CHARACTERISTIC GROUND REACTION FORCES IN SOFTBALL PITCHING

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The purpose of this study was to investigate the ground reaction forces of pushing leg and landing leg during softball pitching with windmill style fastball. Four female elite fastpitch softball pitchers served as subjects. A Peak high-speed camera (120Hz) was synchronized with a force plate (600Hz) to collect the parameters of lower extremity during pitching. Results indicated that the higher impulse of pushing leg and the peak slope of landing leg improve softball pitching performance. In addition, the peak ground reaction forces appeared before the human neuromuscular system responded to modify these forces. The greater ground reaction forces created during the landing phase putting a heavy load on lower extremity. It was suggested that the improvement of lower extremities strength would reduce the injury and improve softball pitching performance.

KEY WORDS: pushing leg, landing leg, ground reaction forces, passive force, softball

INTRODUCTION: Female fastpitch softball is an Olympic sport played by millions of people through the world. The softball pitcher is the most important player of the team. Force is an important aspect of the softball pitch. The pitching mechanics is a coordinate sequence, the great forces are produced from the lower limb drive against the ground and transferred via the landing leg and trunk to the pitching arm to perform the fastball (Alderson & Elliott, 1999; Elliott, Grove & Gibson, 1988). Poor mechanics at the arm may originate in the lower extremities. The movements of lower extremity are composed of two important parts, the pushing leg to drive against the pitcher's rubber and the landing leg to brake. After the landing leg contact the ground, while the upper limb is accelerate velocity to swing forward, the foot applied a force to slow the motion of lower limb and then halt the rotation of the trunk to transfer the energy to pitching arm (Hay, 1985; Elliott et al., 1988; MacWilliams et al., 1998). So the technique of the lower extremity is an important ability of softball pitcher. Although, the survey by the authors showed that Taiwan softball pitchers (N=37; Height:1.67±0.05m; Weight:63.1±7.0kg ; Age:21±4years; Training years:7±4years) have a high percent injury (Lower limb:70.2% : Ankle35% ; Knee:43% ; Hip and Waist: 46%) in landing leg, the injury potential during the activity must be evaluated via the external forces measure.

The purpose of this study was to investigate the ground reaction forces of pushing leg and landing leg during softball pitching with windmill style fastball. The information is useful to coaches, physical education teachers when teaching and coaching the softball pitching and also provide information to reduce the potential injury of softball pitchers.

METHODS AND PROCEDURES: Four high skilled female fastpitch softball pitchers served as subjects. The mean subject characteristics were shown in Table 1. One Peak high-speed camera (120Hz; 1/2000) was positioned perpendicularly 20m from the subject to record the action of pushing and landing legs during pitching. A Kistler force plate (Model 9287, 600Hz) was synchronized with camera to collect the horizontal (Fx) and vertical (Fy) ground reaction forces of legs during pitching. The experimental setup was shown in Figure1. The subject stood 12.19m away from the pitcher's rubber to pitch fastball with windmill style. Each subject performed the pitching with pushing leg on the force plate and next trial by the landing leg on the force plate. The successful pitch was determined with an experienced catcher. Three successful trials of pushing and landing leg contacted the plate were collected for each subject. The trial that produced the highest release ball velocity was selected for analysis.

Data Processing: Body landmarks were digitized by Peak Motus system. A Butterworth Digital Recursive Filter was used for filtering the random noise introduced during the digitizing process. The ground reaction forces were scaled and smoothed by a low pass digital with cutoff frequencies of 30 Hz. The peak slopes were calculated as the $F_r/\Delta t_r$ (F_r: First peak resultant ground reaction forces; Δt_r: Time between foot contact the plate to the peak resultant ground reaction forces appear). The rate of force-decay was calculated as the $\Delta F/\Delta t$ (ΔF: First peak ground reaction forces minus Second peak ground reaction forces; Δt: Time between first peak ground reaction forces appear to the second peak ground reaction forces appear). The impulses were calculated as the $\int F dt$ (F_j: Ground reaction forces; dt: The duration time). All kinetic parameters were normalized to body weight (BW).

Table1 Subject Characteristics (N=4)

	Mean (±SD)
Age (years)	25.0±4.6
Height (m)	1.68±0.06
Weight (kg)	62.3±4.2
Training Years (years)	11.0±4.0

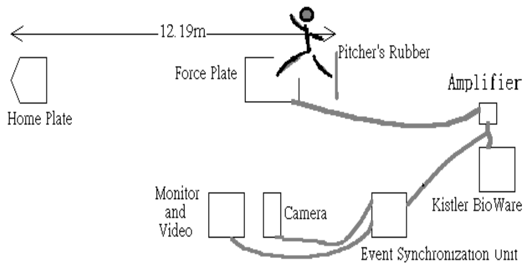

Figure1 - The experimental setup.

RESULTS AND DISCUSSION: GRF of Pushing Leg: Figure 2 shows the typical ground reaction forces of pushing leg during softball pitching. Different from the baseball pitching (MacWilliams et al., 1998) the Fx and Fy were very small before the landing leg contacted the ground. The reason for the smaller forces is that the pushing leg slides forward with the toe, while the landing leg complete the pushing movement. The Fx for the pushing leg increased gradually and reached the maximum of 0.7±0.03 BW. The pushing leg applied this force to drive the body moving forward and the Fy to push the body moving upward. Comparing the relation between the impulse and ball velocity (Table 2), indicated that the subject with a faster ball velocity also had a higher impulse during the pushing phase. The higher impulse produced by the pushing leg may enhance pitching performance.

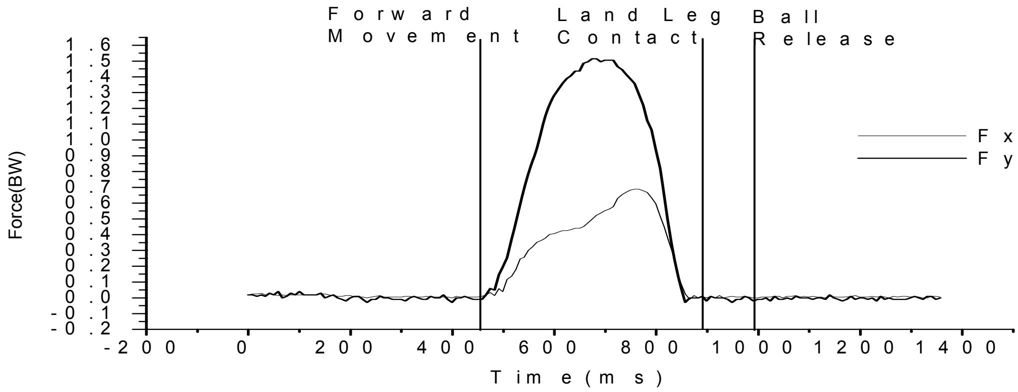

Figure 2 - Ground reaction forces of pushing leg.

Table 2 Impulses of Pushing Leg and Ball Velocity

Subject	A	B	C	D
Impulse (BW*ms)	--	474.8	545.5	576.5
Ball Velocity (m/s)	--	18.18	18.48	18.67

Subject didn't participate in the study of pushing leg.

GRF of landing leg: The time between the landing leg contacted the ground to the ball released was about 0.1sec. Typical ground reaction forces of landing leg are shown in Figure 2. Different from the baseball pitching (MacWilliams et al., 1998), there are two peaks appear after landing leg contact the ground. The value of first peak forces (Fx=–2.24±0.33BW; Fy=3.49±0.21BW) was higher then the second peak forces (Fx and Fy was 1.74±0.22BW and 2.46±0.20BW), in addition, the values of Fx and Fy are greater then the landing leg of baseball pitching (Fx: 0.72BW; Fy: 1.5BW) (MacWilliams et al., 1998). The difference in the GRF values between the softball and baseball pitching may due to the heel landing technique. The purpose of these great forces in softball pitching was to stable the body and halt the landing leg rotation to transfer the energy to pitching arm (Hay, 1993); the results (Table 3) showed the trend that the subject with faster ball velocity also had a higher slope value during the landing phase. This may indicate that the greater and rapidly ground reaction forces produced by the landing leg are important for good pitching performance. However, these greater forces may also increase the possibility of injury of landing leg.

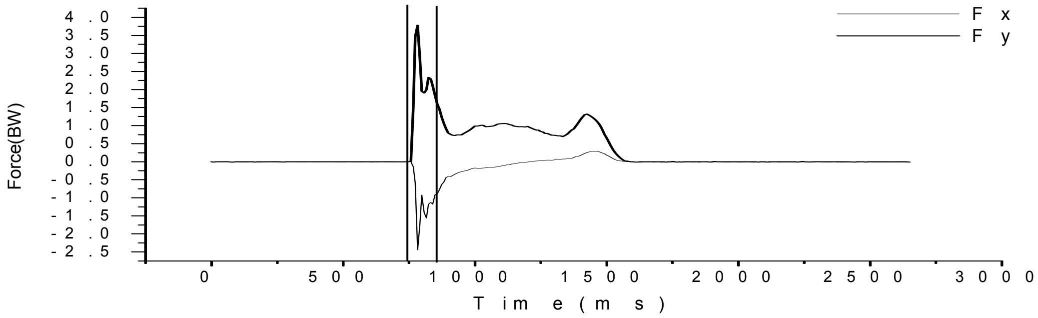

Figure 3 - Ground reaction forces of landing leg.

Table 3 Peak Slope and Ball Velocity

Subject	A	B	C	D
Peak Slope (BW/ms)	83.7	96.0	103.9	212.4
Ball Velocity (m/s)	23.6	23.9	24.0	24.3

The peak forces of Fx and Fy when the landing leg contacted the force plate appear almost at the same time, the peak resultant force of landing leg during softball pitching was 5.37±0.66BW, it was higher then the peak vertical forces of landing leg during high impact aerobic dance movement (1.98BW) and drop landing from 1.32m height (4.6BW) (Richard et al., 1990; Gray, 1991). The first peak forces appeared less then 50ms; the second peak forces of Fy appeared less then 75ms (Table 4). Nigg (1985) had identified impact forces that occurred in less than 50~75ms as passive forces; it implied that the human neuromuscular system do not produce reaction response to modify these forces. These large passive forces may cause injury to bones, joints and soft tissues (Richard & Death, 1990). The results also showed that a shorter time between two peak forces (Table 5). Previous study indicated that the repeated impact forces increase the chance of lower extremities injury (Sheu, 1999).

Table 4 Time (ms) of First and Second Peak Ground Reaction Forces

	First Peak Force		**Second Peak Force**	
	Fx	Fy	Fx	Fy
M	34.95	27.03	65.70	80.70
SD	1.91	2.83	4.00	9.87

Table 5 Rate of Force-Decay and the Duration Time During Two Peak Forces

	Rate of Force-Decay (%)		Duration Time During Two Peak (ms)	
	Horizontal	Vertical	Horizontal	Vertical
M	21.1	28.93	30.8	53.68
SD	15.8	10.13	2.2	12.05

Passive impulse: The passive impulses were calculated as the area of the forces when the landing foot contacted the plate to 50ms, a greater passive impulse could increase the load on lower extremity. The results (Table 6) found that the passive impulses were higher then previous studies on drop landing (12.1~26.0N*s) and the low and high impact aerobic dance (0.0131、0.0295 BW*s) (Sheu, 1999; Richard et al.,1990), the greater passive impulses of landing leg during pitching may due to a shorter time between two peak forces.

Table 6 The Passive Impulse of Landing Leg

	Horizontal Impulse		Vertical Impulse	
Unit	N*s	BW*s	N*s	BW*s
M	32.53	0.0530	64.895	0.1052
SD	4.49	0.0074	8.79	0.0094

CONCLUSION: During the softball pitching, the great forces are produced from the lower limb and transfer via the landing leg to the pitching arm. Further, this study found that the peak ground reaction forces appeared before the human neuromuscular system responded to modify these forces. The greater ground reaction forces created during the landing phase putting a heavy load on lower extremity. The repeating greater impact forces during landing action might cause lower extremities injury. It is suggested that training of lower extremity strength would avoid the injury and improve softball pitching performance.

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