USING A KINECT DEVICE TO EVALUATE AMPLITUDE OF HORIZONTAL ROTATION ON THE POMMEL HORSE

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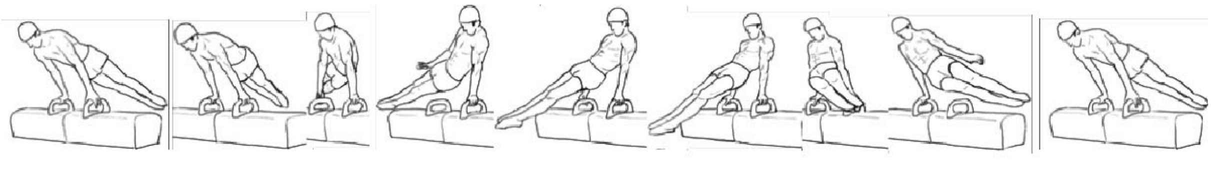
It is difficult to obtain timely feedback from traditional video-based motion analysis during a regular sports training session due to the demands of camera placement and data processing. However, advanced devices such as the Kinect may have practical use in this regard. The present study examined the usefulness of a Kinect device in evaluating pommel horse performance in men's artistic gymnastics. An original algorithm was developed to compute the head-toe distance (HTDh), one of the key performance variables identified in a previous study, using data collected by a Kinect device. Comparing the data from this algorithm to those obtained by traditional video analysis demonstrated that a Kinect device could be useful for computing HTDh in a practical setting, providing immediate and objective feedback.

KEYWORDS: immediate feedback, objective evaluation, kinematics, gymnastics

INTRODUCTION: The pommel horse is a unique event in men's artistic gymnastics, because the skills required in this event mainly involve horizontal rotation of the body. The amplitude of horizontal rotation is one of the most important qualities of pommel horse performance. The *Code of Points* (International Gymnastics Federation, 2016, p. 54) states, 'Ideally circles [see Figure 1] and flairs must be performed with complete extension. Lack of amplitude in body position is deducted as an individual deduction on each element'.



---------- Front support phase ---------- Entry phase ----------------- Rear support phase ----------- Exit phase ---------------------

Figure 1: Circles on the pommel horse and the definition of each phase.

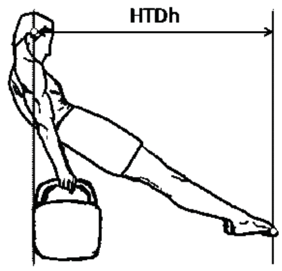


Figure 2: Head-toe distance on a horizontal plane (HTDh).

Previous research involving biomechanical motion analysis has shown that the quality of a skill on the pommel horse—especially the most basic skill, known as circles (Figure 1)—can be discriminated by several mechanical variables. For example, Baudry et al. (2009) reported that circles performed by elite gymnasts were characterised by greater horizontal diameter of the ankles' excursion, as computed using the method of Grassi et al. (2005), and smaller hip angle. They also found significant differences in the horizontal diameter of the shoulders' excursion as well as the shoulder extension angle during the rear support phase (see Figure 1 for the definition of phases). Fujihara and Gervais (2012) employed these variables to evaluate the amplitude of circles, finding that the head position in the rear support phase was significantly correlated with the body flexion angle, the shoulder extension angle and the diameter of horizontal shoulder trajectories but not with the diameter of horizontal ankle trajectories. This result suggested that the diameter of horizontal ankle trajectories contains unique variances that predict performance quality and that the other variables, including the head position, have redundant information with regard to quality prediction (Fujihara & Gervais, 2013). Subsequently, Fujihara (2016) showed that the head-toe distance on a horizontal plane (HTDh; Figure 2) is strongly correlated with the scores provided by human judges as well as with other amplitude variables.

Objective evaluation of the amplitude of horizontal rotation during pommel horse performance can be useful for coaching and potentially for judging, but traditional methodologies have several limitations. To examine the variables described above, either a motion analysis based on videos or an on-line motion capture system has been used. A video-based motion analysis usually requires a time-consuming process of manual digitising, and a motion tracking system necessitates extensive camera setup as well as the use of active or passive markers attached to the gymnast's body. These complexities have limited the practical use of technologically enhanced video evaluation of performance quality for coaching in a regular training session and judging in a competition.

More recently, some studies (e.g. Clark et al., 2015) have sought to conduct motion analysis using a Kinect device, a new type of camera equipped with depth and image sensors. Since a Kinect device can measure the distance from the camera to an object, it opens up new opportunities for motion analysis. By placing a Kinect directly above a pommel horse, the device could measure the distance from the sensor to a gymnast on the pommel horse. Because in most pommel horse skills, the head remains higher than the other body segments at all times, the algorithm to identify the top of the head during a pommel horse performance could be developed. Furthermore, it might also help in identifying the position of the tip of the toes as the farthest point of the body from the head during a horizontal rotation. If the position of these two points during a pommel horse performance can be recognised by using information from a Kinect mounted above the horse, the HTDh could be automatically computed without any of the complicated processes used in traditional motion analysis, suggesting the possible use of this device for objective evaluation during training and possibly even in competitions. The purpose of this study was to assess the Kinect device's ability to evaluate the amplitude of horizontal rotation during pommel horse performance. My hypothesis was that a Kinect device could be used to measure the positions of the head and toes with reasonable accuracy and thus to compute the HTDh and evaluate the amplitude of horizontal rotation during circles on the pommel horse.

METHODS: Eighteen gymnasts performed a set of 10 circles on the pommel horse's two handles. All of them were sufficiently advanced to complete 10 consecutive circles on the horse's two handles without difficulty. The mass, height and ages of the gymnasts were 58.5 ± 9.5 (71.0–27.5) kg, 1.64 ± 0.10 (1.78–1.30) m and 17.7 ± 2.8 (22–11) years. The data were collected at a regular training session. The gymnasts wore regular training shorts, and no marker or other research-related object was attached to them.

A Kinect V2 device was placed 4.58 m above the floor and directly above the centre of a competitive pommel horse, facing downward (Figure 3). The Kinect was connected to a computer, and the image and kinematic data were collected at 30 Hz. The top of the head was defined as the highest point, although some additional criteria were needed to enable the computer program to conduct consistent measurements, due to the poor reflection of laser beams from the gymnasts' hair. The farthest part of the body from the top of the head was defined as the toes. The actual programming code to extract these points from the Kinect data was written by a professional computer programmer from Digital Standard Inc.

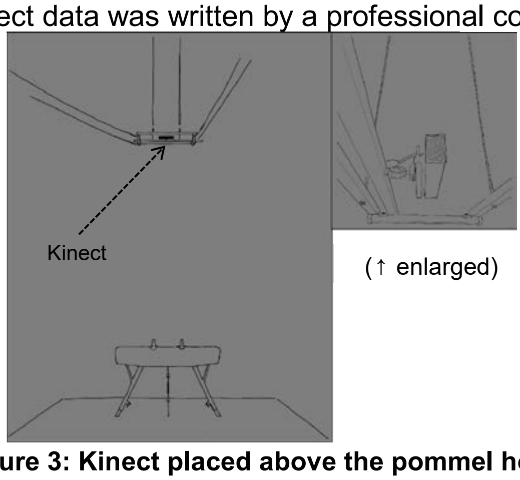


Figure 3: Kinect placed above the pommel horse.

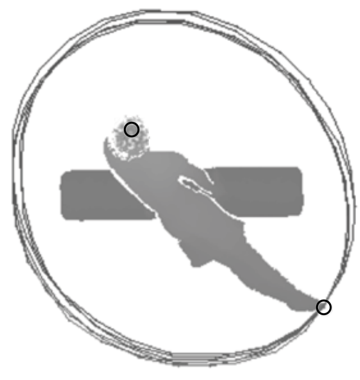


Figure 4: A typical example of the image from the Kinect device.

The image data with recognised positions of the head and toes were visually inspected frame by frame, as a first step to check the validity of the algorithm (Figure 4). Based on the head and toe positions as measured by the Kinect device, HTDh was computed and normalised based on the gymnast's body height. In addition, three digital video cameras (GC-LJ20B, Logical Product Corporation) were used for traditional 3-D motion analysis. The camera speed was 60 fps and the shutter speed was 1/1000 s. These cameras were controlled by a computer with a wireless system and were supposed to be synchronised, but in many cases the cameras did not start at the same time as anticipated. In these cases, a best effort was made to synchronise the video frames from each camera by referencing the timing of the hand contact, release and position of the feet relative to the pommel horse. The space of 4 m x 4 m x 2.75 m around the pommel horse was calibrated based on 125 control points that were recorded prior to the training session. Using Frame Dias V digitising software (DKH Co., Ltd.), the top of the head and the tip of the toes were manually digitised. Both the digitised position data and the data from the Kinect were smoothed by a Butterworth digital filter at the optimal cut-off frequency determined from the residual analysis (Winter, 2009), and direct linear transformation was used for 3D motion analysis. The standard error reported by the software was less than 0.02 m for each axis.

RESULTS: Table 1 shows the mean HTDh as computed by both the Kinect device and the video analysis from the third to the eighth circle. The difference in mean HTDh was 0.35% of body height. Pearson's *r*, computed as a relative reliability index, was 0.94 (see also Figure 5), and the smallest real difference as an absolute reliability index was 1.95. These results collectively confirmed that the HTDh as computed by the Kinect device was very similar to that computed from the video analysis. When closer attention was paid to changes in HTDh during each phase of the circles (Figure 6), it became clear that the difference between the two measurements tended to be larger during the front and rear support phases. According to the visual inspection of each frame image, the algorithm appeared reasonable, although one trial failed to properly recognise the position of the toes (Figure 7).

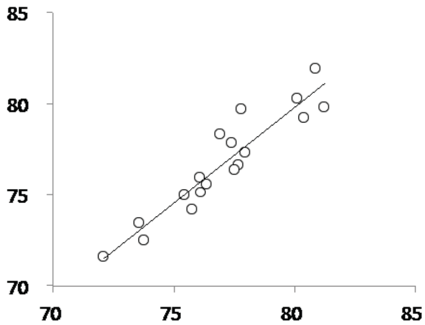


Figure 5: A scatterplot of the mean HTDh derived from the Kinect data (horizontal axis) and from the video analysis (vertical axis).

Table 1: The mean difference (in percentage of body height) in head-toe distance on a horizontal plane (HTDh) between the Kinect system and the video analysis. SEM and SRD denote the standard error of measurement and the smallest real difference, respectively.

HTDh (Kinect)	HTDh (Video analysis)	Mean difference	*r*	SEM	SRD
77.06 ±2.54	76.71±2.84	0.35	0.94	0.70	1.95

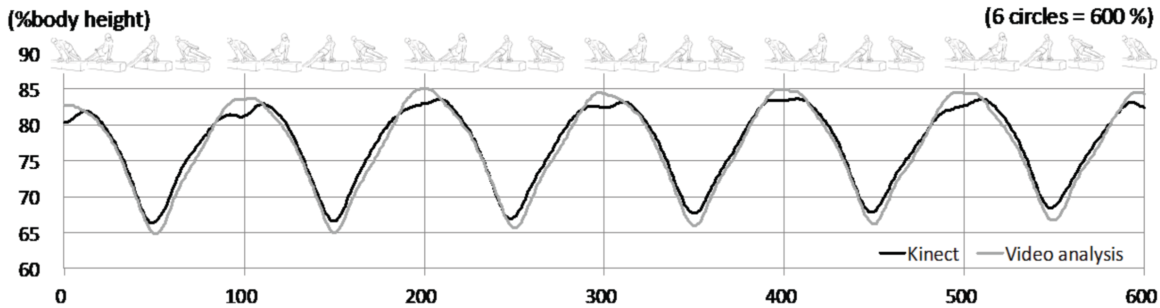


Figure 6: The HTDh as computed using the data from the Kinect (black) and the video analysis (grey). The data for six circles (from the third to the eighth circle) were normalized to 601 data points so that each circle was expressed with approximately 100 data points. The average of 18 gymnasts were depicted, and standard deviation was omitted for clarity.

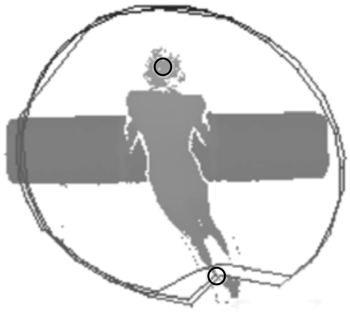


Figure 7: A Kinect image of the trial in which the misrecognition of toes was found.

DISCUSSION: The results of this study supported the use of a Kinect device to compute HTDh during circles on the pommel horse in place of traditional video analysis. The difference in mean HTDh between the two methods was small, and the reliability was reasonably high. The data obtained from the video analysis in this study were not of the highest quality, so some of the measurement errors undoubtedly resided in these data. As Figure 6 shows, the difference between the methods was greater during the front and rear support phases, at which the velocity of the feet reached its peaks; during these phases, the degree of error could have increased in either measurement system. The important finding here is that the data from the two measurements were close enough to demonstrate the practical potential of using a Kinect device.

Constructing the mounting frame for the Kinect above the pommel horse was not easy in our gym. Once it is set up in this location, however, the system is always ready to use and can provide very quick feedback. On the other hand, video analysis requires calibration and digitising as well as other related data-processing steps. An on-line motion capture system requires placement of markers on an athlete and several cameras around a pommel horse, which constrain its practical use.

There are some considerations with regard to using the Kinect device to evaluate pommel horse performance. First, it appears that the laser reflection can be inconsistent when the gymnast is small and his legs are slim, or when he wears clothing of a dark colour. Second, additional studies must be conducted to determine the best use of HTDh in evaluating the amplitude of horizontal rotation, as relying only on the mean HTDh may not be the best way to discriminate performance quality.

CONCLUSION: A Kinect device can serve as a practical alternative to traditional video-based motion analysis for the objective evaluation of pommel horse performance.

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Acknowledgement

The author would like to appreciate the professional skills and kind cooperation provided by Digital Standard Inc. This research has been conducted as a part of the DASH Project at the Osaka University of Health and Sport Sciences.