EFFECT OF STIFFNESS OF KNEE AND ANKLE ALIGNMENT ON THE IMPACT LOADS DURING LANDING IN GYMNASTIC FLOOR EXERCISE

Wei-Ya Hao[1], Xiao-Fei Xiao[2], Cheng-Liang Wu[1,3], Xu-Hong Li[4], Yan-Tao Lou[1]

[1]China Institute of Sport Science, Beijing 100061, China; [2]Binzhou Medical University, Yantai, Shandong 264003, China; [3]Chongqing Three Gorges University, Wanzhou, Chongqing 404100, China; [4]Zhejiang Research Institute of Sport Science, Hangzhou 310004, China

This work was to investigate the effect of stiffness of the knee and ankle alignment on impact loads in lower extremity during gymnastic floor exercise. A movement of a floor exercise landing was captured，with its kinematic data were obtained using digitization software. A multi-body model with 14 segments of the gymnast and a model of the mat were separately developed. Computer simulation of landing with different stiffness of the knee and ankle alignment was performed. The peak vertical and horizontal GRFs were 11.8 BW and 2.5 BW during the actual landing. Peak knee extensor moment was increased by 11.6%, but peak knee flexor was decreased by 5.2%, when the stiffness increased by 40%. This work suggests that increase in stiffness of knee and ankle alignment would increase the peak moment of knee extensor and decrease the peak moment of knee abduction.

KEYWORDS: Floor exercise, jumping down, Ground reaction force, Net joint reaction force, Net joint reaction torque

INTRODUCTION: Elite gymnasts repeat landings or dismounts over 200 times in a week during daily training and competition, and sustain very great ground reaction forces (GRFs) over 8-14 times of body weight (BW) (Gittoes, 2012; McNitt-Gray, 1993; Mills, 2009). The overload GRFs are thought as a main cause of lower extremity injuries among gymnasts during landings or dismounts (Bradshaw, 2012; Harringe, 2007). Movements of lower extremity during landing are thought as main factor except the mat that makes the loadings attenuated (McNitt-Gray, 1993; Wu, 2011). The regulations by International Gymnastics Federation encourage gymnasts land more stiffly in the sake of better aesthetics. The gymnasts would get points penalties if they land with obvious cushion movements of lower extremity (FIG, 2016). This might increase loads upon lower extremity and increase risk of injury.
Joint stiffness is a lumped in mechanics and performance-related variable during dynamic movements, such as landing or push-off (Charalambous, 2012; Dubose, 2017). The aims of this work were 1) to explore the loading characteristics of floor exercise landing, and 2) to investigate the effects of stiffness of the knee and ankle alignment on impact loads in lower extremity during floor exercise.

METHODS: A movement of Arab spring back handspring and double salto backward tucked with 2/1 twist (Fig. 1) performed by an international level male gymnast from Chinese Gymnastic Team was captured by two high-speed video cameras (CASIO EX-F1, 300 Hz, 1/320 s). A Peak frame with 28 markers was used for calibration. Then, the videos of the movement were digitized using SIMI Motion software, and 3D kinematic data were obtained.

Fig. 1 A movement of Arab spring back handspring and double salto backward tucked with 2/1 twist was captured

A multi-body athlete-specific model with 14 segments and 38 freedoms and a model of the mat were developed on the biomechanical computer simulation platform MSC.ADAMS / LifeMod software (Xiao, 2015). The MSC ADAMS is wide used software for computer simulation of dynamics of multi-body, and the LifeMod was developed as a plug-in component for simulation of human movements. The kinematical data of the videos for the floor exercise landing of the gymnast was transformed using our costumed Python script language program before inputting into the computer simulation. After that, the floor exercise landing was simulated and the GRF, net joints reaction forces (JRFs) and torques (JRTs) were calculated. After simulation of the actual landing, the baseline stiffness of the knee and ankle alignment were calculated and defined as 100% k. Then, the landings in the conditions that the stiffness of the knee and ankle alignment was assigned as 60% k, 100% k, or 140% k, were simulated separately. The corresponding GRFs and JRTs were obtained and compared.

Tab. 1 Loads in lower limbs with different knee and ankle stiffness

stiffness（%）	60% k	100% k	140% k
Peak horizontal GRF（BW）	2.5	2.5	2.5
Peak GRF (BW)	11.8	11.8	11.9
Peak knee extensor (N·m)	217	275	307
Peak knee flexor (N·m)	159	154	146
Peak torque of knee in frontal plane (N·m)	282	276	272
Peak ankle extensor (N·m)	117	118	119
Peak ankle flexor (N·m)	84	84	84

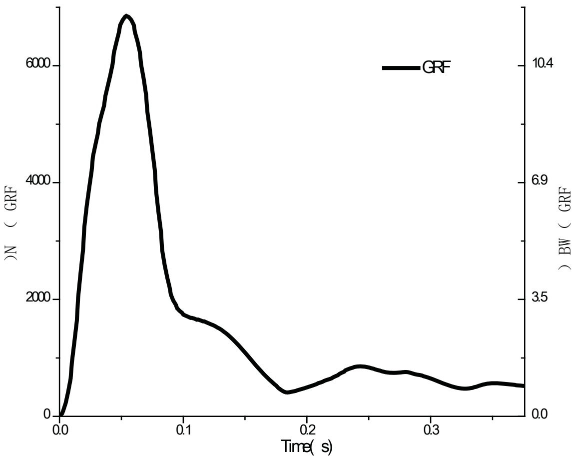
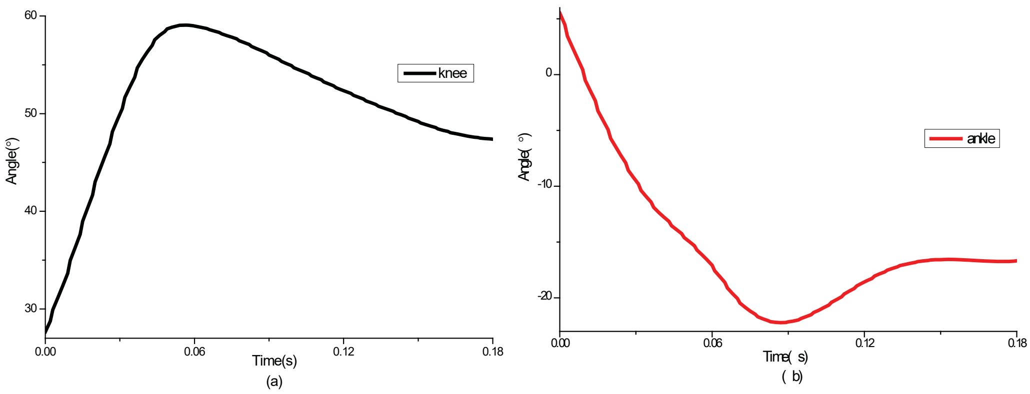


Fig. 2 GRF curve of the landing movement of Arab spring back handspring and double salto backward tucked with 2/1 twist.

RESULTS and DISCUSSION: The GRF of the actual landing (100% k) reached its peak value (11.8 BW) at 54 ms after foot touching the mat (Fig. 2). It was found that the peak horizontal GRF was over 2.5 BW, which suggested greater risk of injury to knee ligaments.
The knee and ankle angles of the actual landing are shown in Fig. 3. The knee flexed in a great range and almost synchronized with the GRF changes (Fig. 3a, and Fig. 2). This result suggests that the flexion of knee played main role in attenuating the landing impact. The ankle dorsiflexed in a relatively small range (Fig. 3b). All the joint movements were unsynchronized. The knee was abducted (frontal plane) with a very great velocity after foot touching the mat (Fig. 3c), while the eversions of the foot were gently (Fig. 3d).
The computer simulation results indicated that changes of the stiffness of the knee and ankle alignment didn't cause much difference upon the joint angles. As shown in Tab. 1, the results also indicated that changes of the knee and ankle stiffness didn't cause much difference upon both peak horizontal GRF component and the total GRF. However, increase of the stiffness of knee and ankle alignment induced great increment of peak knee extensor, whereas decrement of peak knee flexor and peak torque of knee in frontal plane. Nevertheless, the changes of the stiffness of knee and ankle alignment almost didn't affect on the torques in ankle (Tab. 1).



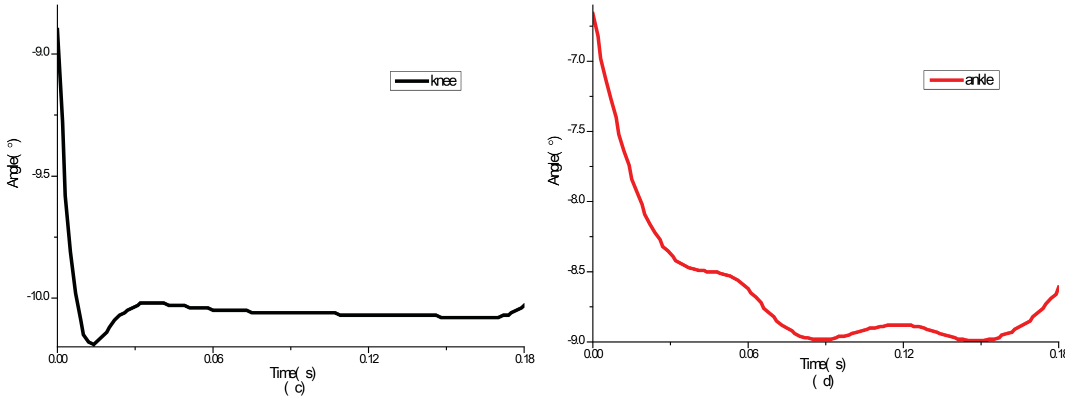


Fig. 3 Joint angle curves of landing movement of Arab spring back handspring and double salto backward tucked with 2/1 twist. (a. knee angle in sagittal plane; b. ankle angle in sagittal plane; c. knee angle in frontal plane; d. ankle angle in frontal plane)

Limitations of this work are existed. First, the kinematic data of the movement was obtained by digitizing videos. Such method ensured the performance of the gymnast was not interfered with, but the digitization cost a lot of time. Second, further research is needed to explore effect of other factors (such as landing postures, mechanical parameters of mat) on the impact loads.

CONCLUSION: This work suggests that landing of floor exercise with somersaults and twists induces great horizontal force on lower extremity, which is greater risk of injuries to knee ligaments. Increase in stiffness of knee and ankle alignment would increase the peak moment of knee extensor and decrease the peak moment of knee abduction. The gymnastic community should reexamine the regulation of landing in the perspective of injury prevention in addition to aesthetics consideration.

REFERENCES

Bradshaw, E.J., and Hume, P.A. (2012). Biomechanical approaches to identify and quantify injury mechanisms and risk factors in women's artistic gymnastics. *Sports Biomech,* 11(3), 324-341.

Charalambous, L., Irwin, G., Bezodis, I.N., Kerwin, D. (2012). Lower limb joint kinetics and ankle joint stiffness in the sprint start push-off. *J Sports Sci*, 30(1):1-9.

Dubose, D.F., Herman, D.C., Jones, D.L., Tillman, S.M., Clugston, J.R., Pass, A., Hernandez, J.A., Vasilopoulos, T., Horodyski, M., Chmielewski, T.L. (2017). Lower extremity stiffness changes after concussion in collegiate football players. *Med Sci Sports Exerc*, 49(1):167-172.

FIG (2016), 2017 code of points men’s artistic gymnastics.

Gittoes, M.Jr, and Irwin G. (2012) Biomechanical approaches to understanding the potentially injurious demands of gymnastic-style impact landings. *Sports Med Arthrosc Rehabil Ther Technol*, 4(1), 4.

McNitt-Gray, J.L. (1993). Kinetics of the lower extremities during drop landings from three heights. *J Biomech*, 26(9), 1037-1046.

Mills, C., Pain, M.T., and Yeadon, M.R. (2009). Reducing ground reaction forces in gymnastics' landings may increase internal loading. *J Biomech*, 42(6), 671-678.

Wu, C.L., and Hao, W.Y. (2011). Research on Kinetics Relationship between Man and Apparatus in Vault. *China Sport Science and Technology*, 47(6), 25-29.

Xiao, X.F., Hao, W.Y.，Li, X.H., He, W.，Lou, Y.T., Wu, C.L. (2015). Comparative study on impact dynamics of floor exercise landing based on different rigid-body models. *J Beijing Sport Univ*, 38(3): 78-83.

Acknowledgements: This work was supported by NSFC (11672080, 10972062) and Basic Research Funding of CISS.