BIOMECHANICAL FEATURES OF LANDINGS OF A COMPLEX FLOOR EXERCISE MOVEMENT

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This study investigated the biomechanical features of sequential landings during two connecting aerial movements in floor exercise. One elite gymnast performed a tumbling sequence consisting of a backward somersault with 3 twists connecting to a backward somersault with 1½ twists in a competition. The performance was recorded using two high speed video cameras (300 Hz). An athlete-specific multi-segment model and a model of the floor were developed. The two landings of the connecting aerial movements were simulated and kinematics and kinetics were compared. Compared with the second landing, the ground reaction forces, loading rate and joint torques of the first landing were all greater, but the duration and height lowered of center of mass during the landing were less. All loads upon the left were respectively greater than those of the right. These results suggest that sequential landing is a forceful and short duration movement while the terminal landing is a relatively less forceful and longer duration movement.

KEYWORDS: floor exercise, landing, ground reaction force, net reaction joint torque.

INTRODUCTION: Elite gymnasts, especially those of international level gymnasts, sustain large ground reaction forces (GRF) during sequential and terminal (or dismount) landings in daily training and competition, which may be over 8-14 times their body weight (BW) (McNitt-Gray, 1993; Mills, 2009; Gittoes, 2012). The gymnast will sustain these landings over 200 times in a week, and thus lower extremity injuries are not rare among gymnasts because of this high total load (Bradshaw, 2012; Harringe, 2007). In a floor exercise routine, gymnasts are required to perform several aerial movements and two connecting aerial movements are encouraged. According to the International Gymnastics Federation (FIG) Code of Points, gymnasts get additional point awards (connection value, CV) if they complete connecting aerial movements (FIG, 2016). The combination of two aerial movements is more difficult to complete and may cause greater landing loads, therefore introducing more injury risk. The aim of this work was to explore the biomechanical features (especially the landing loads) of landings of two connecting aerial movements in floor exercise.

METHODS: One male gymnast (Olympic and World Championships gold medal winner) aged 24 years from the Chinese Gymnastics team participated in this study. He performed one trial of a backward somersault with a triple twist, connecting with a backward somersault with 1½ twists in the qualification competition of Chinese Gymnastics team for the 44th World Gymnastics Championships. The performance was assessed as good by three experienced international judges independently. All tumbling was completed on the floor (Gymnova, France) in the gymnasium of Chinese National Training Centre. Two high-speed video cameras (CASIO EX-F1, 300 Hz, 1/320 s) recorded the trial from the right and behind sides of the gymnast. Calibration was completed before the performance using a Peak frame with 28 markers. Post-performance the videos were digitized using SIMI Motion software (version 9.2.1, Germany) to obtain three-dimensional (3D) kinematic data. The raw 3D data were filtered using second-order Butterworth low-pass filter (6 Hz) before further analysis.
An athlete-specific multi-segment model and a model of the floor were developed using biomechanical computer simulation software (LifeMod / MSC.ADAMS software) (Xiao, 2017; Hao, 2017). The multi-segment model of the gymnast included 14 segments with 38 degrees of freedoms. The MSC ADAMS is popular CAD/CAM software for simulation of mechanical dynamics, and the LifeMod was its plug-in component for simulation of human movements. Using a costumed Python script language program, the kinematic data of the landings of the

two connecting aerial movements by the gymnast were transformed before inputting into the computer simulation. Then, the landings were simulated and the ground reaction forces (GRF) and net joints reaction torques (JRTs) calculated. Kinematics and kinetics of the two landings were then compared.

The first landing was defined as the duration between the touch-down (first foot contact on floor) after the first aerial movement (backward somersault with 3 twists) and the take-off (last foot contact with floor) for the second aerial movement. The second landing was defined as touch-down after the second aerial movement (backward somersault with 1½ twists) and ended at the moment when vertical GRF (VGRF) was 1 BW after its minimum value (Figure 1).

RESULTS: The total VGRF during the two landings are illustrated in Figure 1 with more detailed descriptors such as total landing time shown in Table 1. As can be seen the VGRF for the first landing was over 5 BW higher, with a shorter contact time on the floor (~50 ms less), resulting in a much higher loading rate (~110 BW/s more). Like the VGRF, the horizontal GRFs of the first landing were all greater than that of the second landing. Compared with the right leg, GRFs in all directions upon the left leg were greater.

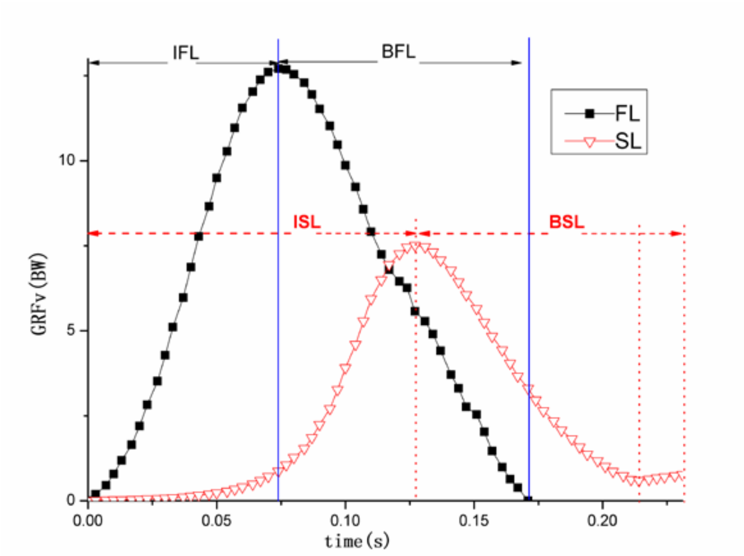

Figure 1: Vertical GRF of the first landing (FL) and second landing (SL) with period divisions.

Table 1: Variables comparison of landings.

Variable	First landing	Second landing
Time (ms)	171	543
Impact time (ms)	74	127
Buffer time (ms)	97	416
Height lowered of COM (cm)	3	31
GRF-vertical (BW)	12.72	7.52
left (BW)	7.37	4.13
right (BW)	5.35	3.39
Loading Rate (BW/s)	171.7	59.2
Peak GRF-sagittal (BW)	5.56	1.50
left (BW)	2.93	0.87
right (BW)	2.63	0.63
Peak GRF-coronal (BW)	4.07	2.35
left (BW)	3.30	1.96
right (BW)	0.77	0.39

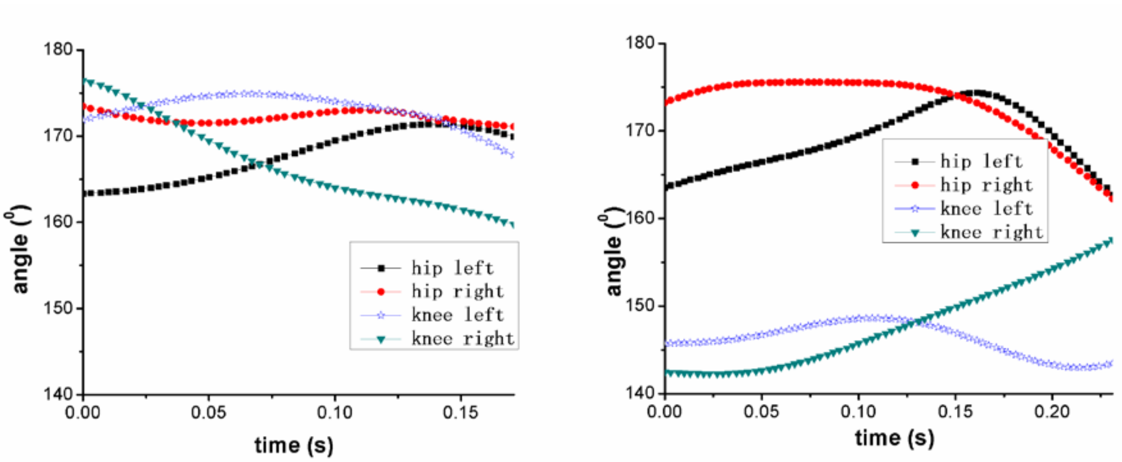

Figure 2: Angle-time histories of lower limbs during first (left plot) and second (right plot) landing.

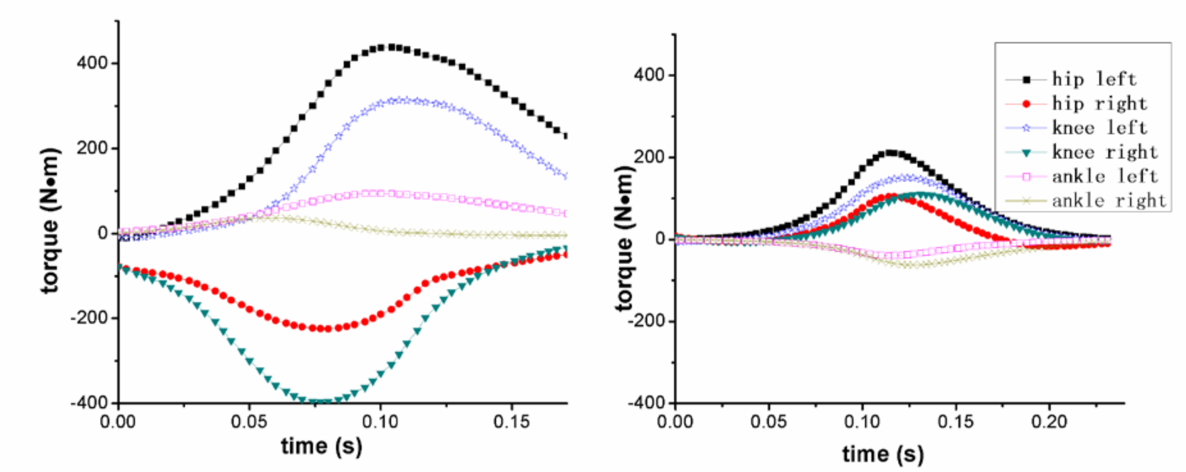

Figure 3: Joint reaction torques of lower limbs during first (left plot) and second (right plot) landing.

The joint angular kinematic and net joint reaction torques are displayed in Figures 2 and 3. Changing of the angles of hips, knees during the two landings are shown in Figure 2, and JRTs in hips, knees and ankles are displayed in Figure 3.
Most joint angle-time histories were different respectively between the two landings (Figure 2). Figure 2 also shows that angles of the right side were all different respectively from those of the left. For example, the right knee was flexed during the first landing, but it was extended during the second landing. However, the left knee was first extended and then flexed during both of the landings.
Joint reaction torques of lower limbs during the first landing were much greater than those of the second landing (Figure 3). Also, the patterns of joint torque curves were much different between the two landings. Specially, all the torque curves were different except those of left hip and knee.

DISCUSSION: This study identified large differences between a sequential landing and a terminal landing during floor exercise. Specifically, the vertical ground reaction force and joint reaction torques were much higher during the sequential landing where the gymnast needed to control their landing and then quickly execute another aerial skill. Specifically, the external load when measured as a VGRF, was 1.7 times larger than the terminal landing. Further, the duration of the terminal landing was 3.2 times longer, and the COM dropped about 10 times lower to enable the gymnast to finish in a stationary position. The total VGRF for the two feet of the first landing was comparable to our previous work (Xiao, 2017; Hao, 2017), in which

landing GRFs of floor exercise were between 9-12 BW. But the VGRF of the second landing was only 7.52 BW. This difference may be due to the second aerial movement being easier than those studied before (Xiao, 2017; Hao, 2017), and because it was a terminal landing where it is well known by gymnasts and coaches that a lower VGRF is better for safety reasons (Sands, 2000; Bradshaw, 2012; Slater, 2015).
Completing a routine of connecting aerial movements is very challenging task for gymnasts (FIG, 2016). The gymnast had different performance strategies in the two landings of the connecting aerial movements. For the first landing, the gymnast firstly impacted the ground and then actively pushed off using his feet and took off for the second aerial movement. The strategy of the first landing was to maintain or increase the kinetic energy and momentums of both forward and rotation. Thus, the first landing should be forceful and lasted in a very short duration, the GRFs and the JRTs would be great. The strategy of the second landing was to finish in a stationary position, dissipating the kinetic energy and momentums. Thus, the second landing lasted in a much longer duration, and both GRFs and JRTs were relatively small. The routine of the connecting aerial movements studied in this work was with a number of leftward twists. The differences in both kinematics and kinetics between the left and right might be caused by these leftward twists.

CONCLUSION: Landings of a routine of connecting aerial movements are very complex task for gymnast. The movement patterns of the two landings for connecting aerial movements are much different due to different landing strategies. The first landing is a forceful and much short duration movement with higher GRFs and JRTs, while the second landing is relatively longer movement with lower GRFs and JRTs. Loads upon the left are greater than that of the right, which might be due to the twists in the aerial movements.

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