ABILITY TO MAINTAIN AMPLITUDE WHILE PERFORMING CIRCLES ON POMMEL HORSE

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Amplitude is an important aspect for performing circles on a pommel horse, but the ability to maintain such amplitude over the course of a long performance, say, over 10 seconds, has not been studied. This study provides pilot data for the ability to perform many circles and maintain amplitude. In all, 28 gymnasts performed as many circles as possible on a pommel horse while maintaining as great an amplitude as possible. Kinematic data were recorded using a Kinect set above the pommel horse, and the head–toe distance on a horizontal plane was computed as an amplitude variable. As a result, the average number of circles was 46; only 25% of participants were able to perform over 50 circles. Even for them, it was difficult to maintain amplitude after 50th repetitions, suggesting that 50 circles was a discriminative number for higher-level performance.

KEYWORDS: Kinect, evaluation, rotation, kinematics, gymnastics.

INTRODUCTION: The pommel horse is one of six events in men's artistic gymnastics, and most skills in this event are based on a single fundamental skill called circles (Figure 1). The gymnast's level of skill in performing circles affects not only the quality of the whole performance on the pommel horse, which is evaluated as an execution score (E-score), but also the potential for achieving a greater-difficulty performance, which is reflected in the difficulty score (D-score).

Figure 1: Circles on two handles on pommel horse.

The amplitude of horizontal rotation cannot be dismissed when considering the quality of circles done on the pommel horse. Lack of amplitude during circles results in an E-score point deduction (International Gymnastics Federation, 2016, p. 54). Previous research has investigated circles' amplitude from a biomechanical viewpoint and used several variables, such as a body angle and the diameter of horizontal ankle rotation (e.g., Baudry et al., 2006). More recently, Fujihara (2016) presented head–toe distance on a horizontal plane (HTDh) as a simple but valid variable for evaluating the amplitude of circles in a practical situation. In addition, Fujihara (2017) computed HTDh, without a traditional video analysis or motion capture, by using kinematic data from a Kinect V2 placed above the pommel horse, demonstrating the practical potential of its application to coaching or judging.

To achieve a high-difficulty routine, however, not only circle quality but also the ability to maintain that quality comes into play. The average duration of the pommel horse routines by the eight finalists on the pommel horse in the 2017 World Championships was 46 ± 5 seconds. The most common experimental task, however, has been a set of 10 circles (e.g., Grassi et al.), which takes only 9–10 seconds. Almost no data is available for any longer performance of circles, despite its significant practical importance. Top Russian coaches documented that no fewer than 50 circles on two handles is one of the technical requirements for high-level pommel horse performance (Arkaev & Suchilin, 2003). A Japanese coaching manual (2002) introduces a set of 50 circles as a daily training exercise for a young high-level gymnast. Both of these books were published in the previous-code cycle, in which competitive routines were relatively shorter than in modern gymnastics

competitions. For a gymnast competing under the current rules, the ability to perform an even greater number of circles would be required for high-level performance; objective data regarding gymnasts' ability to perform many circles and to maintain their quality of circles would therefore be useful for practitioners.
This study provides pilot data regarding the maximal number of circles and the ability to maintain their amplitude. We hypothesised that the most number of circles a gymnast can achieve is related to that gymnast's performance level on the pommel horse and that the amplitude of the circles produced tends to decrease, possibly due to fatigue, as the number of circles gets closer to the gymnast's maximal number.

METHODS: The data from circles performed by 27 university gymnasts and 1 graduate who regularly train in the same gym (mean ±SD: age 19.5 ±1.8 years, 1.65 ±0.05 m) were collected for this study. The competitive level of each gymnast was expressed as the D-score of the given gymnast's routine at the time of data collection and the best competitive score during the past year. Because some gymnasts competed in few or no official competitions, the recorded scores given by the licenced judges in a competition rehearsal training were also counted. All data to be analysed were measured while the gymnasts were performing one of their regular exercises during a daily training. The task was to perform as many circles as possible on the two handles of the pommel horse (Figure 1) while maintaining as high a performance quality as possible, especially maintaining amplitude. All data-collection processes were approved by our institutional ethics review board, and all the gymnasts agreed to participate in the training with the measuring system and to provide the collected data for research purposes.
As was done by Fujihara (2017), a Kinect V2 device was placed above the competitive pommel horse in our training gym and used for kinematic data collection at 30 Hz (Figure 2). The Kinect faced downward onto the centre of pommel horse. While each gymnast performed circles, the Kinect measured three-dimensional kinematic data, without interference with the performance. No marker or any other research-related object was attached to the gymnasts, who wore their own ordinary T-shirts and pants. Because of the differences in the gymnasts' training programs, the total number of trials for each varied, but no gymnast attempted this task more than once on any given day. From the data of over 200 total trials collected over 2 weeks in March 2018, each gymnast's best trial, showing the greatest number of circles, was analysed for this study.

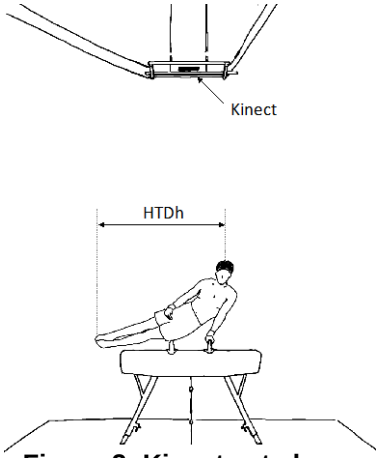

Figure 2: Kinect set above the pommel horse.

The amplitude variable, HTDh (Figure 2), was computed as the horizontal distance between the top of the head and the tip of toes and was normalised based on body height. In the kinematic data set, the highest body part during the circles was defined as the top of the head, and the farthest part of the body from the top of the head was defined as the tip of the toes. All coordinate data were smoothed by a Butterworth digital filter at a cut-off frequency of 6 Hz. Low-quality data resulting from technical issues such as weak laser reflection were not used for analysis. The number of circles was counted when the toes passed the centre of the backside of the pommel horse. The first and the last circles were excluded from the analysis as forming part of a transitional phase. HTDh was calculated for each data point and averaged for each circle, for each 10 circles, and for the final 10 circles. Based on the data from Fujihara (2017), which reported that the average HTDh of 18 gymnasts was 77.0 ±2.5% body height (%BH) (Fujihara, 2017), the amplitude was operationally evaluated as follows: very good = (HTDh ≥ 82%BH); good = (82%BH > HTDh ≥ 79%BH); average = (79%BH > HTDh ≥ 76%BH); poor = (76%BH > HTDh ≥ 73%BH); and very poor = (73%BH > HTDh). The mean HTDh of the first 10 circles was compared to that of the final 10 circles with a paired sample *t*-test as well as Cohen's *d*. Pearson's product-moment coefficient of correlation was used to examine the relationship between the

maximum number of circles and the competitive level. All statistical analyses were processed with an IBM SPSS statistics v.23.

Table 1: Gymnast characteristics and their performances of maximal circle repetition, with amplitude expressed as the average head–toe distance on a horizontal plane.

Gymnast	Body Height	Age	D-score	Season Best	Number of circles	Average head–toe horizontal (%BH)										
						1- 10	11- 20	21- 30	31- 40	41- 50	51- 60	61- 70	71- 80	81- 90	91- 100	(Last 10)
1	1.65	27	5.4	13.90	81	77.6	78.3	78.5	78.1	77.6	76.7	75.5	74.5	73.7		74.4
2	1.56	18	5.4	13.40	62	77.4	77.7	77.6	76.7	76.0	74.8	72.5				74.3
3	1.60	19	5.1	13.90	43	77.2	79.6	79.6	78.0	76.9						77.5
4	1.65	21	5.0	13.10	56	77.7	77.6	77.5	77.4	77.2	77.5					77.4
5	1.57	19	4.8	13.45	52	75.4	76.3	75.4	74.3	72.9	71.7					72.7
6	1.61	19	4.8	12.80	95	75.9	75.4	75.1	74.5	73.9	73.5	72.8	71.8	70.8	67.2	69.0
7	1.68	20	4.7	12.35	45	78.7	78.3	77.9	77.3	74.2						75.5
8	1.58	20	4.5	13.25	45	78.3	78.2	77.7	77.5	76.8						77.1
9	1.60	18	4.5	12.55	47	76.1	77.0	76.8	76.1	74.9						75.3
10	1.70	18	4.4	12.40	42	78.4	78.1	77.7	76.7	76.0						76.5
11	1.74	19	4.2	11.60	39	78.0	77.7	78.8	77.1							77.2
12	1.67	21	4.1	11.90	49	77.4	77.6	76.3	75.4	72.5						72.7
13	1.68	19	4.1	11.85	51	79.6	80.4	80.1	78.8	77.3	73.9					76.9
14	1.71	19	4.0	12.45	43	74.0	74.9	73.7	73.4	73.3						73.4
15	1.63	19	4.0	12.35	49	75.2	76.8	76.2	74.7	72.3						72.5
16	1.60	20	4.0	12.10	44	81.5	82.2	81.7	80.5	79.5						79.9
17	1.59	18	4.0	10.10	33	79.6	81.3	79.9	78.8							79.4
18	1.78	19	3.9	12.65	39	79.1	78.6	78.0	77.3							77.3
19	1.63	18	3.8	11.20	37	77.4	77.7	77.7	76.9							77.0
20	1.69	21	3.7	11.40	45	74.7	74.1	73.4	72.6	71.3						71.8
21	1.62	20	3.7	11.25	57	75.8	75.8	74.6	73.8	72.7	71.4					71.7
22	1.67	19	3.5	11.20	41	75.9	75.1	75.3	74.2	72.3						73.8
23	1.65	19	3.4	10.40	42	75.3	75.7	75.1	74.6	73.9						74.5
24	1.70	20	3.3	10.10	33	73.5	73.9	74.2	73.4							73.8
25	1.66	18	3.0	9.35	33	74.9	75.5	74.0	73.1							73.5
26	1.60	21	2.9	10.05	34	72.2	71.5	71.3	70.2							70.7
27	1.68	19	2.8	10.65	22	80.6	77.0	71.6								75.2
28	1.61	20	2.4	9.60	34	71.3	71.7	71.4	71.1							71.3
Mean	1.65	19.6	4.1	11.83	46.2	76.7	76.9	76.3	75.6	74.8	74.2	73.6	73.2	72.3	67.2	74.7
S.D.	0.05	1.8	0.8	1.30	14.7	2.4	2.5	2.7	2.5	2.3	2.3	1.7	1.9	-	-	2.7

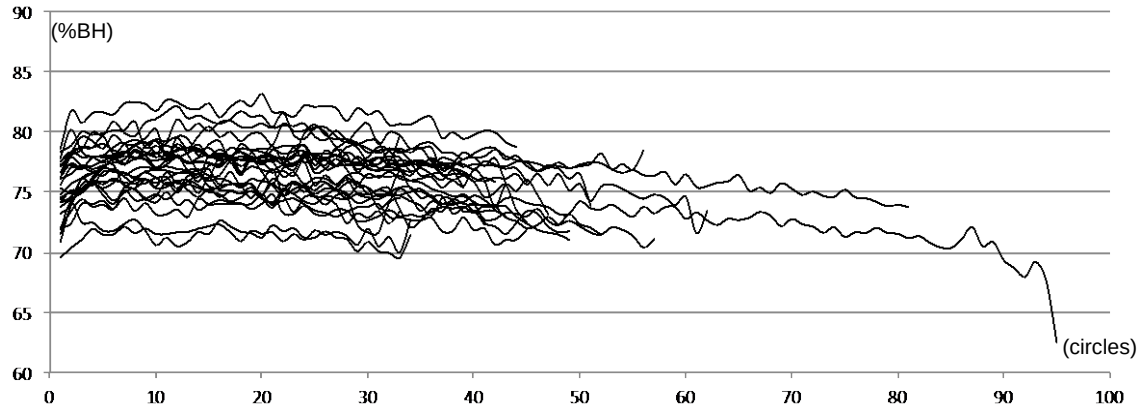

Figure 2: Change in the head–toe distance on a horizontal plane in relation to the number of repeated circles.

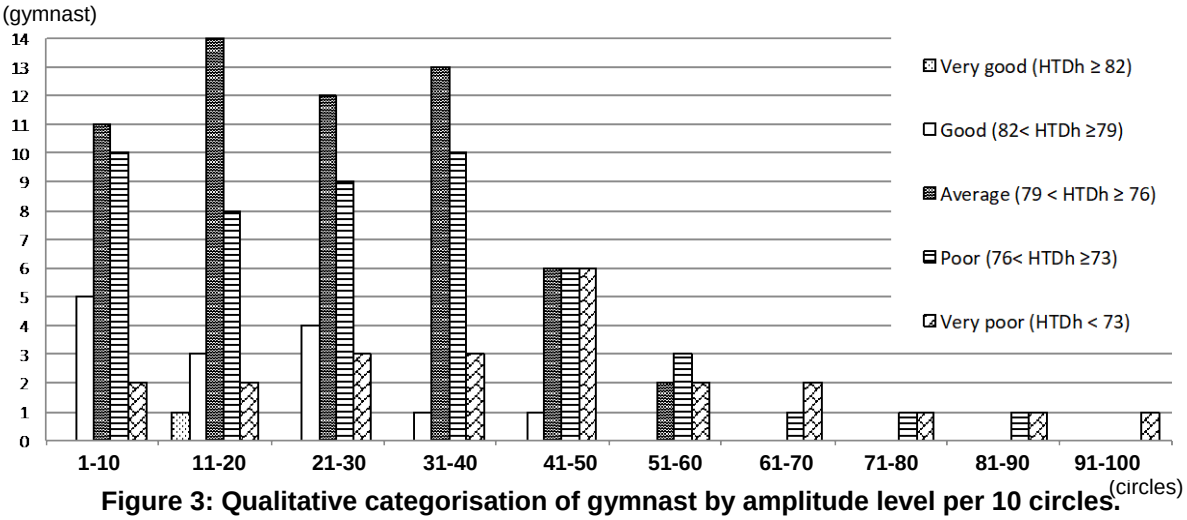

Figure 3: Qualitative categorisation of gymnast by amplitude level per 10 circles.

RESULTS: The average number of repeated circles was 46.2 ± 14.7 for the study population (Table 1) with a range of 22 to 95 circles. Maximal circle repetition was significantly correlated with performance level, as indicated by D-scores of the gymnasts' routines (r = 0.68, p < 0.001), and the best season scores for the pommel horse (r = 0.61, p < 0.01). The average HTDh for each circle fell within the range from 70 to 85%BH, and the average HTDh of the first 10 circles was 76.7 ±2.4%BH (Table 1). Although the average HTDh generally stayed the same until the 30th repetition, the average HTDh of the last 10 circles (74.7 ±2.7%BH) was significantly smaller than those of the first 10 circles (t = 6.019, p < 0.001, Cohen's d = 1.137). Only seven gymnasts reached more than 50 circles, and Figure 2 shows that HTDh tended to drop, especially after 50 circles, even for them. No gymnast in this group could make circles with a 'good' amplitude after 50 repetitions or even with an 'average' amplitude after 60 repetitions (Figure 3).

DISCUSSION: Performing a certain number of repetitive circles is common practice for all levels of gymnasts and is often included in technical tests or domestic compulsory routines. Objective data on a gymnast's ability to perform many circles has seldom been available. In this study, two-thirds of university gymnasts in one group performed over 40 circles, but only one-quarter of them attained over 50 circles. Maintaining 'good' or 'average' amplitude up through 30 circles appeared to be relatively easy but became more difficult after that; in particular after 50 circles. These results suggest that ability to perform 50 circles is a marker for high performance ability (Arkaev and Suchilin, 2003). The ability to perform many circles was significantly correlated to skill level evaluated by D-scores and season's best scores. Interpretation of results is inevitably limited by the competitive level of the participants; data for higher-level gymnasts are necessary. These data, were obtained during the participating gymnasts' regular training without interference by any research-related object; this means high ecological validity. Since gymnasts regularly use systems and accumulate data in daily trainings, longitudinal data showing their training progress could be of interest.

CONCLUSION: Pilot data demonstrated that gymnasts generally maintained their amplitude for 30 circles but amplitude decreased near the end of the trial. Their performance level on the pommel horse was found to be related to the ability to perform many circles.

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