# A COMPUTER SIMULATION OF KINETICS IN LANDING OF GYMNASTICS VAULTING

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Gymnasts suffer from high impact loadings during landing and/or dismounts, and injuries are not unusual. The aims of this work were to develop a method for measuring or calculating the landing GRFs, which can be applied in practice and/or competitions, and to get loadings upon lower limbs during vaulting landings. A multi-body model with 19 segments and 52 freedoms was developed on the biomechanical simulation platform, software MSC.ADAMS / LifeMod. In order to test the validity of the model, the kinematics and simulation upon a university student's drop jump were studied. The differences of maximum GRFs obtained from simulation studies and a force plate were less than 2.0% of the maximum GRF got by the force platform. After that, a vault performed by an elite gymnast was simulated and GRFs and net joint reaction forces and torques at ankle, knee, and hip were obtained.

**KEYWORDS:** vaulting, drop jump, Ground reaction force, Net joint reaction force, Net joint reaction torque

**INTRODUCTION:** In order to obtain higher difficulty scores, elite gymnasts always try to performance aerial skills in vaults with more rotations and/or twists, which need higher take off height. This is a great challenge for them to land without moving the feet or losing balance. They suffer from landing ground reaction forces (GRFs) over several times body weight (BW) during landing, and must attenuate the loadings (McNitt-Gray, 1993; Wu, 2011). Lower extremity injuries are common among gymnasts during landings and or dismounts (Bradshaw, 2012; Harringe, 2007). Thus, the landing GRFs, joints kinetics, as well as landing surfaces mechanical characteristics have been extensively studied for prevention of lower extremity injuries (McNitt-Gray, 1993; Pérez-Soriano, 2010; Mills, 2009). However, it is almost impossible to directly measure loading GRFs in gymnast daily practice and/or competition conditions. Joints loadings are even more difficult to be obtained. The aims of this work were to develop a method of measuring or calculating landing GRFs, which can be applied in practice and/or competition, and to ascertain loadings upon lower limbs during vaulting landing.

**METHODS:** A multi-body model with 19 segments and 52 freedoms was developed on the biomechanical computer simulation platform MSC.ADAMS / LifeMod software (Wu, 2011). The software MSC ADAMS is a world wide used software for computer simulation of mechanical dynamics, and the LifeMod is a plug-in component for simulation of human movements. In order to test the validity of the model, a male university student (24 y, 1.70 m, and 70 kg) completed a barefoot drop jump test from 40 cm height. He repeated the jump 3 times. While jumping, a motion capture system (Motion Analysis Corporation, USA) with 8 infrared cameras and 2 high speed video cameras (SONY, HVR-V1C) were employed to capture the movements of the landing. Both of their frame frequencies were 200 Hz. A force plate (Kistler 9287B) was mounted under a mat (20 cm thickness) used to record the landing GRFs (1000 Hz). The kinematic data captured by Motion and digitization of the videos (software SIMI Motion 3D) were separately used for calculating the landing GRFs through computer simulation using LifeMod. The kinematic data of the videos was transformed using a costumed Python script language program developed by our research team before input to the computer simulation. The GRFs obtained by simulations and force plate were compared using Coefficient of Multiple Correlation (CMC; Yu, 2006), and differences were also measured.

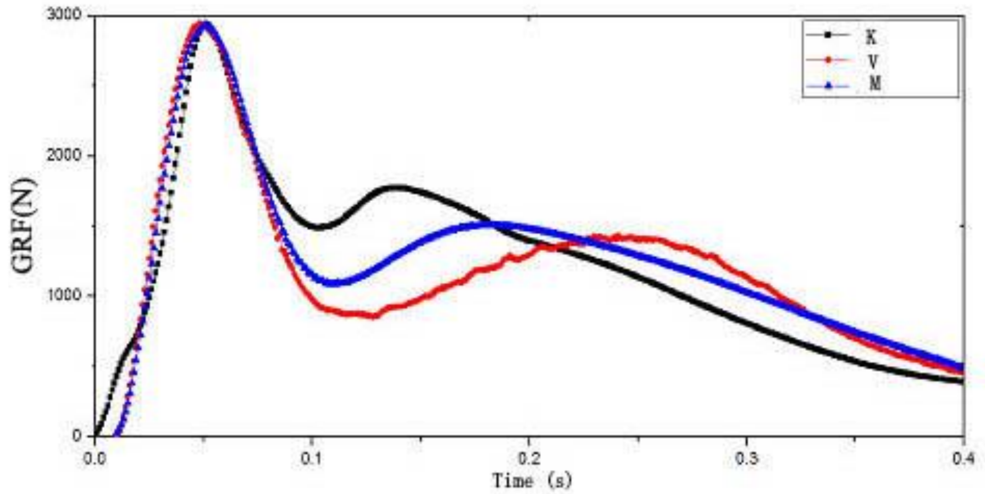


**Figure 1: Comparisons of GRF curves obtained from the three kinds of method. Notice: K, measured by Kistler force plate; V, computer simulation based on videos; M, computer simulation based on Motion.**

A female champion vaulting routine in the 2011 Chinese Gymnastics Championship, Tsukahara Stretched with 2/1 Turn (720°) off, was captured by two high-speed video cameras (CASIO EX-F1) with 300 Hz frequency and 1/320 s shutter speed. Kinematic data were obtained through digitization and calibration using SIMI Motion 3D analysis software and a PEAK frame with 25 markers. The 3D kinematic data were introduced into LifeMod to construct the athlete-specific model. With the help of software MSC ADAMS, model of a landing mat environment was established, and its contacts with the human model were defined respectively. After that, inverse and forward dynamics of the vaulting landing were analyzed by LifeMod/ADAMS, and the GRF net joints reaction forces (JRF) and torques (JRT) were calculated.

**RESULTS and DISCUSSION:** The GRF comparisons among the three methods (computer simulation based on the kinematical data from Motion and videos, and Kistler plate) indicated that the model developed is valid (Fig. 1). The relative differences of maximum GRFs were less than 2.0% of the maximum GRF got by the force platform. The CMC between GRF from videos and that from Kistler was 0.906, while the CMC between GRF from Motion and that from Kistler was 0.964. The CMC is frequently used as a measure of similarity of waveforms (Yu, 2006), and a CMC in the range of 0.75~1.0 is an indicator of high similarity of two waveforms. It also can be noted that the peak GRFs and time reaching the peaks were close (Fig. 1), which indicated that the loading rates were close too.

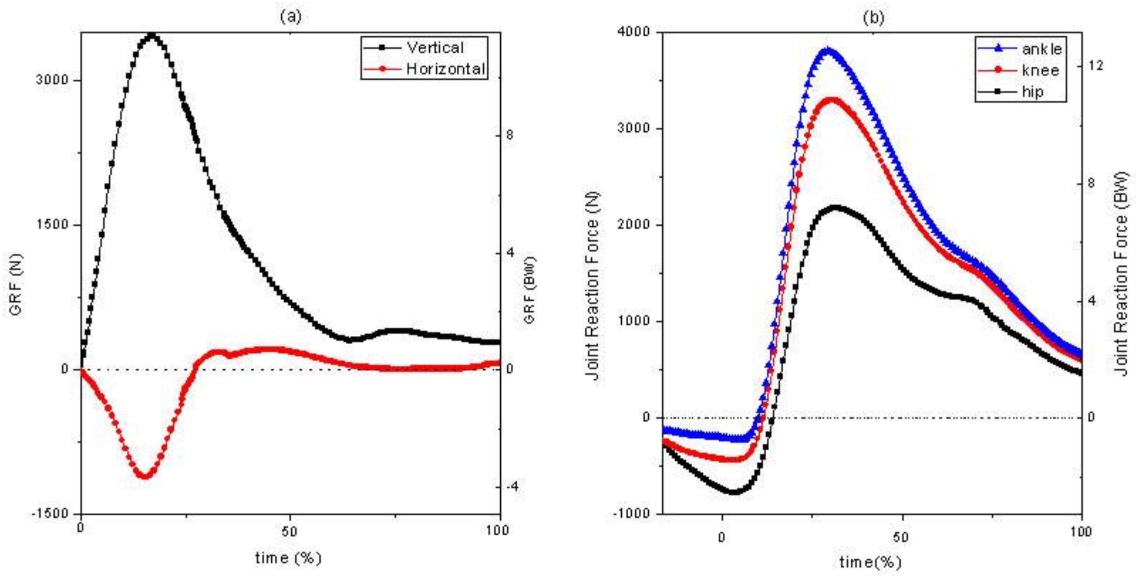


**Figure 2: The GRFs and joints reaction forces during the vaulting landing**

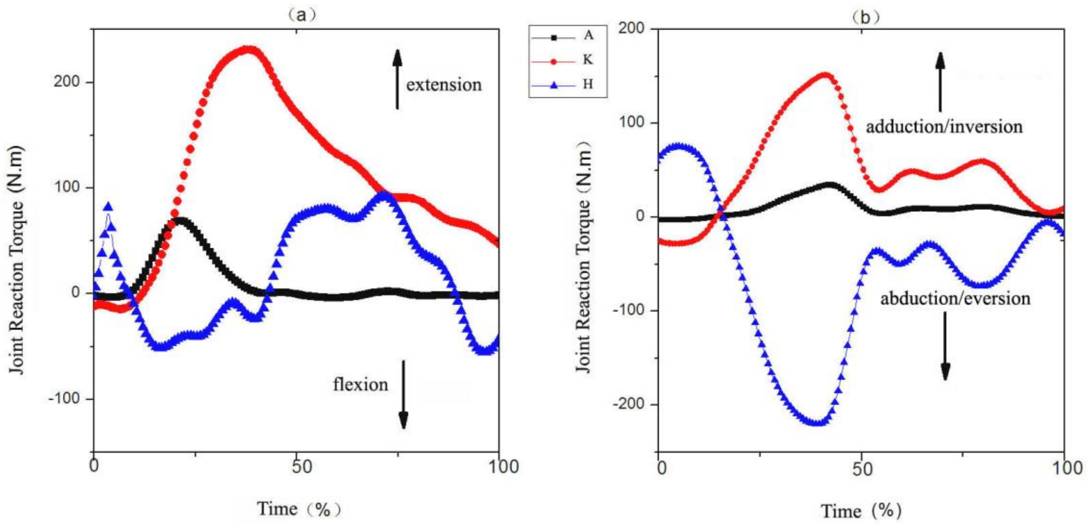


**Figure 3: Joints reaction torques (right leg) in sagittal (left) and frontal planes. Notice: A, ankle; K, knee; H, hip**

The total landing action lasted for about 120 ms, from forefoot contacting the mat (0%) to contacting the mat again (100%). It is obvious that the landing included two phases, impact phase and balance phase (Fig. 2a). The peak vertical GRF in impact phase was about 3463 N, or 11.40 BW and reached this peak 21 ms after beginning of landing. The average loading rate was 164.94 N/ms. The impact phase lasted for78 ms. The vertical GRF in the balance phase was 0.91 BW, and this phase was relatively longer. The horizontal GRF increased sharply to decrease the forward velocity of the athlete, and then reduced to zero at 18 ms. The peak horizontal GRF was -1115 N (-3.71 BW). The peak JRFs for ankle, knee, and hip were 8.75 BW, 7.81 BW, and 5.30 BW respectively (Fig. 2b). The JRFs reached corresponding peaks were at 15ms, 17ms, and 19ms. The movements of human muscular skeleton system delayed the peak forces at knee and hip.

The JRTs of lower limbs during the landing were analyzed. In the sagittal plane, the torque at the knee of right leg was greatest with peak torque of 231.07 N.m, at hip was less, and that at ankle was the least with 69.24 N.m (Fig. 3a). However, in the frontal plane, the abduction torque at the hip was the greatest with peak of -219.78 N.m, adduction torque at knee was less, and inversion torque at ankle was the least (Fig. 3b). In a literature, matching simulation indicated that moments applied on shank and thigh in the sagittal plane during landing of a forward rotating vault by a male gymnast were 377 Nm and 266 Nm (Mills, 2009). These moments were greater than the torques obtained in this work. This may be reasonable because the body weight of simulated male gymnast (75 kg) was greater than that of the girl gymnast (31 kg) this work.

In summary, a multibody model of human for biomechanical simulating landing was developed using the software MSC/ADAMS/LifeMod. The drop jump experiment tested the model to be valid. Finally, the model was applied to simulate a vaulting performed by an elite gymnast. The GRFs, joints reaction forces and joint reaction torques were obtained and analyzed. The model developed in this work may be further applied in further simulations for analysis of sports technique and injury mechanisms of lower limbs.

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