# INFLUENCE OF A SUSPENDED AID ON THE HIP MOMENT PROFILES DURING CIRCLES ON POMMEL HORSE

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Because a suspended aid – a usual training aid for practicing circles on pommel horse – applies forces at the distal part of the legs, we hypothesized that it has a large influence on the hip moment profiles during circles. This study was conducted to test the hypothesis. Eighteen gymnasts performed three sets of 10 circles with and without a suspended aid, and 3-D coordinates were acquired using a Qualisys motion capture system. The force applied from the aid was determined based on the cable tension measured with a load transducer. Hip joint moments were computed with the assumption that the total leg was a single rigid body. The results confirmed that the aid altered the hip flexion-extension and lateral flexion-extension moments. Understanding such an influence will be important whenever a suspended aid is used for training.

**KEY WORDS:** gymnastics, body weight support, hip joint moment, technique, training aid

**INTRODUCTION:** A suspended aid is a popular training aid for practicing “circles,” the most basic skill in pommel horse exercises (Figure 1). With such an aid, a gymnast’s legs are suspended from above, so his legs are supported. The use of a suspended aid is recommended not only for a beginner to experience the overall motion of circles but also for a more advanced gymnast to refine his technique (Karácsony & Čuk, 1998).

**Figure 1: Circles performed with the suspended aid.**

Even though a suspended aid helps a gymnast perform circles in a kinematic sense, having an additional external force on the legs could largely alter the dynamics of circles. Because the distal end of the legs is usually suspended, the moment arm relative to the hip joints is almost as long as an individual’s legs. This long moment arm may cause a substantial change in the hip joint moment profiles.
The aim of this study was to investigate the influence of a suspended aid on the hip joint moment profiles during circles. Fujihara and Gervais (2009) presented hip joint moments during circles with no aid. Considering that gymnasts keep their legs straight and together, they assumed all segments of the lower extremities to be a single rigid body. Under such an assumption, moments at each side of the hips cannot be determined. Nevertheless, it was useful to analyze overall hip motions and therefore can be applied to test our hypothesis.

**METHODS: Data collection**: A suspended aid was constructed with a rotator twisting belt. The inside of the ring frame was arranged so that it fitted to the various sizes of gymnasts’ legs. The cable suspending the aid was attached to a swivel on a beam running 4.1 m above the surface of the pommel horse.
After general and event-specific warm-ups, the gymnasts were fitted with lightweight retro-reflective makers as shown in Figure 2, and the anatomical calibrations were conducted prior to the main trials. The anatomical landmarks selected were based on the adjusted Zatsiorsky and Seluyanov’s data (de Leva, 1996) for estimating body segment parameters.

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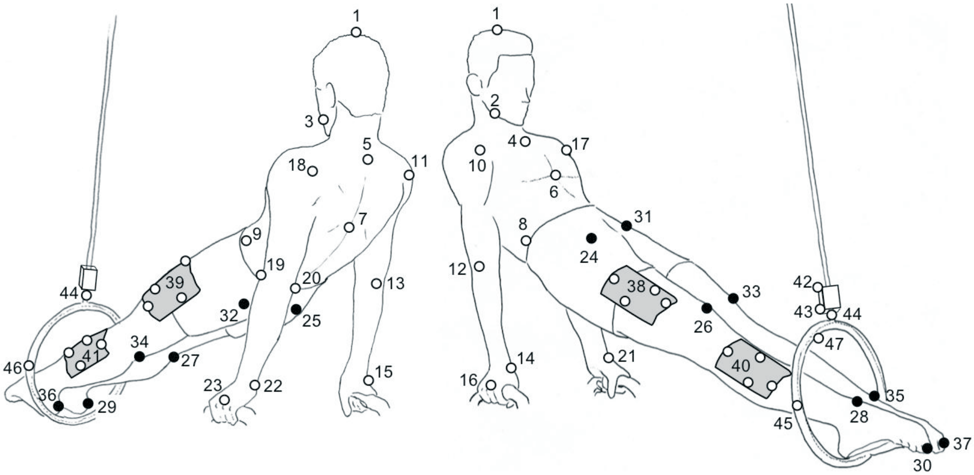


**Figure 2: Marker placements. The markers from 24 to 37 (filled circles) were removed after anatomical calibrations.**

Eighteen gymnasts (mass = 47.7 ± 10.8 kg, height = 1.55 ± 0.11 m) performed three sets of 10 circles on the pommel horse in two conditions: with and without the suspended aid. They had 9.4 ± 2.9 years of experience in competitive gymnastics, trained 20.3 ± 3.5 hours per week at the time of data collection, and were capable of performing 20 consecutive circles on a pommel horse. Either condition was randomly assigned for the first three sets of 10 circles, and then the gymnasts performed another three sets of 10 circles in the other condition. Three-dimensional (3-D) coordinates of the markers were captured using 13 Qualisys Proreflex cameras operating at 100 Hz. The cable tension was measured with a single-axis load transducer (LCCB-500, Omega engineering inc.) embedded between the cable and the twisting belt. The load transducer was calibrated by suspending known weights (from 5 to 100 pounds), and the obtained regression equation showed a high linearity ($R^2$ = 0.9996). The force data were recorded with the motion capture system via an analog board (USB-1616FS, Measurement Computing) at 1000 Hz. Our local ethics committee approved all experimental protocols, and each gymnast provided written informed consent.

**Data analysis**: The 3-D coordinates data were smoothed using a fourth-order Butterworth digital filter at the optimal cut-off frequencies (2.4 Hz - 11.6 Hz) determined by automatic algorithm of Yokoi and McNitt-Gray (1990). The 3-D coordinates of the anatomical landmarks on the lower extremities were reconstructed based on the coordinates of the cluster markers using the least square method (Cappozzo et al., 1997). 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.

To compute hip joint moments, all segments of the lower extremities—feet, shanks and thighs—were assumed to be a single rigid body (Fujihara & Gervais, 2009). The moments of inertia of the total legs were computed using the parallel axis theorem based on the six segments. Note that under this assumption, hip joint moment for adduction at each side of the hip, which was probably present to keep two legs together, was not taken into account. The hip joint moments were estimated by solving Euler's equations with two rigid bodies: the total leg and the lower trunk. Three local reference systems, two for the segments and one for the joint, were defined using a vector product (Figure 3). In addition to the joint moments, the joint power was computed as the product of the joint moment and the joint angular velocity, which was defined as the relative angular velocity of the distal segment with respect to the proximal segment. The joint moments and powers were normalized by the product of each gymnast's body weight and height.

To determine the aid reaction force, the Newton's equation of motion was formed in the local reference system that was embedded in the suspended aid involving four forces: the cable tension ($F_{cable}$), and the force applied from the legs ($F_{leg}$), gravity for the aid mass ($F_g$), and the centrifugal force acting on the aid ($F_{cent}$).

$$\sum \vec{F} = \vec{F}_{\text{cable}} + \vec{F}_{\text{leg}} + \vec{F}_{\text{g}} + \vec{F}_{\text{cent}} = \vec{0}$$

The right side of the equation was zero because there was no motion of the aid in the local reference system. The $F_{leg}$ was the only unknown variable in the equation, and its reaction force was computed as the aid reaction force. The point of force application for the $F_{leg}$ was assumed to lie on a circle that has the radius of $d$ in the plane of the twisting belt. The value of $d$ was determined based on the direct measurement during the experiment. Then, the point of force application ($P$) for $F_{leg}$ was computed as:

$$\vec{P} = d \times \frac{\vec{F}_{\text{leg}}}{\left|\vec{F}_{\text{leg}}\right|}$$

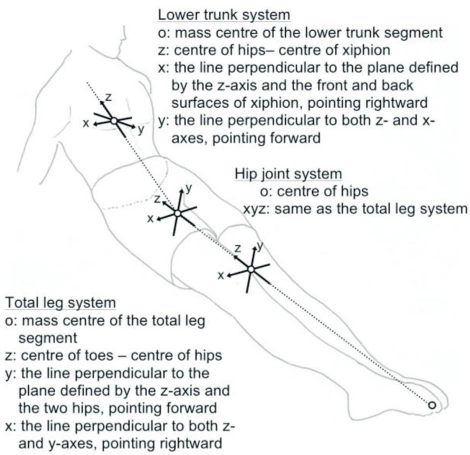


**Figure 3: The definitions of the local reference systems for joint moment computations.**

The free moment ($M'$) was calculated by subtracting the moments caused by the cable tension and the forces applied from the legs from the total moments. That is:

$$\overrightarrow{M'} = I \cdot \vec{\alpha} - \vec{P}_{\text{PFA}} \times \vec{F}_{\text{leg}} + \vec{P}_{\#44} \times \vec{F}_{\text{cable}}$$

where $I$ is the inertia of moment, $\alpha$ is the angular acceleration of the aid, $P_{PFA}$ and $P_{\#44}$ were the position vectors of the point of force application for $F_{leg}$ and marker #44 in the local reference system, respectively.

For each set of 10 circles, 7 circles (3rd - 9th) were used so that the mean data for each variable were computed from the data of 21 Circles (7×3 sets).

**RESULTS AND DISCUSSION:** The results of this study confirmed that the aid had a large influence on the hip joint moment. When the gymnasts performed circles without the aid, the net moment for the flexion-extension motion was very small throughout a circle (Figure 4). This suggested that the gymnasts exerted a similar amount of flexion and extension moment at the hip joint, possibly with an intention to keep their bodies straight. However, a net moment never tells us how strongly the agonists and antagonists co-contracted (Winter, 2009). The greater co-contraction increases the joint stability. On the other hand, when the gymnasts performed circles with the aid, we found the flexion moment during the double-hand front support phase, the leftward lateral-flexion moment during the left-hand support phase, the extension moment during the double-hand rear support phase, and the rightward lateral-flexion moment during the right-hand support phase. In short, the gymnasts pushed down on the aid throughout a circle. In the coaching literature, circles with a suspended aid (so-called “bucket-circles”) are recommended to refine circles technique (Karácsony & Čuk, 1998). However, it is anecdotally known that apparently nice circles with a bucket cannot be directly transferred to circles without it. The difference in the net hip joint moment can partially explain how bucket-circles are different from circles with no aid.

**CONCLUSIONS:** A suspended aid could be used for a variety of purposes, and how to incorporate such training into a learning protocol is left to gymnasts and coaches. However, it is beneficial to know how a suspended aid influences the mechanics of circles. In this paper, we showed that the use of the aid had a large influence on the hip moment profiles during circles. The gymnasts pushed down on the aid throughout a circle, and such moment profiles would not be appropriate for circles without the aid. When the intended purpose of training with a suspended aid is to refine circle technique, understanding the difference in the hip moment profiles will be critical.

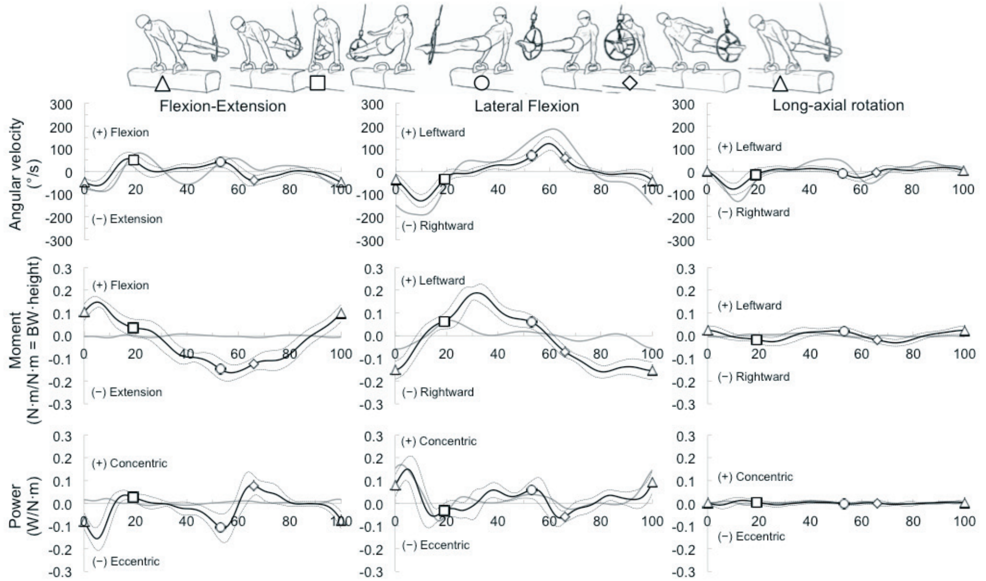


**Figure 4: Angular velocities, moments, and powers at the hip joint during circles without the aid (grey) and with the aid (black). The solid lines indicate average of 378 circles (18 gymnasts × 21 circles) and the broken lines indicate the ± 1 standard deviation from the average. The standard deviation was shown only for circles with the aid for the graph clarity.**

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