KINETIC ANALYSIS OF THE UPPER LIMBS IN BASEBALL TEE-BATTING UNDER LOW HITTING POINT HEIGHT CONDITION

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Hitting low height balls is more difficult for baseball batters in comparison to hitting high and middle height balls. The purpose of this study was to investigate the kinetic features of the individual upper limb joints among different skill level players in baseball tee-batting under the low hitting point height condition. Twenty-three collegiate baseball players were instructed to hit three kinds of hitting point height balls. Kinematic and kinetic analyses were implemented together with a motion capture system and an instrumented bat. The findings indicate that highly skilled batters exert great extension torque of the barrel-side (top hand) shoulder joint in the first half of the forward swing period in order to hit low point height balls. It is speculated that the large initial flexion angle of the barrel-side shoulder joint can help to increase the torque and angular velocity of the shoulder joint.

KEY WORDS: upper limb kinetics, instrumented bat, different skill level.

INTRODUCTION: A baseball batter has to control a bat accurately into the hitting points of balls thrown on various trajectories. Tago et al. (2006) reported the difficulty of hitting low height balls via the kinematic analysis of the tee-batting motion under different hitting point heights condition. Since bat motions are generated mainly by the joint torques of the upper limbs, it is necessary to clarify the kinetic characteristics of the upper limb joints to evaluate batting techniques. Therefore, Ae et al. (2014) analyzed the kinetic features of the individual upper limb joints in the tee-batting under different hitting point heights condition. This study reported that vertical movement of the bat is mainly caused by the flexion/extension torque of the individual shoulder joints, and that torques and powers of the upper limb joints under the low condition are larger than those under other conditions. We hypothesised that focusing on the differences between the skill levels helps to acquire an effective knowledge of the adjustment technique under the low height condition. From these studies, a comparison of kinetics between high and low skill level players during low hitting point batting will provide useful information for improvement of the batting performance under the low height condition. The purpose of this study was, therefore, to investigate the kinetic features of the individual upper limb joints among different skill level players in baseball tee-batting under the low hitting point height condition.

METHODS: Twenty-three collegiate baseball players (height: 1.74±0.04 m, mass: 74.1±6.2 kg) participated in this study. Three kinds of hitting point height for tee-batting (high, middle, low) were set for each participant who performed seven to nine trials at each height. Participants were instructed to hit the balls in the same manner as balls thrown by pitchers. Three-dimensional coordinate data (body: 47 markers, bat: 6 markers) were captured by a motion capture system (VICON MX+, 12 cameras, 250 Hz) and were smoothed with a Butterworth digital filter (7-15 Hz). Kinetic data of individual hands were measured with an instrumented grip-handle equipped with 28 strain gauges (1000 Hz) that had a similar structure to the instrumented bat proposed by Koike et al. (2004). Then kinetic data of the individual upper limb joints, such as joint torque, joint torque power, and mechanical work, were obtained from inverse dynamics calculation using numerical computation with Matlab (Mathworks Inc.). These kinetic data were normalized using the time of the swing start when the bat-head speed exceeds 3 m/s to the ball impact as 0-100%. A high skill level group (HSG, 7 participants) and a low skill level group (LSG, 8 participants) were extracted according to the skill level judged from the number of successes and failures of the trials

Table 1: Results of the performance under low hitting point height condition for high and low skill level groups

High skill group

Trial	Part. 7	Part. 8	Part. 10	Part. 12	Part. 19	Part. 21	Part. 23
1	○	×	×	○	○	×	×
2	○	○	○	○	○	○ (analysed)	○
3	×	○	×	○	×	×	○
4	○	×	○	○	○	○	×
5	○ (analysed)	○	○	○ (analysed)	×	○	○ (analysed)
6	×	○ (analysed)	○ (analysed)	○	○	○	○
7	○	○	○	○	○ (analysed)	×	×

○: Success ×: Failure [grey]: Analysed trial

Low skill group

Trial	Part. 5	Part. 6	Part. 11	Part. 14	Part. 17	Part. 18	Part. 20	Part. 22
1	×	×	×	×	×	×	○	×
2	×	×	×	×	×	×	○ (analysed)	×
3	×	×	○	○ (analysed)	×	×	×	×
4	○ (analysed)	×	×	×	○ (analysed)	×	×	×
5	×	×	×	×	×	×	×	×
6	×	×	×	×	×	×	×	×
7	×	×	○ (analysed)	×	×	×	×	○ (analysed)
8	−	×	−	×	−	○ (analysed)	×	−
9	−	○ (analysed)	−	×	−	−	−	−

under the low hitting height condition (Table 1). The successes of the trials were judged by whether the participant hit the ball into the target (2×2 m) which is located 3 m away from the participant. The gray hatching on Table 1 denotes the analysed trial of each participant in this study. Differences between HSG and LSG were obtained using an independent *t*-test at a significance level of 0.05.

RESULTS: Table 2 shows the maximum bat-head speed, and peak and average forces exerted along the bat. The values for the knob-side hand (bottom hand) of HSG were significantly greater than those of LSG.
Figure 1 shows the time histories of averaged joint torques about flexion/extension axes at individual shoulder and elbow joints. The barrel-side (top hand) shoulder extension torque was significantly larger in HSG than in LSG during 5-35% time, and then the extension torque of HSG increased until around the impact. The barrel-side elbow extension torque was larger in LSG than in HSG during 20-60% time. The knob-side shoulder extension torque was significantly larger in LSG than in HSG during 70-90% time. The knob-side elbow extension torque was larger in all participants than HSG and LSG during 0-90% time.
Figure 2 shows the time histories of averaged joint torque powers about flexion/extension axis at individual shoulder and elbow joints. The positive power at barrel-side shoulder joint was significantly larger in HSG than in LSG during 10-50% time, and then the positive power in HSG increased until around the impact. The positive power at barrel-side elbow joint was larger in HSG than in LSG during 60-90% time, and then the negative power was larger in LSG than in HSG at the impact. The negative power at knob-side shoulder joint was larger in LSG than in HSG during 60-80% time, and the positive power was also larger in LSG than in HSG around the impact. The positive power at knob-side elbow joint was larger in HSG than in LSG around the impact.
Figure 3 shows the mechanical work done by joint torques of individual upper limbs. The positive work done by joint torque about flexion/extension and adduction/abduction axes of the barrel-side shoulder joint were larger in HSG than in LSG. The negative work done by joint torque about flexion/extension axis of the barrel-side elbow joint was larger in LSG than in HSG, while that of pronation/supination axis was larger in HSG than in LSG. The work

Table 2: Maximum bat-head speed, peak and average forces exerted along the bat

	Maximum bat-head speed [m/s]	Peak force [N]		Average force [N]	
		Barrel-side hand	Knob-side hand	Barrel-side hand	Knob-side hand
HSG	37.2±1.1	173.9±38.6	682.4±51.8	69.3±24.3	177.6±24.5
LSG	35.3±1.6	160.7±37.1	601.6±82.6	57.5±21.5	147.1±17.1
Significant	HSG>LSG *	n.s.	HSG>LSG *	n.s.	HSG>LSG *

*:p <0.05

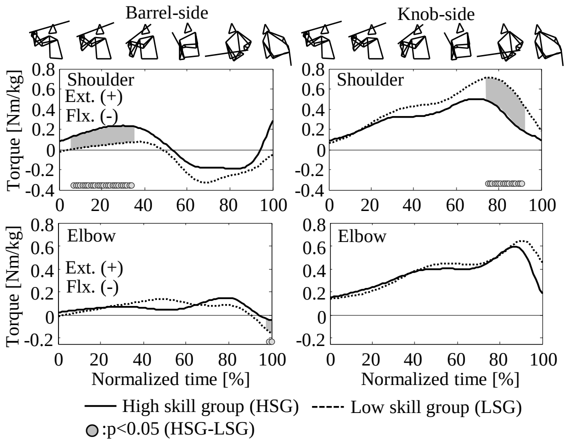

Figure 1: Time histories of averaged flexion/extension torques of the individual shoulder and elbow joints.

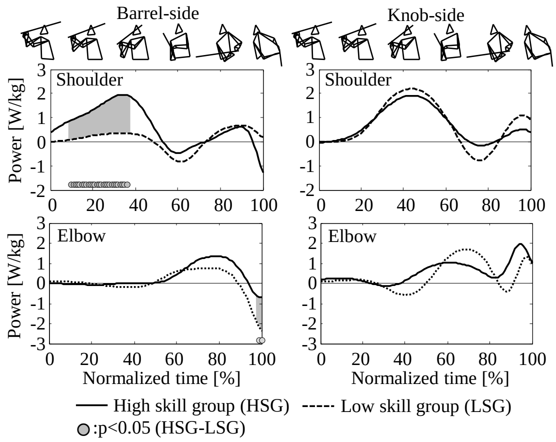

Figure 2: Time histories of averaged torque powers at flexion/extension axis of the individual shoulder and elbow joints.

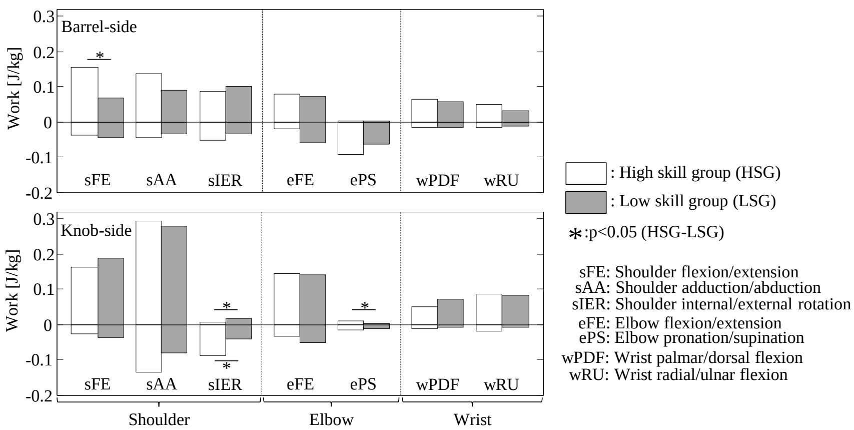

Figure 3: Mechanical work done by joint torques of the individual upper limbs.

done by joint torque about flexion/extension and adduction/abduction axes at knob-side shoulder were larger in comparison to those of barrel-side upper limb joints, and the negative work done by adduction/abduction axis was larger in HSG than in LSG. In addition, the negative work done by internal/external axis was significant greater in HSG than in LSG. Although the work done by elbow and wrist joint torques showed large values, there were no significant differences between HSG and LSG.

DISCUSSION: Participants in HSG generated a large extension torque and positive power at the barrel-side shoulder joint in the first half of the forward swing period (Figures 1 and 2). Since the shoulder flexion/extension torques contribute to adjusting the vertical bat movement (Ae et al., 2014), we suggest increasing the barrel-side shoulder extension torque in the period in order to hit low height balls successfully.
Figure 4 illustrates the stick figures of Participant 23 and Part. 20 who have been selected as representative of HSG and LSG, respectively. These participants were selected from the maximum bat-head speeds under each hitting point height condition. The results of Part. 23 showed the largest speed under all heights among all participants, and the results of Part. 20 showed the smallest speeds under high and middle height conditions and showed 21st speed under the low height condition, which was selected considering the rank of total speed under the three kinds of the hitting point conditions (Part. 20 was 23st). The initial flexion

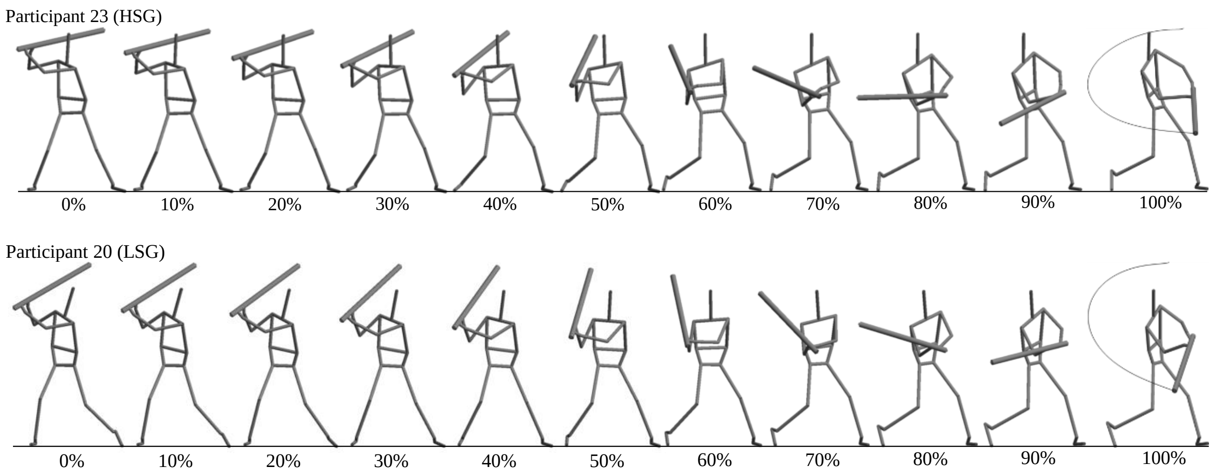

Figure 4: Stick figures during forward swing motion for Part. 23 (HSG) and Part. 20 (LSG) under the low hitting point height condition.

angle of the barrel-side shoulder joint of Part. 23 (HSG) was larger than that of Part. 20 (LSG); (Part. 23: -65.5°; Part. 20: -55.5°). Since the difference in the initial shoulder angle affects the position of the bat, the configuration of the upper limbs, and the range of motion of the shoulder joint, the difference of the initial angle might affect the ability of generating large torque and angular velocity at the shoulder joint in the first period.

Participants in LSG generated a large extension torque of knob-side shoulder joint in the last half of the forward swing period and flexion torque of barrel-side elbow joint prior to the impact (Figure 1). The average time curve patterns of those torques in LSG were similar to the average patterns for all participants under the high point condition (not shown in this paper). That is, the torque patterns in LSG are not for the low height condition but for the high height condition.

CONCLUSION: This study focused on the kinetic features of the upper limbs under the low hitting point height condition in order to find useful information for improving baseball batting performance. The knowledge obtained from the investigation of the differences of kinetic characteristics between high and low skill level batters indicates that participants in HSG exert great extension torque of the barrel-side shoulder joint in the first half of the forward swing period in order to hit low point height balls. It is speculated that the large initial flexion angle of the barrel-side shoulder joint can help to increase the torque and angular velocity of the shoulder joint.

REFERENCES:

Tago, T., Ae, M., Fujii, N., Koike, S. & Kawamura, T. (2006). Effects of the height of hitting point on joint angular kinematics in baseball batting. *Japanese Journal of Biomechanics Sports & Exercise*, 10(1), 2-13 (in Japanese).

Ae, K., Koike, S. & Kawamura, T. (2014). Kinetic analysis of individual upper limbs in baseball tee-batting motion at different hitting point heights. *Japanese Journal of Physical Education Health and Sport Sciences.* 59(2), 431-452 (in Japanese).

Koike, S., Iida, H., Fujii, N., Kawamura, T. & Ae, M. (2004). An instrumented bat for simultaneous measurement of forces and moments exerted by the hands during batting. *The Engineering of Sport*, 5(2), 194-200.