	100
3	9.375 ± 0.556	90	77	-0.11	9	20	30	99
4	9.350 ± 0.387	89	77	-0.11	9	28	31	98
5	9.300 ± 0.594	89	76	-0.17	16	26	29	100
6	9.300 ± 0.622	90	77	-0.17	11	15	29	100
7	9.100 ± 0.898	92	78	-0.20	-2	33	32	95
8	9.100 ± 0.707	88	75	-0.09	13	22	29	100
9	8.975 ± 0.822	87	73	-0.05	24	16	27	98
10	8.975 ± 0.608	88	76	-0.07	16	17	28	103
11	8.750 ± 0.686	91	77	-0.18	15	27	31	96
12	8.575 ± 0.939	89	76	-0.15	3	24	29	98
13	8.425 ± 0.911	86	75	-0.06	15	18	28	98
14	8.425 ± 0.709	84	71	-0.05	22	7	26	95
15	8.300 ± 1.030	84	71	-0.01	35	10	26	96
16	7.950 ± 0.526	88	74	-0.05	25	9	28	94
17	7.300 ± 0.963	87	73	-0.08	24	21	29	95
18	6.650 ± 1.109	87	72	-0.04	35	14	27	94
Aver -age	8.728	88	75	-0.10	15	20	29	98
SD	0.798	3	2	0.06	11	8	2	3

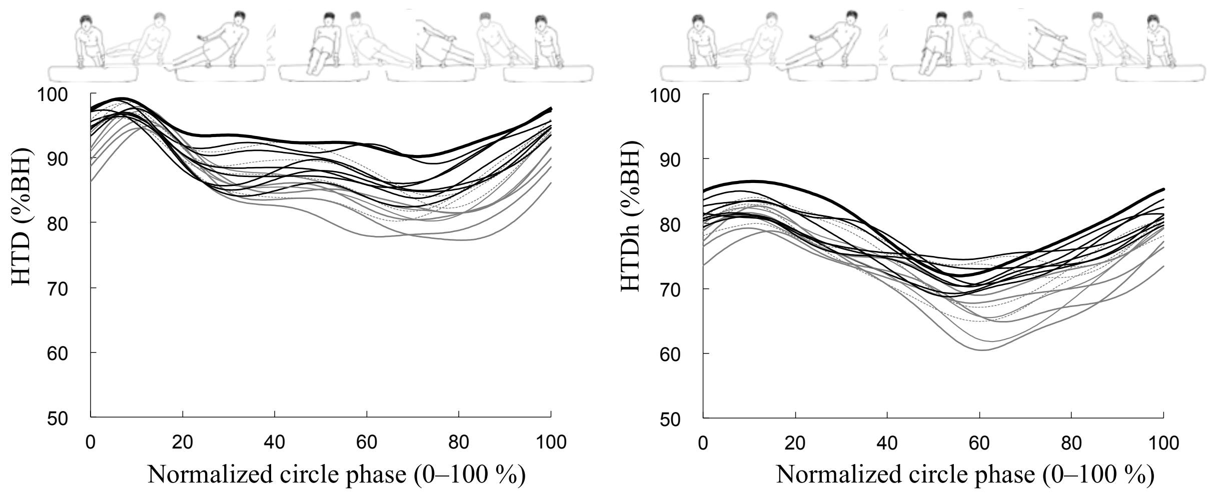

Figure 3. Change in HTD and HTDh during a single circle. Each line represents the average of 21 circles by each gymnast. Higher-scored (>9.0) - and lower-scored (< 8.5) gymnasts are shown in black and grey lines, respectively. The grey broken lines are the gymnasts whose scores were between 9.0 and 8.5. The thickest black line shows the highest-scored gymnast (9.675). The gymnasts with higher scores demonstrate relatively higher HTD and HTDh throughout a whole circle, particularly from the rear support.

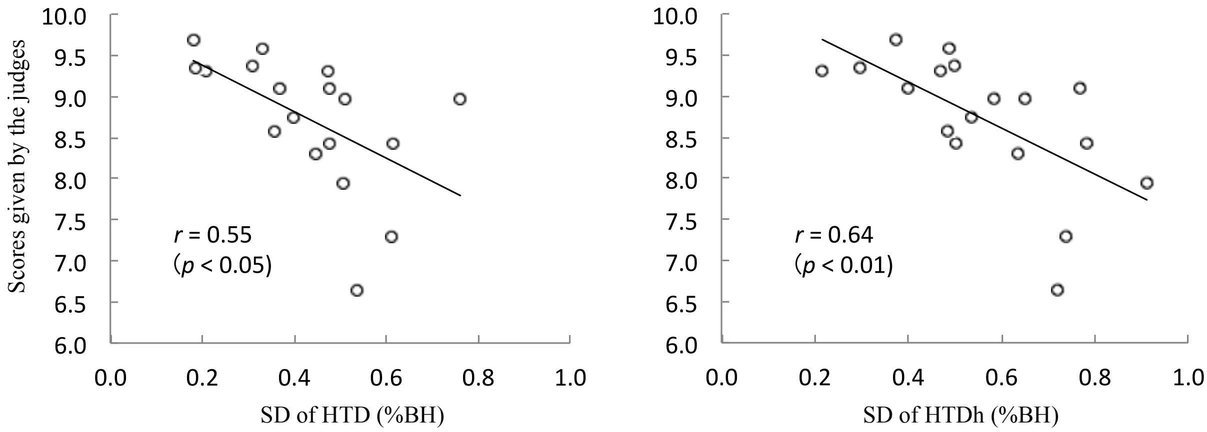

Figure 4. The relationships between the scores given by human judges and the standard deviation of HTD (left) and HTDh (right) among 21 circles (7 circles x 3 sets).

Table 2
Correlations among the scores and the amplitude variables.

Variables	*r*	*p*	Critical *p*	Sig.
Body flexion	0.737	0.000	0.007	*
HTDh	0.735	0.001	0.008	*
Ankle diameter	0.725	0.001	0.010	*
Head position	-0.576	0.012	0.013	*
HTD	0.556	0.017	0.017	*
Shoulder extension	0.517	0.028	0.025	
Shoulder diameter	0.498	0.035	0.050	

Table 3
The results of stepwise multiple regression analysis.

Model	Predictors	Adjusted R^2	F	Sig.	Partial Correlation (Excluded variables)					
					HTD	Head Position	Body flexion	Shoulder extension	Shoulder diameter	Ankle diameter
1	HTDh	0.511	18.78	0.001	-0.593	0.059	0.295	-0.172	-0.297	0.550
2	HTDh, HTD	0.662	17.65	0.000	-	-0.24	0.329	0.036	-0.006	0.304

DISCUSION

Providing simple, scientifically rigorous and ecologically valid methods to assess the quality of skill is a desirable tool for coaches, sports judges, and scientists. This study investigated the use of HTD, a simple measure using head and toes to evaluate the quality of circles, finding that its horizontal component, HTDh, is a potential variable. The results shown in Figure 3 supported the possible use of HTDh both on individual and group levels. The higher-scored gymnasts showed less decrease in HTDh during and after the rear support phase, resulting in the greater

HTDh on average (Table 1). HTD also showed a strong relationship with the scores and the other variables but not as strong as that of the HTDh. When both HTDh and HTD were used to predict the scores, more variance was significantly explained (Table 3). Whilst there are more thorough ways to evaluate the quality of circles e.g. using multiple biophysical variables to reflect different aspects, but HTDh seems to be a good option as a single variable to evaluate the amplitude of horizontal rotation.

Recall that in this study the judges followed two rules: that a perfect score was 10.0, and that a deduction was applied in step of 0.1 according to technical faults or execution errors. The highest score seen among the participants was 9.675 (Table 1), so all of them seemed to have room to improve their performance to some extent. In fact, some judges provided their comments on the performances in addition to the score. Based on their comments, a judge appears to look at body extension, amplitude, rhythm, leg form errors, consistency, and the timing of hip turns. The scores given by the judges in this study should be considered to be more comprehensive and therefore more complicated than just focusing on the amplitude. In Figure 4, a few of the lowest-scored gymnasts showed relatively greater deviation from the regression line, implying that the judges more than likely found multiple technical errors, including the amplitude, in those performances. As shown in Figure 4, the lower-scored gymnasts demonstrated less consistent performances. Looking to future studies, an examination of the relationship between the amplitude variables with respect to human-judged evaluation that is concentrated only on the amplitude would be interesting.

Using HTDh as an objective measure for the amplitude may become more attractive when its computational simplicity is taken into account. For instance, the body flexion angle was slightly better than HTDh for predicting a score (Table 2), but this variable used in this study as well as the previous studies (Fujihara & Gervais, 2010; 2012) required the 3-D angular computations in a couple of moving coordinate systems. The results of 3-D angular computations were often influenced by the definition of angles as well as the way to determine the joint centre. HTDh, on the other hand, required only the 3-D positional data of the two points and a simple computation of the distance between them. It is much simpler and easier to quantify the amplitude as a measure of the performance quality. Computing the head mass centre using Grassi et al’s method, which computes the horizontal diameter of ankle or shoulders trajectory, also needs only positional data to quantify performance quality (Grassi et al., 2005). In their method, the average position throughout a whole circle is regarded as the centre of rotation, and the radius or diameter is calculated based on this rotational centre at each time point. It is, therefore, impossible to evaluate the amplitude at any single time frame independently. In contrast, HTDh does not need any reference point for its computation. It is only the distance between the two points at any time. Furthermore, there is no need for the identification of the phases. Because the shoulder extension angle and the head position as the amplitude variables were expected to show significant differences during the rear support phase, identifying a phase is a necessary requirement to compute these variables.

While some may argue that sports like gymnastics need objective scores to prevent issues associated with human qualitative assessment, others may argue that the quality of a performance in such sports should not or cannot be evaluated in any quantitative manner. This is mainly a matter of validity. The question is not whether it is qualitative or quantitative but whether it is valid or invalid. Human perception tends to be influenced by various factors. For example, Plessner and Schallies (2005) reported the significant influence of viewpoint when the gymnastics judges were asked to evaluate the Cross on rings. Judges in artistic gymnastics are seated in assigned locations around the apparatus when judging performances at competition (Article 5.6, p18, International Gymnastics Federation, 2017), implying people tacitly accept a possible influence of a view angle. Considering the plane of motion during circles on pommel horse, the amplitude of horizontal rotation would be best evaluated from above. Figure 5 may help us to accept the possible influence of the view angle on our impression of the performance. Although recent TV broadcasts often include video from above, in the current rules, no judge on pommel horse may evaluate from above. An aerial view is also unlikely to be available in regular training facilities. As discussed in Fujihara, Yamamoto, and Fuchimoto (2017), objective information could become more useful to supplement subjective feedback or evaluation if such objective information with good validity and reliability is provided with an easy and immediate manner at a low cost. The immediate feedback of the HTDh could be of very practical benefit to gymnasts and coaches.

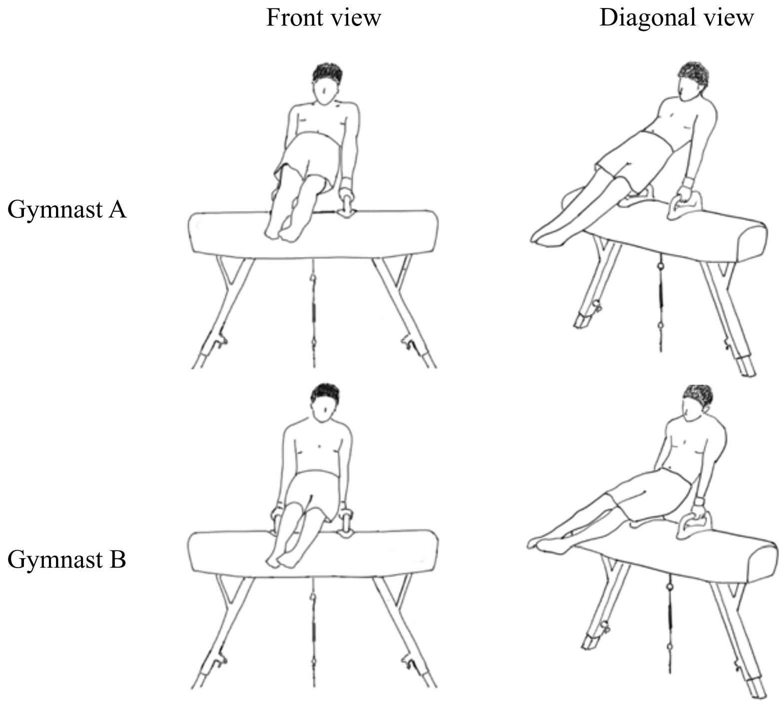

Figure 5. Descriptions of the possible different impression caused by a different view position. For each gymnast A or B, two figures shows the rear support position at the same time from a different viewpoint. The difference in body alignment, especially a piked body in gymnast B, is less clear in the front view. It should be noted that the original videos for tracing these figures were not those that were recorded for the current study. Therefore the models for these figures are do not match with any individual shown in Table 1.

This simplicity may contribute to a more practical application of biomechanical knowledge in a regular training or possibly in a competition. To date in the gymnastics community, the complexity of typical biomechanical procedures have limited the practical use of such an objective information for coaching in a regular training session or judging in a competition. Nevertheless, more recent technology may change the situation in the near future. Mr. Morinari Watanabe, the current president of the International Gymnastics Federation, presented his plan to develop a judging support system in collaboration with a Japanese company, Fujitsu (Liubov, 2017). Fujihara (2017) introduced the potential usage of a Kinect device to identify the top of the head and the tip of toes during circles on pommel horse, as a non-invasive approach to provide immediate feedback in a regular training session. Although the Kinect system captured the positions of the top of the head, not the head mass centre, to compute HTDh, the possible difference should be within an acceptable range in a practical setting. When we computed HTDh with a vertex instead of the head mass centre, the Pearson's correlation coefficient was still high (r = 0.69). On a horizontal plane, the top of the head would be closer to the head mass centre than a vertex.

To use HTDh as an amplitude measurement, there are several things to be considered. First, what would be the best use of HTDh was not considered in the current study. Only the average of HTDh during a whole circle was computed, but there might be a more valid way to evaluate a performance. Because especially in the front support position, it is less persuasive to argue that the greater HTDh always means the better performance. Therefore, setting a certain benchmark value for amplitude could be a possible option. Let us say that 80% of body height is the standard, and then a point is deducted if HTDh is lower than this value thus indicating lack of amplitude. Such an evaluation method was tested, but the correlation with the scores was very similar to the case with mean HTDh (r = 0.73) with the current data set. Second, using multiple variables in addition to HTDh could improve the score prediction because the ankle diameter still seemed to contain unique information, which was not reflected in HTDh. One possible explanation for this is the presence of centrifugal force. Fujihara (2016) presented that skilled gymnasts are better at maintaining a higher centrifugal force during a transitional phase than their unskilled counterparts. A greater centrifugal force contributes to a horizontal rotation of the mass centre that is dynamically balanced on a higher plane, resulting in a greater diameter of the distal points (feet and toes). This detail may not be fully reflected in HTDh, therefore accompanying measures could improve the validity of the evaluation. We have to acknowledge that the results of this study were based on relatively homogenous samples of the gymnasts and the scores of only four judges. Finding the best way of score prediction was beyond the purpose of this research. Additionally, a different aspect of performance quality, such as consistency, will be a task for future study.

CONCLUSIONS

Previous findings led us to hypothesize that the distance between the head and toes, HTD and HTDh for its horizontal version, could be a more practical and simpler tool to evaluate the amplitude of circles. In this study, we investigated HTD and HTDh by examining the relationships between these novel variables and the human-judged score as well as the other amplitude variables used in the literature. The results supported the use of HTDh rather than HTD or any other amplitude variable as a single variable to objectively evaluate the amplitude of circles on pommel horse. In addition to the potential validity as an objective measure, its simplicity in concept and an actual process to obtain the data may provide us more opportunities to apply it in a practical setting. As such this grounded scientific approach with high ecological validity presents practical applications and warrants the further exploration of the use of HTDh. Integrating an advanced technology and a novel idea may enhance the quality of information to the sport.

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